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Venetie, Alaska Energy Assessment

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Sandia National Laboratories

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Abstract

This report summarizes the Energy Assessment performed for Venetie, Alaska using the principals of an Energy Surety Microgrid (ESM) The report covers a brief overview of the principals of ESM, a site characterization of Venetie, a review of the consequence modeling, some preliminary recommendations, and a basic cost analysis.

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Chapter 1

Executive Summary

In 2012, the Department of Energy's (DOE's) Office of Indian Energy (OIE) tasked Sandia National Laboratories (Sandia) to provide technical assistance to the Alaskan village of Venetie on their electrical system. In response, a preliminary assessment was done using the Energy Surety Microgrid™ (ESM) assessment concept applied to the electrical power system. The report covers a brief overview of the ESM concepts and details of the analysis.

The village of Venetie is located approximately 160 miles north of Fairbanks, Alaska. The village is isolated with travel to the village only available through air traffic. The village has a population of 200 people, which fluctuates during the year. Diesel generators supply, almost exclusively, the electrical energy for the village. There are three generators located in the village powerhouse, a 125 kW, a 180 kW, and a 190 kW units. The 180 kW and the 190 kW generators are currently in service, and the 125 kW unit failed with no plan to put back into service. The generators are housed in a sub-standard, tight building at the center of town next to a washeteria. Combined heat and power is utilized by sending the generator waste heat to the washeteria to supplement the heating requirements of the boilers. The generator building is due to be replaced in the near future. Venetie has kept fairly extensive generator fuel logs including generator loads. However, there is no detailed load data available. The average summer load (May-August) fluctuates around 60 kW. The load during spring is 80 kW. The winter load fluctuates from 140 - 150 kW and the load during the fall is around 110 kW. The generators feed a 12,470/7200 kV overhead distribution system. The three-phase distribution system splits out and distributes throughout the village and is not equally balanced, which causes some undue frequency fluctuations and power quality issues. The loads in the village comprise a couple of relatively large loads, such as the school, with the balance from residential housing. Each home uses from one to two kW load, on average. The bottom line is that the powerhouse and generators need to be replaced in order to increase the safety, reliability, and efficiency of operation. The village is on the Alaska Energy Authority (AEA) list for Rural Power System Upgrade Program and should be eligible for assistance from AEA in replacing the existing system. How far out in the future the replacement will take place is not known exactly, but the process should begin to take place within the next two or three years.

The village of Venetie is located in a region in which there are few renewable energy resources available. The region has a mean wind velocity to low to make wind power a practical solution. Although Venetie is located along the Chandalar River, the river is braided and is too shallow to be an option for hydrokinetics. Additionally, during the winter, the river freezes over. Venetie is located in a boreal forest, so biomass (woodchips) is an option, though electric generation in a rural, isolated village does not have a precedent and therefore is experimental and costly. Lastly, there is no known geothermal source in the area. PV is a viable alternative with commercial, off-the-shelf components available, though there are some significant drawbacks. Due to its location near the Artic Circle, the sun does not shine down on the village for more than three months out of the year. Although the sun does shine continuously during the late spring/early summer months, it is during the time period of low demand.

The system was investigated and an extensive consequence model was created. While the model was created for Venetie, the basic foundation of the model can be extended and applied, with some modifications, to similar villages in Alaska as well as in rural areas of the continental United States. Seven different generator configurations were modeled, including the configuration that exists in Venetie at this time. The most important takeaway from the configuration runs was that running the one lone, over-sized generator constantly allows for significant savings through more efficient operation of the generators. Additionally, the models were created that included various PV penetrations ranging from 7% to 100% penetration. When the PV systems got to be larger than 20 kW, energy storage was needed. A 40 kW PV system required a 40 kWh battery and an 80 kW PV system required a 250 kWh battery.

Three design options were given. The first option was to relocate the powerhouse to near the airport and the existing bulk fuel storage area. This would require a new powerhouse and attendant electrical power generation equipment as well as an upgrade of the distribution line from a single-phase, 7.2 kV medium voltage distribution line to a three-phase 12.47 kV medium voltage distribution line from the village to the airport. To match the electrical power demand of the village more closely, the best combination was found to be one 125 kW diesel generator and two 60 kW diesel generators. This combination gives redundancy as well as allows for the seasonal peak demand to be efficiently met. The annual reduction in fuel used, solely through more efficient operation, is nearly 3000 gallons. The approximate cost for replacement will be between $2.25 and $2.5 million dollars. The second and third options start from the basis that the existing electric power generation will be replaced. Design option two calls for addition of PV but without energy storage, which means a system of 20 kW in size. The installed unit cost of the system was assumed to be $10/W, which gives a cost of the system at $200,000. At that cost point, assuming the consequence model calculated net annual savings of $16,531, a simple payback was twelve years and a benefit to cost ratio of 1.23. However, $10/W cost is very uncertain and could easily be higher.

Design option three assumed a PV system with energy storage incorporated. A system with 40 kW and a 40 kWh battery was determined to have an investment cost of $435,000, based on $10/W for the PV and $874/kWh for the battery. Under this scenario with a net annual savings of $23,284, the simple payback was nearly 19 years with a B/C ratio of 0.8. The larger system of 80 kW PV and a 250 kWh battery had a cost of greater than $1 million with a net annual savings of $32,332, resulting in a simple payback of 31.5 years and a B/C ratio of 0.47.

Additionally, levelized cost of energy analysis was done on the three options and compared to the existing diesel genset system and to a new diesel genset and powerhouse.

Based on these numbers, the most cost effective system would be the 20 kW PV system without any energy storage. Caution needs to be taken to ensure that any system installed would have adequate support from the community and that the community is willing and capable of assuming the responsibility for the system, both financially and technically. Additionally, for any installed system to have long-term benefit to the community, it should match the community's ability to operate and maintain the system. It is also important to note that the recommendation is contingent upon replacing the existing generators. If the existing generators were to be used, during the low peak-load summer season, running the generators when coupled with a 20 kW PV system would result in forcing the generators to operate in a inefficient, motor damaging mode.

Chapter 2

Project Scope

This project provides technical assistance to the DOE/OIE program for the power system at the village of Venetie, AK. Here we present background information on Sandia National Laboratories Energy Surety Microgrid™ (ESM) concept as applied to remote Alaskan villages, characterization of the Venetie electrical system and a preliminary set of recommendations for improvements for the village that follow the ESM concept.

The results of this study are based on data collected during a site visit the first week of July 2012. This data includes 1) monthly sold energy starting April 2011 and running through March 2012, 2) energy use by categories, 3) generator fuel consumption, 4) generator resources, 5) fuel storage capacity, and 6) information on the distribution system. Although considerable background data was collected during this visit, additional data is still required for a complete and thorough characterization of Venetie's electrical energy use patterns necessary for a detailed, complete, and robust ESM design. In particular, measured load data is extremely desirable. Because the analysis of Venetie's power system contained in this report does not include measured load data, the conceptual design presented here provides only high-level design options with our best estimates of generator requirements. As such, this report is meant to be a precursor to a complete conceptual and engineered design that may be undertaken at a future date.

A more exacting design requires accurately measured, high temporal resolution load, voltage and frequency data obtained for at least one week during each season, but preferably taken on a continuous basis for a full year. The full year dataset would provide both normal power demand and abnormal demands such as unusual peaks or lows. Due to the significant variation of peak loads from winter to spring to summer to fall, the full year dataset would significantly reduce design uncertainties and allow for a more optimal sizing of new generators. Other needed data includes high temporal resolution solar radiation and wind velocity measures.

This report includes the following topics:

- A brief review of the ESM concept as applied to remote Alaskan villages
- Characterization and description of the current Venetie Electric Utility system
- First order recommendations for improving the generation system and estimated cost estimates

- An example of a consequence model approach to illustrate and explore potential design options

Also discussed in this report are data, modeling, and other information requirements for a more extensive analysis leading to a complete and thoroughly vetted microgrid design. These requirements include the following:

- A more complete analysis made possible through accurately measured data.
- First order load-flow model required to investigate potential instabilities to provide guidance design details
- Performance/reliability modeling that optimizes system components such as generators, electrical load, renewable generation, switches against cost and reliability.
- More extensively developed consequence model that includes input from PV and/or wind generation to provide detailed analysis of generator duty cycles and resultant generator performance measures given accurate and high temporal resolution load data and accurate solar radiation and wind velocity data.

Chapter 3

Energy Surety Microgrid Design Analysis

3.1 Introduction

The Sandia-developed Energy Surety Microgrid™ (ESM) methodology directly links five energy surety principles (safety, security, reliability, sustainability, and cost effectiveness) with critical power needs. It does this by integrating distributed energy resources (DERs), including backup generators, photovoltaic (PV) systems, small wind turbines, electrical energy storage, etc., into a local electrical distribution service area (microgrid) and controlling those resources to optimize system performance. Although the ESM methodology was designed for grid-tied smaller distributions systems such as those of military bases where critical functions must continue during grid failure, some of the methodology can be applied to stand-alone microgrids such as those at remote Alaskan villages. It is necessary to note that the extent of the ESM Design Analysis is dependent on the size, complexity, and service requirements of the microgrid. For example, a large military base with numerous critical missions requiring uninterruptible electrical service and with a variety of armed service tenants, each with different load service priorities, will require a more complex and larger microgrid than a small Alaskan Village with few absolutely critical loads and limited renewable energy resources. A key ESM design feature that is applicable to Alaskan village microgrids is active, real-time management of interconnected generator resources for producing the required power in the most efficient, reliable, and cost effective manner. This interconnection allows for matching the load to generator resources, and immediate access to backup generators in case of a generator failure. Here we present a high level description of the ESM Design Analysis process we have implemented for complicated microgrid systems required by the most complex facilities where the ESM process has been implemented. It is presented in this form because much of the process is applicable to small remote Alaskan villages such as Venetie even though these villages do not require extensive control and cyber security systems.

3.2 ESM Energy Surety Principals

The five energy Surety Principles (safety, security, reliability, sustainability, and cost effectiveness) are discussed individually in this section to provide the groundwork for the ESM Design Analysis that follows this section.

The *Safety* principle is that the ESM will not create any new safety hazards and will, in fact, reduce safety risks associated with the operation of a complex microgrid. A functioning and well designed ESM is safer than a system that relies on human intervention during contingencies because the ESM is designed to respond to contingencies automatically. This cuts down on the need for human intervention and the risks associated with judgment errors made under duress.

Reliability of a power system is the ability to provide sufficient power; especially during contingencies. Achieving complete 100% system reliability is often impractical due to the prohibitive costs associated with a system designed to meet all contingencies, no matter how unlikely they may be. However, significant reliability gains can be achieved by designing ESM systems that match load with generation resources while providing additional back-up generation and with a robust control system designed to effectively respond to contingencies.

Security refers to having a power system resilient to all threats including intentional sabotage. Recently, grid security has become a pertinent issue, due to the threat of cyber attack. Given that an ESM requires significant levels of software, control, and networking, cyber security becomes a salient element of the ESM microgrid design. The ESM design process promotes incorporation of cyber security standards such as encryption, firewalls, strong password requirements, and other measures that enable command and control of the microgrid.

Sustainability is the ability to sustain the power system for an indefinite period of time, but doing so in a manner that does not compromise future demands on the system. ESM systems are commonly based on diesel generation. It is widely recognized that the use of diesel fuel is not sustainable because it is not a renewable energy resource. However, reducing the rate at which diesel fuel is consumed results in a more sustainable system from both the long-term resource availability and value proposition points of views. ESM systems conserve fuel by matching loads to generator resources and automatic switching of generators to efficiently meet the load. Optimal switching of generators has other sustainability paybacks such as reduced diesel generator maintenance costs and longer generator life cycles. A second way to conserve fuel is through the addition of renewable generation resources. High penetration of intermittent and variable renewables such as wind and photovoltaic (PV) generation is made possible with an ESM system.

Cost effectiveness has to be a key component to an ESM system as applied to remote Alaskan villages. Cost effectiveness can be attained through ESM designs that significantly improve fuel efficiency, decrease maintenance costs, and lengthen life cycles of generators through control of generators to optimally meet loads. Incorporation of renewable generation can significantly increase cost effectiveness depending on the intensity and reliability of the renewable resource, system cost and service expectancy, and installation and maintenance costs.

A second strategy for meeting cost effectiveness goals involves the philosophy of using existing infrastructure to the extent possible to meet the objectives of the ESM. Decisions to alter the existing system are base on an understanding in the tradeoffs between component replacement and associated costs and the impacts of reusing existing equipment on ESM performance.

3.3 Pre-ESM System Characterization

Development of a full ESM implementation following the principles described above involves engineering analyses for the facility for which the microgrid will be designed. This process involves characterization of the system, analysis of system design options through modeling, cost analysis, and design and performance analysis. The following sections give an outline of the ESM process as applied to remote Alaskan villages.

The first task in the design process is to gain an understanding of the current system and the load requirements of that system, both for normal and contingency operation such as loss of load due to failure in the distribution system or potential load not served due to generator failure. In the first case, an appropriate generator must be on-line to meet the reduced load and for the second case, it might be feasible to select specific loads that would be served by the reduced generation. These loads could be selected based on a triage of the negative impacts that reduced generation could have on the community as a whole. These and other design considerations are realized through a systematic site characterization process where consideration is given to the unique circumstances of each village:

- Load Characteristics: Discussions with the power system operators yield information on load characteristics, measured data availability, and additional data required for modeling efforts. Discussions with the community result in an understanding of which functions are critical within the community for times when generation is curtailed.
- Characterization of existing electrical system: The design and state of repair of the current system is investigated and evaluated with the help of on-site operators and electrical contractors. This effort results in an understanding of the strengths and limitations of the current system and this understanding is used as the starting point in the ESM design process.
- Characterization of potential new energy sources: This effort includes an evaluation of available renewable energy sources such as wind and PV generation and may also include a cost/benefit analysis of energy storage
- ESM capability requirements: Once the above three efforts are completed, various ESM designs can be explored where cost and need are balanced to produce an acceptable design that meets the principles of the ESM.
- Information technology (IT) requirements: The IT requirements are driven by the ESM design as well as the benefits of incorporating the village network (if present) into the design and, if incorporated, the vulnerability of the village network to cyber attacks.

3.4 ESM Electrical System Modeling

Electrical system modeling includes load flow, performance/reliability, grid dynamic and consequence modeling. Load flow modeling uses grid dynamic tools such as PSLF, MATLAB, etc., to build a load flow model of the microgrid design to calculate voltages and flows based on generation and loads to initially examine if there are any voltage issues introduced by the microgrid.

The grid dynamic model is a more detailed load flow model which involves microsecond scale grid dynamics modeling based on inputs such as generator capabilities, inverter characteristics, system protection capabilities, etc., to better design microgrid control algorithms, investigate required generator ramp rates and potential storage requirements necessary for the microgrid - particularly important when renewables are incorporated, and to mitigate any stability issues which might be discovered by the model.

A performance/reliability model uses data obtained for the load flow model to develop a sequential Monte Carlo model to optimize key microgrid components against cost under a variety of contingencies including weather, maintenance, component failure, and failures from cyber attack. The output of the model is statistical quantification of the performance of the microgrid for different combinations of microgrid components.

The consequence model uses systems dynamics software (like PowerSim Studio®) to track microgrid performance under varying load scenarios. This modeling paradigm complements the performance/reliability model results because the consequence model illustrates how the optimal combination of components interacts in time series plots and the performance metrics can be compared to that of the performance/reliability model results as a means to build confidence in the modeling.

For the consequence model, time sequence load data are used as input to the model as well as generation from renewable resources such as PV or Wind. Within the model the load is distributed among user defined diesel (or other fuel based generation) generator resources according to user defined generator duty cycles. Impacts on generator performance from other energy sources such as energy storage devices and fuel cells can be investigated along with various penetration levels of wind and PV. The model quantifies the generator performance in terms of fuel consumption, power output intervals, ramp rates, and stop-start cycles. This output takes the form of histograms, time series line plots, stacked plots showing generator duty cycles, and tables. Model runtimes vary from several seconds to 3 minutes depending on the simulation time duration. The choice of simulation duration is dependent of the objective of the project and the available data, but commonly the duration ranges from a few hours, a day, a week, a month or a year. As such, the user can run multiple design scenarios in a matter of minutes making what-if scenarios very easy to undertake.

Consequence modeling is not strictly necessary for the microgrid process itself, but the results can help one understand the tradeoffs between different design options, help guide the design team toward the optimal ESM design, illustrate principles to non technical people, and help stakeholders understand why a particular microgrid design was chosen.

3.5 Cost Analysis

Accurate cost estimates need to include as much information as possible on the costs for the design, engineering, construction, as well as overhead costs associated with implementing a microgrid. Maintenance requirements should also be considered in the costs for the microgrid. The design costs include all of the costs necessary for a design firm to survey the electrical system, do supporting analysis, and create design drawings to outline the changes in the existing grid necessary to implement the microgrid. The engineering costs include all of the additional support to review and oversee the design and construction of the microgrid and additional analysis necessary for the microgrid implementation not performed by the design or construction firms. The construction costs include the costs associated with the procurement of the microgrid equipment, the labor costs to install and test the equipment, and any overhead costs associated with a general contractor assigned to oversee the construction.

Our cost analysis approach is to first estimate base costs for all the equipment to be installed in the ESM as a springboard for developing other cost estimates. Once the base equipment costs are estimated, the labor costs are estimated and added to the base cost to obtain overall base costs to install the equipment.

Rules of thumb for obtaining rough estimates of cost as borne out from our experience and from industry practices are as follows: The construction management oversight costs are estimated to be 20% of the overall equipment costs. The engineering and design costs are estimated to be 12.5% each of the construction equipment costs. A 25% contingency is required to take into account the lack of complete information at the conceptual design level. As more complete information is available, the level of contingency for the estimate decreases. Not included in the estimates are any additional facility overhead costs associated with the project. Note that the multipliers applied above are generally for projects in the contiguous United States and that the cost multipliers for Alaska are higher and would vary according to the remoteness of the installation. Our cost estimate approach is summarized as follows:

- Calculate construction baseline costs (C): Includes equipment procurement costs and labor cost to install the equipment
- Calculate construction management cost: (CM=0.2*C)
- Calculate design cost (CD=0.125*C)
- Calculate engineering cost (CE=0.125*C)
- Sum all costs: CT=C+CM+CD+CE
- Multiply CT by 0.25, add to CT to obtain an upper limit on cost: CR=CT+CT*.25
- The cost range is CT through CR.
- Add any overall facility overhead costs to these estimates or estimate it to be 10% of CR costs)

For example, if it is determined that the overall costs for procuring and installing equipment including labor for a small project is $1000K, then the construction management costs can be estimated to be $200K. The design and engineering costs are estimated to be $125K each. Therefore the overall minimal costs for this ESM will be $1450K, and the range of costs including a contingency will be $1450K - $1800K. Additional facility overhead costs if known or estimated can be added to these cost ranges. Table **??** below, shows an example cost breakdown using the above approach for a facility with three major pieces of equipment. The table illustrates that at least 45% to 90% of additional costs must be budgeted above the equipment procurement and installation costs (Compare Equipment and Installation Costs with Total Costs and Total Costs with Contingency).

Obtaining cost estimates for electrical equipment and labor includes some of the following resources and strategies:

- General electrical equipment and installation cost data can be obtained with estimate resources such as RS Means
- For equipment not included in these, published reports or equipment manufacturers can be consulted for additional cost estimate information
- Regional Davis-Bacon labor wage rates can be used to modify the basic installation labor costs for the equipment for specific regions
- An additional labor productivity adjustment of 15% for construction costs is included to take into account for any additional costs associated with military safety and security requirements and training needed to work on a military base
- Labor overtime is not included in the estimates

The estimates typically used in this analysis are for generic equipment based upon resources available like RS Means, published reports, or manufacturer information. Actual estimates for equipment to be used in an ESM are typically based on quotes from bids made by engineering design and construction firms. Also, labor rates using Davis-Bacon can be modified through productivity factors to adjust for lower productivity in difficult environments. Labor rates will also vary between firms and may be impacted by travel requirements. One of the principal objectives of a conceptual design process is to obtain estimates of the range in costs rather than a firm cost range. In the case of a conceptual design, many of the details of an actual design and construction process need to be more fully scoped. Thus the conceptual design process is used to get a better idea about the range of costs associated with a project.

3.6 Design Analysis

The design analysis phase involves compiling all of the information from the activities described above and analyzing the information to specify microgrid components, network controls and pro-

Table 3.1: Example cost estimates for a facility.

Equipment	Equipment & Installation Costs ($K)	Construction Overhead (20%) ($K)	Design Overhead (20%) ($K)	Engineering Overhead (20%) ($K)	Total Costs ($K)	Total Costs w/ Contingency (20%) ($K)
Equip. A	200	40	25	25	290	363
Equip. B	300	60	38	38	435	544
Equip. C	500	100	63	63	725	906
Total Costs	1000	200	125	125	1450	1813

tection, and detail required level of cyber security design analysis as described below. The component Design Analysis includes the following determinations: 1) optimal generation capacities of renewable and diesel generators, energy storage, and the electrical distribution system; 2) optimized placement of microgrid components such as generators, switches, and transformers, and 3) the required microgrid control system.

3.7 Microgrid Controls

The microgrid controls and protection design analysis uses its own set of analysis tools to develop the control/protection strategy for the proposed microgrid. Controls/protection can include micro-EMS, SCADA, pilot or network-enabled adaptive relaying, AMI, energy efficiency measures, and direct load control as determined by the analysis. Cyber security analysis uses other described analysis as well as independent analysis to evaluate the cyber security for the proposed microgrid. The analysis includes available options for network protection (firewalls, VPNs, QOS, etc.), access control (passwords, multi-factor authentication, RBAC, etc.), logging, forensics, and administrative and procedural security controls and options to implement these. The analysis includes consideration of possible attack vectors as well as both the prevention and recovery aspects of cyber protection to better minimize effects from potential cyber-attacks.

3.8 Performance Analysis

Performance analysis evaluates design, controls, and IT options in terms of quantified costs and benefits. All of the previous analysis techniques and/or results from these techniques are used to quantify the required metrics for this analysis:

- Likelihood of un-served critical load

- Generator fuel requirements
- Reduced emissions
- Reduced possibility of cyber-attack
- Reduced loss of loads

Performance analysis, while not strictly necessary to develop a microgrid, can provide the value proposition required to justify the need for a microgrid while determining an optimal microgrid design.

Chapter 4

Venetie Electrical System Characterization

4.1 Introduction

Venetie is located approximately 160 miles north of Fairbanks along the Chandalar River, a tributary to the Yukon River. According to the 2010 census, the village of Venetie has a population of 166 people, but the population fluctuates during the year. Venetie village covers approximately 20.8 square miles. All travel to and from Venetie is via air traffic via 4,400 ft. airstrip located approximately 1.5 miles south of the center of village.

Sandia personnel visited the village of Venetie, Alaska July 1st and 2nd, 2012, to begin the process of characterization of the existing electrical infrastructure. Connie Fredenberg and Grace Oomituk, both employed by MarshCreek, LLC provided a tour of Venetie Village. MarshCreek, LLC is an energy consulting/construction firm contracted by DOE/NREL and tasked with helping Venetie Electric Utility to obtain the Independent Utility Operators Certification with the Alaska Energy Authority. With this certification, Venetie Electric Utility will be eligible for state subsidies to offset high diesel fuel costs as well as grants to improve their electrical system. This support is generally in the form of a monthly subsidy to cover the high cost of producing power and targets isolated, small, rural communities.

4.2 Generation Resources

4.2.1 Current System

The Venetie distribution system consists of a set of 480V generators housed in a slightly elevated generator building near the center of the village, which supplies power to the village. The generators connect via riser cables outside the generator building to three single-phase polemount 75 kVA transformers (225 kVA total) with a voltage step-up to 12470/7200V to an overhead distribution system, which supplies the village. The majority of the distribution system is three phase, but there are some portions with single-phase service such as a long 1.5 mile single-phase feed from the village to the airport runway. Venetie does not have a current electronic layout of their distribution system.

The electrical energy for the village is supplied by diesel generation only. Three generators are located in the generation building; a 180 kW generator unit that is currently in service, a newly rebuilt 190 kW generator but not yet installed (to be installed January, 2013) and requires additional parts for installation, and a 125 kW generator which has failed and has been taken out of service for the foreseeable future. All three generators have John Deere engines. The 180 kW generator is matched with a Kohler generator and the other two units are matched with MagnaPlus generators. The generator building is located across from the village washeteria where generator waste heat is piped over to the village washeteria to supplement the heating requirements of the boilers. Until the 190 kW generator is installed, the village is without backup power and a generator failure will entail loss of electrical power to the village.

The generator building is undersized which has resulted in a very cramped working space with very tightly fitted controls. This situation results in a poorly ventilated building causing significant heat build-up such that the room becomes excessively hot in the summer months. Additionally, lighting is inadequate. With these difficult working conditions combined with the age of the generators and lack of backup generation, there are serious concerns about both the short and long-term reliability of the village electrical supply. Fuel supply the generator building is from a 1,500-gallon tank in close proximity to the powerhouse. Fuel is continuously pumped to the generators from this tank. This tank is filled from main 14,000-gallon tanks located near the airstrip. A 5,000-gallon tanker truck is used to truck fuel from the main storage tank to the generator supply tank, a distance of 1.5 miles. The main tanks are filled from air tankers with a carrying capacity of 4,400 gallons. The average Venetie Electric Utility fuel usage is 4700 gallons per month indicating that the electrical generation requires one airlifted fuel delivery every three weeks or so. In practice fuel deliveries occur more often because of other non-specified diesel usage. Transport of fuel from the main tanks to the generator tanks occurs more often.

4.3 PV System

4.3.1 Existing PV

Venetie has some existing solar arrays. There is a 2.5 kW rooftop system on the Washeteria and a 2.5 kW tracking array. Both systems have Sunny Boy 2500 inverters, which are located in the Washeteria. The efficiency of the systems is not known. These systems offset some of the loads for these facilities but are an insignificant energy source for the current Venetie electrical system, since they only supply energy to these buildings and are capable of supplying 5 kW of total energy at maximum.

4.3.2 Previously Existing PV

Between 2000 and 2004, Venetie evaluated on-site PV systems as a method for reducing diesel fuel consumption for electrical generation. The Department of Energy Office of Energy Efficiency and Renewable Energy, Tribal Energy Program funded the project. The only information we have been able to obtain on this evaluation is the 2004 Year End Project Review Meeting presentation, held in Golden, Colorado [?].

Among the project goals were the following objectives "Determine the feasibility of powering an entire remote village with renewable and sustainable energy resources" and "Evaluate our existing PV systems' fuel savings and integration with our village electricity grids." As part of this project, a PV performance monitoring system was installed which apparently helped solve "earlier power system integration problems." Apparently Venetie had a 2.2 kW tracking array and a 1.2 kW fixed array. Little additional information has been located concerning details of this study and we have not been able to locate any of the data from this project. Project results and data from this project could significantly improve our understanding of energy demand characteristics and be invaluable for analyzing of potential costs/benefits of PV generation.

4.4 Other Potential Renewable Energy Sources

4.4.1 Biomass

The village of Venetie is surrounded by boreal forest comprising spruce, aspen, and poplar. A study funded by the DOE in 2009 that looked at the feasibility of developing biomass as a renewable energy resource for the communities of Fort Yukon, Chalkyitsik, and Venetie indicated that sufficient biomass exists to sustainably use as a renewable resource to replace fuel oil for heat on a select number community facilities. In Venetie, the payback period was estimated to be approximately six years [?]. In Ft. Yukon, construction is starting on a biomass boiler as a supplement to the exiting district heating system. The local residents will harvest the fuel for the biomass boiler from the adjacent forests. New technology is emerging that allows for the generation of power with biomass. If this technology can be proven for use in isolated rural communities such as Venetie, it could be of great benefit. The fuel would be locally procured from a renewable resource. This would keep the control of the fuel source within the community freeing the community from dependence upon costly delivery of fuel oil. It also would provide regular, sustainable employment to the community, thereby keeping the money within the community. The success of the Ft Yukon biomass boiler project and the sustained success of the locally procured fuel source could and should lead to the use of biomass as a viable renewable energy resource. One significant drawback is the greater complexity of the systems requiring a higher level of technical ability by those who operate and maintain the systems.

4.4.2 Hydrokinetics

Venetie is located in a broad valley adjacent to the flood plain of the Chandalar River, a major tributary of the Yukon River with headwaters 100 miles to the north on the south slope of the Brooks Range. At Venetie, the river is a low gradient, braided, undeveloped river with large seasonal flow fluctuations that enhance sediment and debris transport and the river surface freezes in the winter. The low gradient excludes the possibility of dam hydropower and the freezing and debris excludes hydrokinetics (run-of-the-river power generation) as a renewable energy resource for Venetie (personal communication with researchers at University of Fairbanks, ACEP/AHERC).

4.4.3 Wind Energy

The evaluation of the economic viability or technical feasibility of wind generation for Venetie is not within the scope of this project due to the likely high vary high installation and maintenance costs of wind farm for Venetie. However there are indications that wind energy may one day be a viable option for Venetie. The following is a very brief summary of wind resource potential and potential logistical and technical roadblocks to wind energy in the vicinity of Venetie.

Wind energy potential is poor for most of the lowlands of northeast Alaska located south of the Brooks Range. However ridge tops can have ratings as high as superb. Located 10 miles to the northwest of Venetie is a ridge that is rated fair, and further west along the ridge, 16 miles distant from Venetie the wind resource is rated outstanding to superb (Figure **??**) [**?**]. These ratings meet the criteria given in the Alaska Wind Energy Development: Best Practices Guide to Environmental Permitting and Consultations published by the Alaska energy Authority, Sept 2009. The guide recommends "If the wind map shows potential for wind power generation, long-term data should be collected from nearby airports or weather stations. After a potential wind farm site has been selected for further study, the long-term data will be compared and correlated to site specific data collected using an anemometer." [**?**]

A significant consideration with regards to wind generation in Alaska is the impact of cold weather on wind turbines due to potential icing of sensors and blades, increased fatigue on components, and changes in seals and lubricating oil properties at lower temperatures. Other concerns include safety factors for maintenance workers and impacts on the performance of wind turbines in extreme weather conditions. Maintenance may also be difficult or impossible due to deep snowfall and distance from Venetie. Additionally, shipping imposes size limitations on blades as well as installation infrastructure such as cranes, backhoes, cement and cement trucks, road building equipment and so on. Costs and future maintenance of running transmission lines to areas of high wind energy potential may make this an unrealistic source.

4.5 Load Characterization

According to the 2010 census there were 85 housing units listed for Venetie. Each housing unit is estimated to require 1-2 kW, which is higher in fall and winter. The majority of these loads arise from lighting, and the rest mostly from television, computing, and refrigeration. Resistive heating is not used in any of the housing units as heat is supplied by wood burning. In addition to these residential loads, there are several major non-residential loads including the following commercial, community, and government buildings (also see Figure **??** and Figure **??**):

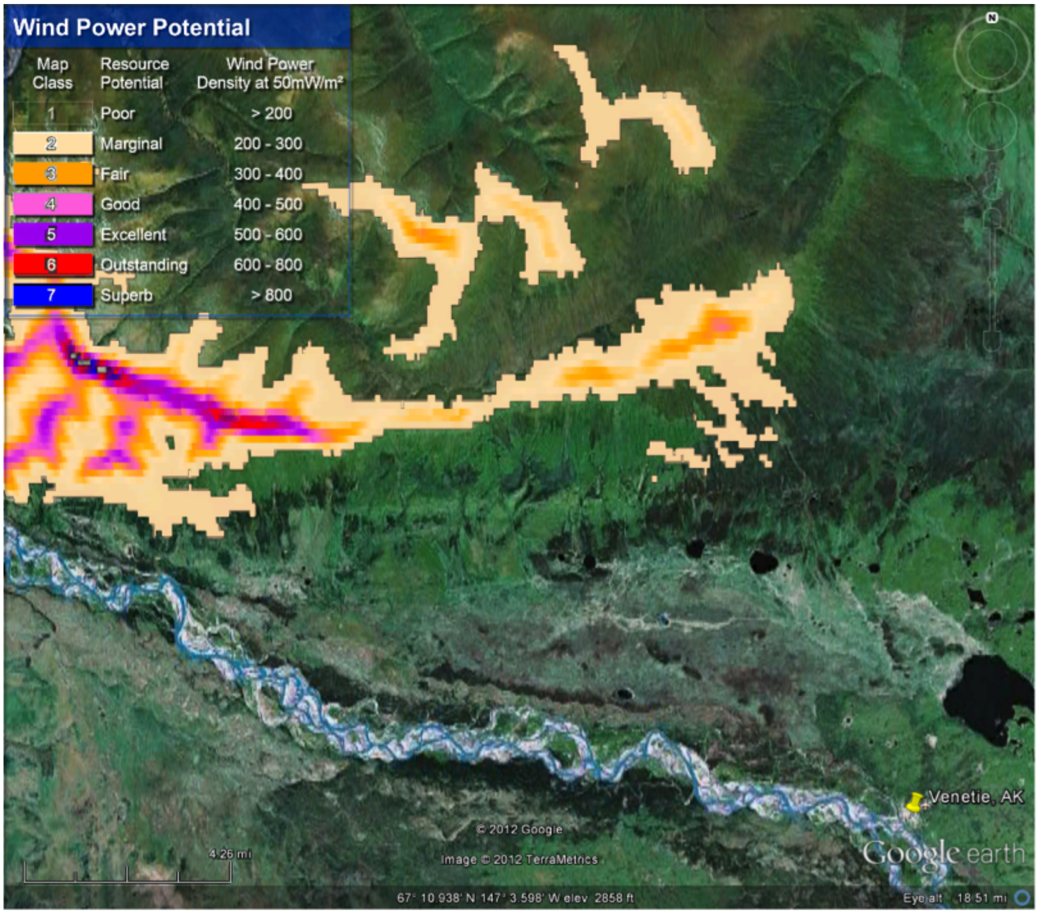


Figure 4.1: Google Earth Image with wind resources in the vicinity of Venetie superimposed.

- John Fredson Elementary and High School
- Village Council and Tribal Government (3 buildings)
- Myrna Roberts Health Clinic
- Washeteria
- Village Store
- Post Office
- Community Center
- Other miscellaneous buildings

Breakdown of electrical energy consumption for each of these buildings is not available, but the aggregate is reported as the non-residential kWh use in Table **??** . The school has the largest load, which is estimated to be 30 to 40kW when school is in session during the fall and winter months. Seasonal peak loads as obtained from the Venetie Electric Utility, but not specifically recorded are as follows:

- Winter (December - February): 150kW
- Spring (March - May): 80kW
- Summer (June - August): 70kW
- Fall (September - November): 110kW

Loads manually recorded on Alaska Energy Authority Plant Logs verify that the spring and summer loads approach these peaks, but fall and winter peak loads could not be verified due to a lack of recordings on the logs.

A breakdown of the electrical energy consumed (kWh sold) by Venetie's residential and non-residential loads from April 2011 through March 2012 as shown in Table **??** as provided by Connie Fredenberg of MarshCreek LLC. This data was used to calculate the daily average load for each of the months. The average daily kW use for each month, presented in Table **??**, was calculated from the electrical energy sold data given in Table **??** by dividing the kWh by the number of days in the month. The calculated average daily loads are compared with the peak load estimates by taking the difference between the two values (see also Table **??**). In the discussion that follows, we illustrate that while this data is useful and important to have as part of the energy demand characterization, it does not provide enough detail to sufficiently minimize such that the most optimal generator resources can be determined. A brief discussion of the shortcomings of the load data is given next to illustrate this point.

The largest average daily occurred in October (70kW) and November (69kW) and February (86kW) and the smallest daily load occurred in April (32kW). The remainder of the average daily loads falls between 52 and 60kW. The difference between the calculated daily average loads and the reported seasonal loads are highest for the winter months: December = 98kW, January = 97kW, and February = 64kW. The next highest are for the fall months: September = 52kW, October = 40kW, and November = 41kW. The differences for all the other months are less than 23kW, except for April, which is at 48kW. The difference between the average load and the reported peak load is greatest for the winter months, followed secondly by the fall months, then by the spring and summer months. Of the spring months April stands out as an anomaly with the difference within the range of the fall months. The total average daily load for April is also anomalously low compared to both the summer and spring months.

Without having the actual load data, one is forced to reconcile the differences and anomalies cited above through assumptions to formulate a daily load profile. For instance, the assumption could be made that the seasonal loads always peak at, or near the values given during any week and that the load occurs mid afternoon. The weekend load could be assumed to be 40kW less than the weekday load since that is the approximate demand for the school while it is in session. Using the monthly energy demand as a known, we can develop a cyclical daily load profile that hits both the weekday and weekend peaks and, when integrated over the month, yields the energy consumed for that month. In other words, the assumed daily cycles in load are required to equal the calculated average daily load. There are several problems with this approach; first, while it is possible to develop daily load profiles that meet the constraints described above, critical features of the load profile will likely be incorrect, yet important to quantify. These features include the rate of rise and fall of the load and the consistency and accuracy of the peaks and lows from day to day and week to week. Also not considered in developing the load profiles would be unique tribal or community events that either significantly decrease or increase power demand over periods of hours to days at a time as well as other activities that might impact the load such as construction projects. The anomalously low April demand is an obvious case in point; the power demand could have been low all through April, or perhaps it was normal for a spring month, then the demand significantly dropped off for a week or two.

Another example of how this information is lacking concerns the large difference in the winter loads and the calculated average daily loads. For example, the December difference of 98kW and an average daily load of 52 kW is difficult to reconcile as the load would have to drop to -46kW in order to retain the daily average of 52kW (52kw - 98kW = -46kW).

The above examples clearly show that other information is needed to reconcile the winter peak loads with the average daily loads. Analysis of high temporal resolution load data is the most reliable and accurate basis upon which an efficient and robust microgrid system can be designed.

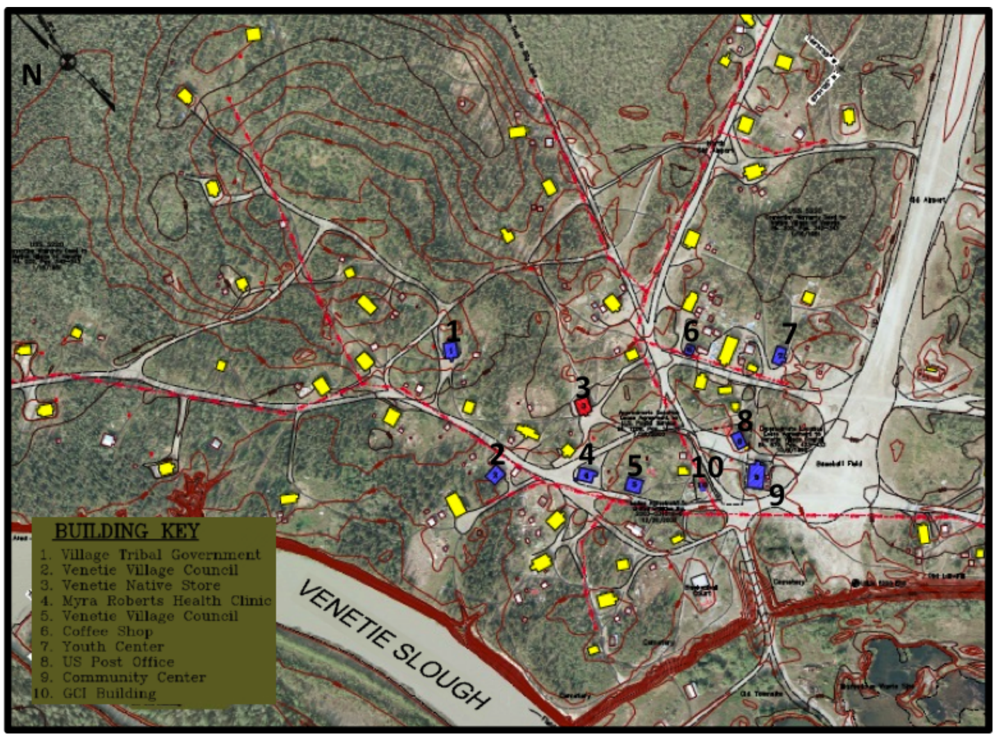


Figure 4.2: Plan-view map of North Venetie, AK showing key buildings.

4.6 Historical System Failure Modes

Identifying historical system failure modes is vital to characterizing the load and a valuable aid in the microgrid design process. Venetie Electric Utility personnel have reported to us that that

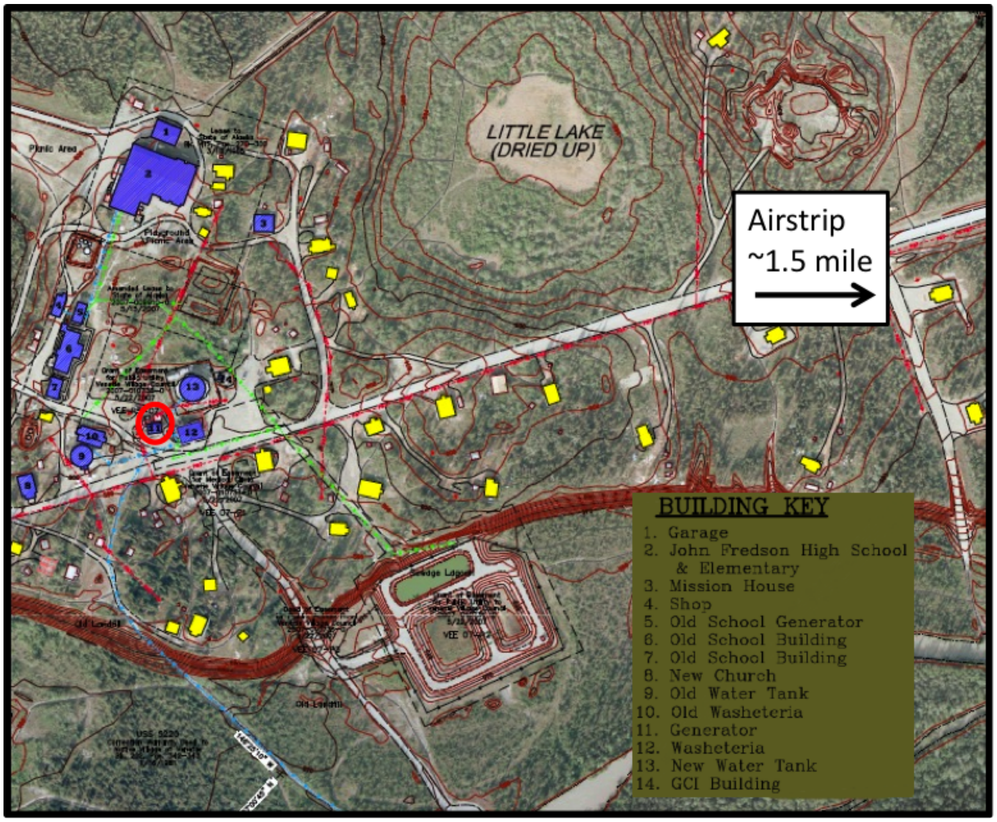


Figure 4.3: Plan-view map of South Venetie, AK showing key buildings and generator building circled in red.

there are intermittent loads that have caused the shutdown of the main generator due to excessive frequency excursions. One of the loads is the school sump pump, which can introduce 15kW steps in power demand, and another is the airstrip lighting, which is enabled by a pilot prior to nighttime landing. The runway lights are located 1.5 miles from the generators and are serviced by a single-phase conductor. To remedy shutdowns from these events, the generator under/over frequency and voltage controls have been relaxed such that a frequency dip to 58 Hz is allowed to persist for 6 seconds instead of a factory setting of 2 seconds to permit the generators to rebalance.

4.7 System Operation Costs

Another valuable piece of information regarding load characterization is the operation and maintenance costs, of which fuel costs typically make up a large percentage. Thus fuel costs are the major contributor to the cost per kWh, a metric that allows for easy comparisons with generation costs of other systems. For Venetie, the total residential electrical energy use was 199,787kWh (Table **??**) out of the total 513,257 kWh used or about 39% of the total. A total of 56,493 gallons of fuel were consumed at an average cost of \$5.53/gallon (Table **??**). The total fuel costs was \$312,406. With additional support services costing \$72,534, the total cost for electrical services

Table 4.1: Venetie Energy Use (April 2011 − March 2012).

Electrical Energy Sold (kWh)			
Month	Residential	Non-Residential	Total
April	13,519	9,427	22,946
May	14,824	27,244	42,068
June	16,466	24,544	41,010
July	15,565	22,008	37,573
August	17,596	26,824	44,420
September	17,821	23,914	41,735
October	19,249	32,665	51,914
November	19,962	29,964	49,926
December	17,139	21,407	38,546
January	16,222	22,932	39,154
February	16,599	43,526	60,125
March	14,826	29,015	43,841
Total	199,787	313,470	513,257

for this period was $384,940. Dividing the total cost by the total energy used yields an estimate of the per-unit electrical energy cost: $0.609/kWh. For comparison, the national average cost is about $0.0455/kWh [**?**]. Thus, during this period, the fuel cost alone amounted to 81% of the total energy production cost, hence the emphasis on fuel consumption reduction in this analysis.

Table 4.2: Calculated average daily loads and difference between the total average daily loads and the report seasonal loads.

	Average Daily Load (kW)			Daily Average and Seasonal Peak Load Differences (kW)	
Month	Residential	Non-Residential	Total	Seasonal Peak Load	Difference
April	19	13	32	80	48
May	20	37	57	80	23
June	23	34	57	70	13
July	21	30	51	70	19
August	24	36	60	70	10
September	24	32	56	110	54
October	26	44	70	110	40
November	28	42	69	110	41
December	23	29	52	150	98
January	22	31	53	150	97
February	25	65	89	150	61
March	20	39	59	80	21

Table 4.3: Venetie Fuel Use (April 2011 - March 2012).

Fuel Costs			
Month	Fuel Price (/gal)	Fuel Used (gal)	Actual Cost
April	$5.87	2,594	$15,214
May	$5.90	5,171	$30,511
June	$5.75	4,513	$25,951
July	$5.74	7,657	$43,957
August	$5.61	5,063	$28,381
September	$5.77	4,365	$25,190
October	$5.65	4,368	$24,674
November	$5.79	4,576	$26,499
December	$5.59	4,587	$25,627
Jan	$5.63	4,500	$25,340
Feb	$5.81	4,599	$26,721
Mar	$6.04	4,500	$27,159
Average/Total	$5.76	4,708	$325,224

Chapter 5

Conceptual Design, Preliminary Recommendations and Follow-up Steps

5.1 Introduction

As noted in our electrical system characterization section, the existing generator building houses three generators, two of which are non operational and the building is inadequate; it has poor ventilation, insufficient lighting, and cramped working space. These inadequacies create a difficult and potentially dangerous environment in which to maintain the equipment. Additionally, the 180 kW generator provides all of the primary electrical power to the village with the only significant backup being a generator dedicated to the public school. Also noted is that preparations are underway to bring the 190 kW on line as a backup generator. Three additional concerns about the current generation system include the following: First, the functional generator is oversized (180 kW) for all but the highest peaks such that the generator very likely operates at less than 30% capacity for lengthy periods of time. This operation results in low fuel efficiency and increased maintenance and shortening of service life due to "wet stacking," a condition that occurs when diesel generators run light loads. The potential for wet stacking will likely be greater for the larger (190 kW) generator when it is brought online. Second, the generator building is not co-located with the main fuel storage tanks. This requires that fuel be shuttled from the main fuel tanks located near the airport to the fuel tank located next to the generation building. The shuttling of the fuel is accomplished with a dedicated fuel truck. Potential breakdown of the fuel truck or potential extreme weather conditions add to the risk of loss of generation. Additionally, diesel fuel spills are likely. Third, Venetie is a remote village supplied by diesel fuel through air transport. As such diesel is becoming prohibitively expensive, with an average diesel fuel cost of $5.53 per gallon during 2011 through 2012 resulting in a very high average electrical rate of $0.75/kWh.

5.2 Design Overview

Taking these considerations in mind, we present three design options to address these issues. In the first option, the current generator building and generators are replaced with new facilities and the next two options include the first option with the addition of generation from a photovoltaic system

(PV) for the second, and energy storage for the third option. PV generation could significantly reduce fuel costs in proportion to penetration levels and energy storage would provide higher levels of PV penetration. The following is a list of these options further discussed with analysis below:

- Option 1: New Venetie Generation Facility. The new facility would 1) completely replace the existing building, 2) contain generators optimally sized to match village loads, and 3) be located in close proximity to the bulk fuel storage tank at the airfield and fuel would be supplied directly from the tanks to the generators. The new generation facility would require the installation of step-down transformers near the facility. These transformers could be purchased new or the transformers currently near the existing power plant could be relocated to the new facility. Additionally, a three-phase distribution line needs to be constructed from the new power plant to the current distribution system hook-up at the center of the village (1.5 miles).
- Option 2: New Venetie Generation Facility with limited PV. Option 2 includes Option 1 with the addition of a low penetration of PV (PV rating $<$ 50% load). The addition of PV generation would reduce diesel fuel consumption. Here optimal PV capacity and new diesel generator capacities would be selected such that the generators produce power in the ranges where wet stacking does not occur, which corresponds to the high fuel efficiency ranges, i.e. power production would be greater than 50% of capacity. Thus the generator capacities required with and without a PV system (Option 1 versus Option 2) would likely be different.
- Option 3: New Venetie Generation Facility with DC Bus and energy storage with extensive PV ($>$ 50%). This extends Option 2 by the use of a dedicated DC bus permitting incorporation of energy storage technologies. Energy storage would have two functions; first, it would dampen large load oscillations arising from high PV penetration, which would reduce diesel generator ramp rates while assuring a stable system. Second, it would reduce fuel consumption by allowing the diesel generators to operate at their optimal power production ranges.

5.3 Generator Capacity Considerations and Load Uncertainty

The generator capacities selected for the three, microgrid design options are the same. These selections are preliminary because the selections are based on the historical monthly fuel and energy use data supplied by the village and estimated seasonal peak loads provided by the Venetie Electric Utility personnel and Marsh Creek LLC -the Venetie electrical contractor- and not on actual load data (See Table **??**). Accurate load data is required to design an optimal system that would provide reliable and cost minimized service while providing generation resources for future growth. Thus we recommend that dedicated meters be installed at the existing generator building to collect 15 minute to 1 hour demand (kW) and energy use (kWh) data for the entire village for up to a year. Measured load data would reduce the design uncertainty and could result in recommendations of slightly larger, smaller or different combinations of generators required to optimize generator performance. A meter is being installed in February 2013 that will capture the load data for one year.

A system has been set up where monthly load data will be sent to Sandia National Laboratories and collected. At the conclusion of the data gathering exercise, the data will be made available to parties that demonstrate a need. However, the diesel capacity recommendations for the microgrid design options discussed below could be reasonably close to the optimal generator resources if the data used in this analysis is representative of the actual load profiles. Specifically, assumptions inherent in calculating power demand from monthly energy data have to be reasonably correct.

5.4 Generator Capacity Selection Strategy

Primary factors in selecting generator capacities include sizing generators to 1) meet peak demands, 2) provide for redundancy, and 3) to allow the generators to produce power in optimally efficient power production ranges. Additional considerations include selecting generators designed for continuous duty and not backup duty. The first criterion for generator selection is the peak demand. This occurs in the winter months for the village and was reported to be approximately 150kW. Therefore the single generator capacity, or the combined generation capacity if more than one generator is used, must exceed 150kW. At the same time the generator assets must provide sufficient redundancy in anticipation of contingencies that require back-up generation. These contingencies may be that a generator fails to start, fails while running, or be off-line for maintenance. Having redundancy requires that an additional generator, or suite of generators, be available to meet the expected peak load should the on-line generator fail or if the primary generator is off-line for maintenance. The need for additional redundancy occurs if a primary generator is out of service and the back-up generator fails. Additional redundancy was not considered since the loss of a generator at any given time, even considering downtime for maintenance, is a low probability event. Another consideration is the likelihood that a failure would occur during peak load and, if it did occur, would it be possible to shed some load such that required redundant generator capacities could be reduced to save cost and perhaps allow for generator capacities that are better matched with the low loads as well as the peak loads. This is another instance where actual load data could provide additional refinement to the microgrid design options. The primary criteria for the design presented here is the assumption that significant diesel savings, maintenance costs, and savings through delayed replacement of generators requires that the generators operate as efficiently and reliably as possible. Efficiency and reliability are linked through proper maintenance and proper generator output relative to the generator's power production capacity. According to most manufacturers, reliability is enhanced if the generator output is at least 30% of rated capacity. Continual under-loading results in wet stacking which impacts long-term reliability (i.e. decrease useable life) of generators. Wet stacking occurs when optimal air-to-fuel ratios are not sustained resulting in lower operational temperatures and un-burnt fuel is deposited in the exhaust valves, piston rings, fuel injectors, turbo chargers, and other engine components requiring additional maintenance to remove these deposits. If this maintenance is not performed the engine looses significant fuel efficiency and, if not properly remedied, eventually fails prematurely. The key to avoiding wet stacking is, as noted, to operate generators as much as possible above the 30% of capacity threshold. Operating the generators above 50% of rated capacity for most of the operation time is more optimal with the most optimal output around 90% of rated capacity. Running generators at high output not only avoids wet stacking, it also assures optimal fuel consumption efficiency as indicated in Table **??**.

Table 5.1: Typical Generator Efficiencies for Different Loads.

Example Generator Efficiencies				
	100% Load	75% Load	50% Load	25% Load
60kW	29.9%	29.5%	28.7%	22.9%
80kW	29.6%	27.5%	24.6%	22.2%
100kW	31.9%	31.2%	31.5%	25.6%
125kW	33.6%	32.6%	32.1%	27.2%
150kW	31.6%	30.4%	29.7%	22.6%
180kW	33.8%	33.0%	31.7%	26.7%
200kW	32.8%	33.5%	31.1%	24.6%
230kW	33.3%	34.3%	32.4%	26.5%

5.5 Microgrid Design Options

5.5.1 Design Option 1

The first design option involves replacing the old facility with a relocated facility near the airstrip within pumping distance of the bulk storage tanks. This option would include the construction of a weatherproof building required to house the three sets of new generators and associated equipment.

We highly recommend that the new generator building be located near the airstrip away from the village allowing for direct piping of diesel fuel from the bulk diesel storage tanks located near the airfield. Having the generator building located in close proximity to the bulk diesel storage tanks has several advantages over the current location; first, the need to shuttle diesel to town would be eliminated and, consequently, system reliability would significantly improve. Fuel shuttling introduces numerous failure modes and very likely reduces the reliability of the system while increasing fuel spill risks.

Conceptual Design

A schematic of our conceptual design for the first option (Option 1) is presented in Figure **??** showing the components of a new Venetie generation facility. The components include two 60kW generators and a 120kW generator, three-phase line to connect with the Venetie distribution system, bulk fuel storage tanks and necessary plumbing to connect these fuel tanks directly with the generators, and the necessary pumps required to supply the generators with the diesel.

A full assessment of the equipment needed to relocate the generator facility to the airstrip would require 1) an evaluation of the existing bulk fuel tanks to determine if they could, or should be used as the supply tanks or whether they should be replaced, 2) an assessment of the current feeder and supporting infrastructure to determine what components of the existing system could be reused. The existing feeder from the airport to the village and the generator facility is an overhead single-phase line used to feed power to the runway lights. It is tapped into the existing village distribution system near the current generation facility. This feeder would need to be upgraded to a three-phase distribution line. Options for the existing three-phase transformers are to relocate them, or, if these transformers are in a deteriorated state, purchase new transformers. In either case, the existing 480V generator output to the 12,470V distribution infrastructure would be preserved.

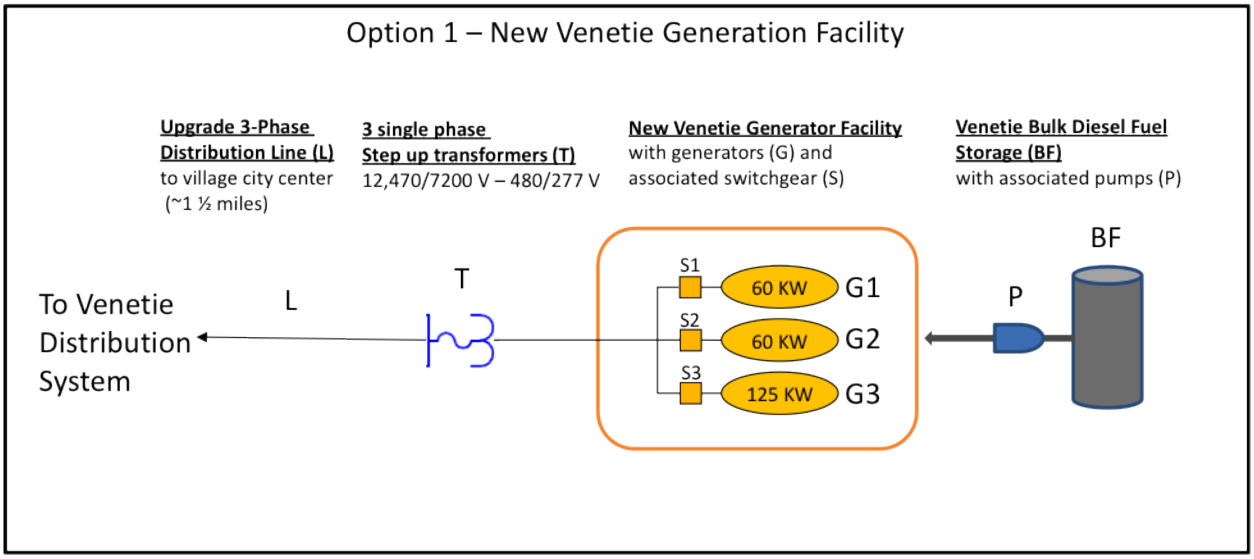


Figure 5.1: Schematic of Option 1 showing the components of the new Venetie generation facility and associated upgrades required for connection to the existing distribution system.

Generator Capacity Selection and Generation Scheduling for Option 1

The generator capacity selection was based on the average and estimated peak information as documented in Section **??**. As a review, the seasonal peaks were estimated by the Venetie Electric Utility personnel and not based on measured data. The average power demand for each month was calculated from the total monthly energy delivered. The data covered the interval from April 2011 to March 2012, as shown in Figure **??**.

A simple evaluation of the optimal generator size is as follows: For six months out of the year the average power demand is less than 60 kW and the peak use is a maximum of 80kW. Other times of the year the peak load varies between 110kW and 150kW with the average load varying between 40 and 90kW. A single 60 kW generator would cover the average load for these seven months and a 125kW generator in conjunction would cover the peak loads over 60kW up to 125 kW. During the summer months, the 125 kW generator could pick up any peak load above 60kW. A second 60kW generator would provide the needed redundancy for much of the year; it could replace the other 60kW generator or both of the 60kW generators could replace the 120kW generator. The 125kW generator could cover peak loads between 110 kW and 150 kW.

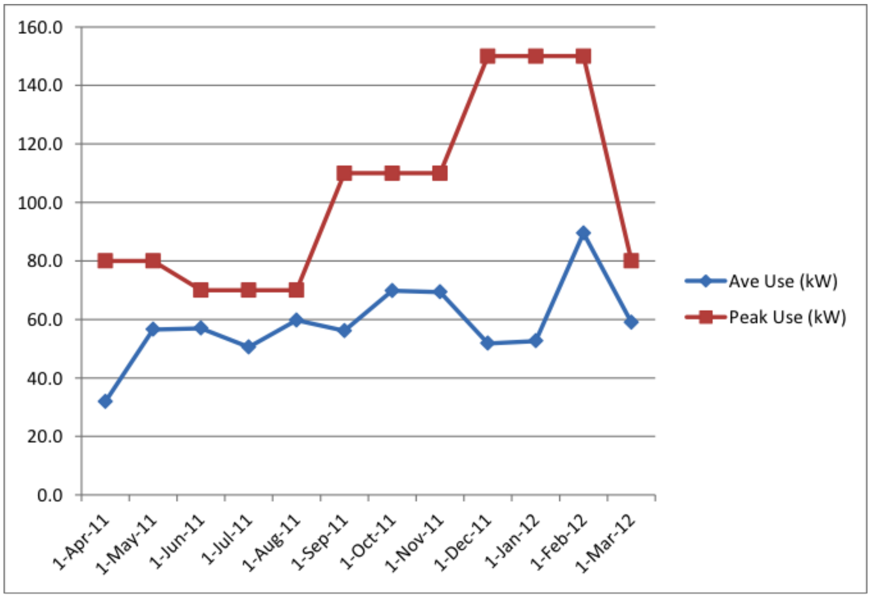


Figure 5.2: Plot showing the average and estimated power demand (kW) for Venetie from April 2011 through March 2012.

Generalized scheduling intervals over which a generator, or combination of generators would be operative given the generator capacities specified above is demonstrated in Figure **??** where the 100% (solid line) and 50% (dashed line) capacities of each generator is plotted along with the Venetie load data given in Figure **??**. Note that G1 and G2 refer to the 60kW generators and G3, the 125kW generator. Since generators G1 and G2 have a combined capacity of 120 kW, they could run in tandem during months when loads are below this level. For example, from March through November when generator G1 and G2 are operational, if loads drop below 50 kW or so, only one of the two generators would be required to operate in order to run efficiently. As loads increase to 50 kW the second kW generator could turn on. This way, generators could be run as efficiently as possible and still meet load requirements with redundant back up generation. A similar type scheme could be devised for the months when G1/G2 and G3 were required to operate.

During the winter months when the peaks are around 150kW, G1 or G2 could run with G3 resulting in a combined capacity of 185/205kW and when the load dropped below 60kW, the 120kW generator could be dropped. It is important to note that measured load data would be invaluable to explore optimal scheduling and validate selected generator capacities.

Potential Fuel Cost Savings for Option 1

Table **??** listed the information we obtained for the costs per gallon and fuel used for Venetie for one year as reported in Table **??**. From this information we made some preliminary estimates of potential fuel savings if the more optimal combination of generators as described in the previous

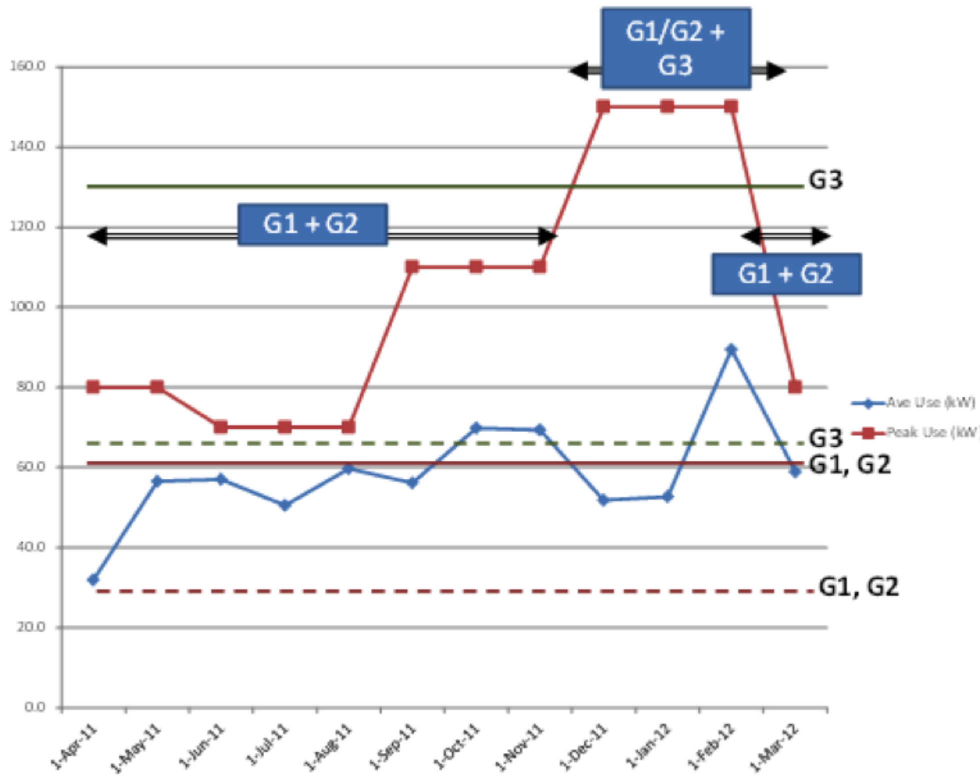


Figure 5.3: Plot showing a possible seasonal generator schedule for a new generation system at Venetie.

section were employed. The Average Power Output, as calculated from Table **??**, was used in conjunction with power production/efficiency rating curves and a energy to volume of fuel conversion factor to obtain an estimate of the fuel consumption of the proposed system. Note that the average power output for each generator is actually slightly higher than the reported monthly energy values due to transmission and other losses. Thus the savings could be slightly less than those calculated. There are other factors that would impact the accuracy of the calculations such as 1) variability in load which is not captured in the average data and would result in high ramp rates and associated lower generation efficiencies, 2) errors in ratings curves due to environmental effects and specific installation details, and 3) changes in the load from year to year. However, the high cost of fuel combined with the current extreme inefficient operation of the generators results in a sufficiently large savings potential that errors such as those mentioned above are small compared to the savings potential.

Table **??** shows the potential cost savings from running the generators more efficiently. The current costs in the table come from the amount the village paid for fuel for that month, not the amount of fuel used. Therefore, the cost savings is an estimate based yearly savings that may be realized by deploying a new set of generators. As discussed previously, we need better monthly load data both to determine what size generators to use as well as determine what schedules to run them to make their use the most efficient. These calculations resulted in an annual savings of $24,000 using optimally sized generators (Table **??**). The Load% was calculated by dividing the

Average Generator Output by the generator capacity rating. Note that Load% calculation is based on the manufacturers rating for that generator which may be different than the “referred to” rating. For example, the 60kW maximum capacity is specified as 56kW. The Load% is then converted to generator efficiency from a manufacturers Load% versus Efficiency% rating table. The efficiency is then used to calculate fuel consumption with an energy/fuel volume conversion factor. Also note that the Total Cost data has been increased by 10% to reflect less efficiency due to account for ramping of the generators.

5.5.2 Design Option 2: New Venetie Generation Facility with limited PV

Option 2 adds a limited amount of PV to Option 1 described above. The addition of PV provides additional, offset of diesel fuel costs. This option is illustrated in Figure **??** below. We tentatively suggest that a maximum of 50% PV could be added to the system without further modifications beyond Option 1 such as the addition of storage to buffer against rapid load fluctuations from variable PV generation. The PV facility would be located near the generator facility, contain an inverter, and be connected directly to the main generator outputs. The PV facility would offset an equivalent amount of diesel generation and therefore fuel consumption, the exact quantity and timing of which would be dependent upon the weather and the time of year.

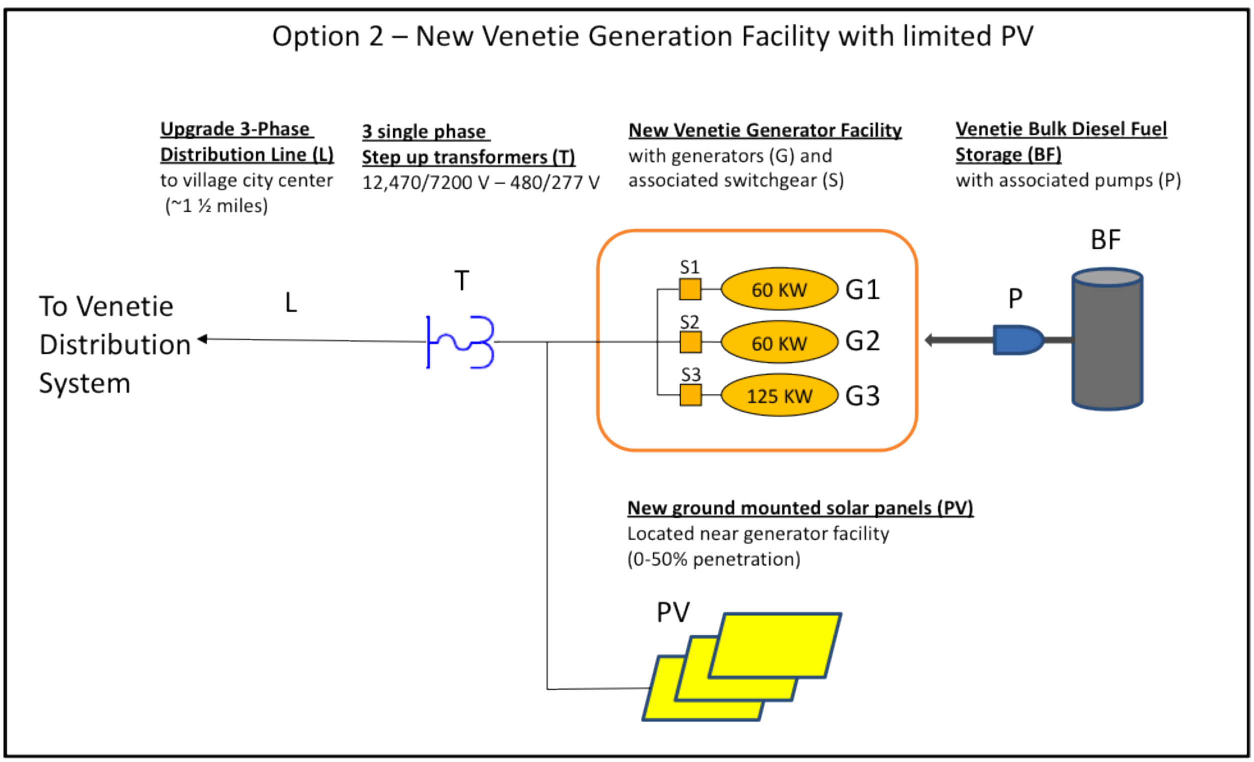


Figure 5.4: Schematic of Option 2 showing the components of the new Venetie generation facility and associated upgrades required for connection to the existing distribution system.

PV Benefits associated with Option 2

The calculation of the potential benefits of PV is based on the following assumptions:

- Average yearly solar radiation for Venetie can be approximated by that for Bettles, AK
- Average yearly load is 60 kW
- Average fuel cost for diesel is $5.80/gallon
- Average fuel use for 2-60 kW generators is 4.8 gallons/hour (50% loading at 28% efficiency)
- The average load and fuel costs remain constant over the next few years.

Since PV is utilized to offset generator fuel use, the benefit analysis is based on the savings in fuel consumption. The simplest assumption is that each kW of PV offsets a kW of generator use and the associated fuel use. This leads to a simple calculation of fuel saved: for a PV system output of 20 kW and a load of 60 kW, the generator supplies 40 kW or 66.7% of load they would supply without the PV system. Therefore the fuel consumption rate would be 66.7% of the rate required without augmentation from PV. So instead of a fuel consumption rate of 4.8 gallons/hour, the rate with PV generation would be 3.2 gallons per hour.

As the example calculation given above illustrates, fuel savings provided by PV is proportional to the extent of PV generation, which is related to the level of penetration and the capacity factor of the PV system. These factors provide a second method for calculating potential fuel savings with the advantage that measures of the PV output is not required, rather capacity factors gleamed from studies of other PV systems installed in similar settings can be used to calculate average PV generation. PV penetration can be defined as the percent of rated PV installed relative to the peak load of the system it is installed on. So a 6 kW PV system for a 60 kW peak load, has a 10% penetration. Because PV Penetrations ranging from 10 - 50% are manageable with current diesel generator and control technologies for small microgrids, such as that serving Venetie, this range of penetration is being proposed in Option 2.

The capacity factor of a power plant is the ratio of the actual output of a power plant over a period of time to its potential output if it had operated at full capacity the entire time. For PV systems located in the southwest US, the capacity factor can be in the range of 24% to 33% whereas in Alaska the capacity factors are expected to be at best 15%. The lower capacity factor is due to 1) long-continuous periods of no or little sunshine, although continuous sun during the summer months can offset some of this long period of no generation, 2) the effect of high latitudes on the increased effective thickness of the atmosphere and resultant radiation scattering which decreases direct solar radiation, and 3) relatively common cloud cover.

Fuel savings can now be calculated using the penetration and capacity factors:

- Average PV output = PV penetration * peak load * PV capacity factor

- Average PV output = 10% * 60kW * 15% = 0. 9kW
- Total Energy Generated = Average PV output * total hours of PV generation
- Total hours of PV generation = 365 * 24=8760 hours
- Total Energy Generated =0. 9kW * 8760 hours = 7884kWh
- Total Fuel Saved = Total PV Energy Generated * gallons of fuel per kWh
- Gallons per kWh = 38kWh * 28% (efficiency) = 10.6 kWh/Gal
- Total Fuel Saved = 7884kWh / 10.6 (kWh/Gal) = 743.8 Gallons
- Total Fuel Cost Averted = Total Fuel Saved * Fuel Cost
- Fuel Cost = $5.53 per Gallon
- Total Fuel Cost Averted = 743.8 Gallons * $5.53/Gallon = $4113

For a 60 kW system, with at 6 kW PV system (10% penetration) and a 15% capacity factor - the average expected output for the PV will be 6 kW * 15% or 0.9 kW.

Finally the installed cost of the PV system needs to be factored in to compare the amount of savings from the PV to the overall costs. PV installed costs are usually measured in $/W or $thousands/kW. PV costs vary considerably depending on manufacturing and tax incentives available for PV as well as the size of PV installed. In the continental US, the lowest current costs for large-scale PV systems are in the range of $3/W, and for smaller systems, e.g. 100 kW, the cost is in the range $5/W.

Table **??** below provides some initial estimates for different PV penetrations varying from 10-50% assuming a $10/W cost and a 15% capacity factor. Preliminary research seems to indicate that a $10/W cost for a system and 15% capacity factors for Venetie are conservative estimates.

5.5.3 Design Option 3: New Venetie Generation Facility with DC Bus and energy storage with extensive PV

The final option to consider is higher penetration of PV than that Presented in Option 1. While higher PV penetration would offset additional diesel fuel costs, additional capital costs would be incurred due to the need for additional system controls and energy storage as illustrated in Figure **??**. Pending a more extensive analysis, our conjecture is that these controls and energy storage may be required for PV penetrations of 30% or more and would definitely be required for penetrations above 50%.

Like option 2, the PV would be placed away from the airfield but near the generator facility in a series of ground mounted units, which could be connected to the main generator outputs. However with option 3, the PV and energy storage devices would be connected to a common DC bus and this common DC bus output would then be connected to the distribution grid. Like Option 2, the PV output would supply additional power to the distribution grid whenever sun was available and thus offset the equivalent amount of diesel generation and therefore fuel which would otherwise be used without a PV system. However in Option 3, the PV system would primarily charge the energy storage device and the stored energy would be used to 1) moderate swings in the load resulting from variable PV generation, and 2) improve the diesel generator efficiency by scheduling charging the storage device during low load periods.

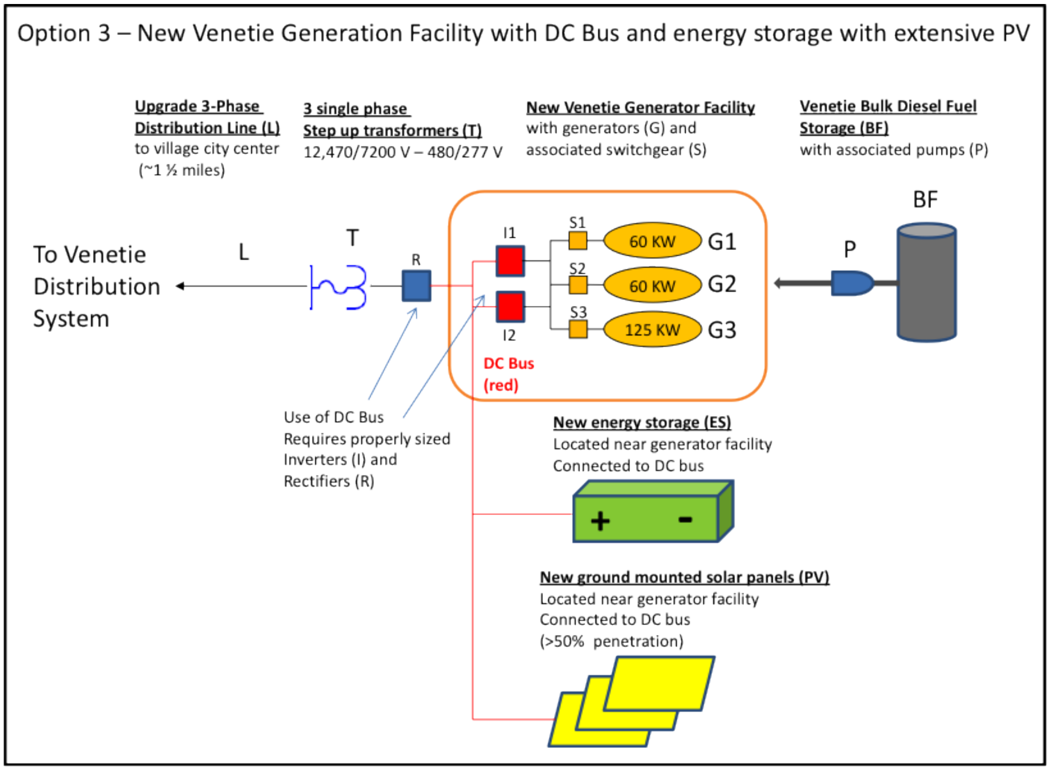


Figure 5.5: Schematic of Option 3 showing the components of the new Venetie generation facility, associated upgrades required for connection to the existing distribution system including a DC bus and energy storage components.

Table 5.2: Potential Fuel Cost Savings for Option 1.

Month	Ave Gen Output (kW)	Load (%)	Efficiency (%)	Fuel Use per Hour (gal)	Days in Month	Fuel Used per Month (gal)	Cost of Fuel ($/gal)	Total Cost ($)	Current Costs ($)	Cost Savings ($)
April	35.8	64.0	29.1	3.0	30	2171	$5.87	$14,007	$15,214	$1,207
May	68.5	59.6	32.3	5.2	31	3874	$5.90	$25,144	$30,511	$5,367
June	77.9	45.6	32.5	5.9	30	4242	$5.75	$26,830	$25,951	-$879
July	60.5	35.4	32.2	4.6	31	3436	$5.74	$21,696	$43,957	$22,261
August	71.8	42.0	32.4	5.4	31	4049	$5.61	$24,969	$28,381	$3,412
September	61.1	35.7	32.2	4.7	30	3358	$5.77	$21,316	$25,190	$3,874
October	75.7	44.3	32.4	5.7	31	4261	$5.65	$26,477	$24,674	-$1,803
November	87.5	51.2	32.6	6.6	30	4739	$5.79	$30,190	$26,499	-$3,691
December	67.3	39.4	32.3	5.1	31	3808	$5.59	$23,404	$25,627	$2,223
January	69.9	40.9	32.3	5.3	31	3947	$5.63	$24,449	$25,340	$891
February	115.2	67.4	31.3	9.0	29	6282	$5.81	$40,147	$26,721	- $13,426
March	60.5	35.4	32.2	4.6	31	3436	$6.04	$22,809	$27,159	$4,349
Total								$301,440	$325,224	$23,784

Table 5.3: PV Costs and Savings assuming \$10/W costs and 15% capacity factors.

PV Penetration	PV System Size (60 kW * PV Penetration) (kW)	Cost (\$)	Fuel Saved (gal/year)	Cost Savings (\$/year)
10%	6	\$60,000	743.8	\$4,113
20%	12	\$120,000	1487.5	\$8,226
33%	20	\$200,000	2479.3	\$13,710
40%	24	\$240,000	2975.1	\$16,452
50%	30	\$300,000	3718.9	\$20,565

Chapter 6

Consequence Modeling Approach for Microgrid Design Analysis

6.1 Introduction

The consequence model was constructed in PowerSim Studio®, an object oriented software package designed specifically for systems modeling where time sequenced flow rate of such things as materials, energy, water, and widgets, are accumulated in storage as a result of the influences of other components of the system, and/or as a result of direct feedback loops between the inflows, outflows and/or storage. This modeling platform is ideal for investigating microgrid designs because complex structure can be captured within the model and mathematical integration required for calculating accumulations is done behind the scenes. This allows the modeler to concentrate on the capturing important relationships in the structure of the model. Additionally, user interfaces for changing values of variables and observing results are easily constructed. Finally, fast runtimes allow for quick scenario testing and what if analysis.

The ability to easily change parameter values, run the model quickly, and view pertinent results was used to construct a load profile for an entire year. Normalized load profiles were scaled to match, along with other criteria, the monthly energy use data given in Table **??**. Once a satisfactory load profile was constructed, it was fed into the dispatch component of the consequence model that distributes the load among generator resources specified by the user in look-up tables. Other model components track the generator duty cycles and calculates and tracks various generator performance measures such as fuel consumption, and generation power production intervals in terms of the percent of time each generator is within given ranges of their full capacities.

During each simulation, the dispatch component of the model simultaneously feeds the load data to seven different user specified suites of generators, allowing for immediate comparison of generator performance parameters. The generator suites are specified by the user in tables within Excel, which the consequence model accesses during the simulation. This involves specifying the maximum capacities of each of the generators and lowest desired generation level for each of the seven suites of generators. For the consequence model simulations presented in this report we limit the generator sizing to three cases, 1) the current operation at Venetie (one 180kW or on 190kW generator serving the load), 2) those recommended in previous sections of this report, and 3) other suites of generators to illustrate other options.

6.2 Consequence Modeling Discussion Overview

The consequence modeling discussion begins with a description of the method for developing the high temporal resolution load profile and then continues with the evaluation of the generators operation strategies, first without photovoltaic generation (PV), then with PV generation.

6.3 Development of Load Profiles

The load profiles used in the consequence model are based on two twenty-four hour, one-hour interval load profiles developed for the Alaskan Village Electric Load Calculator, Figure **??** (Devine and Baring-Gould, 2004). One profile was used for weekday loads and the other for weekend and holiday loads. Each profile was normalized to its peak.

The normalized load profiles were brought into a component of the consequence model specifically built to allow for trial and error scaling. Scaling involved modifying the curves until they were in agreement with the following data and information:

- The total "kWh Sold" data presented in Table **??** (Venetie Energy Use) from which the total average "kW Used" was calculated
- General information obtained from the site visit such as 30 to 40 kW daytime demand from the school and estimates of the seasonal peak demands (see the section titled "Venetie electrical System Characterization"
- A six-week load profile gleamed from a slide (#37) in a presentation titled "Powering Remote Northern Villages With the Midnight Sun" made to the Office of Energy Efficiency and Renewable Energy, Tribal Energy Program, FY 2004, authored by Lance Whitwell (Tribal Energy Manager), Marjorie John (Assistant Energy Manger), and Myles O'Kelly (independence Power and Energy Consulting) (See Figure **??** below)
- Alaska Energy Authority Plant Log from Venetie recording the power production of the generators and time of the recording for three months in written log form, usually recorded twice daily

The development of the load profiles was sequenced as follows:

- First, the normalized load profiles (Figure **??**) were visually studied to identify general characteristics of the load profile that could be used to constrain the scaling parameters. These general characteristics were selected with consideration of the following load characteristics gleamed from the data and information given above.
  - Weekend load peaks are less than the weekday loads by about 20 kW and weekend load bottoms are usually 5 to 10 kW less than the bottoms of the weekday loads

- Weekend loads typically oscillate about 30 kw while weekday loads oscillate almost 50 kw
- The weekend load seems to be peak and then fluctuate around that peak whereas the weekday load seems to reach a peak and back off from that peak fairly rapidly
- The weekday load seems to have a secondary peak late in the day, this appears as a shoulder before the load drops to a minimum
- The trend in the load show a gradual increase which probably results from shorter and colder days.

- Second, the variation in the school load was compared to the variation in the load in Figure **??** to ascertain that the load in this was consistent with the expected variability resulting from school operations.

  - The school adds an additional 30 to 40 kW load while school is in session. It is likely that most of this load cycles each day and is responsible for some of the variability in the Venetie load.
  - The variability in the surrogate weekday load in Figure **??** needs to reflect the daily cycling of the school load.
  - Because the weekday variation observed in the load in Figure **??** is usually greater than the 30 to 40 kW specified load for the school, the variability in the Figure **??** load is sufficient to account for the cycling of the school load, plus additional cycling from other daytime loads.

- The normalized load profiles were scaled according to the information given in the first bullet above. The blue normalized load profile in Figure **??** (normalized Selawik profile) was used for the weekend profile due to its flatter peak whereas the red normalized profile (normalized Scammon Bay profile) was used for the weekday profile due to its more pronounced peak and the presence of a shoulder, or evening peak.

- The scaled profiles were then offset by Venetie's average monthly power demand given in Table **??** and plotted in Figure **??** of this report. This was accomplished by coding the consequence model to change the offset according to the month of the simulation time. This offset was then globally adjusted to minimize the difference between the Total Energy reported in Table **??** and that accumulated over corresponding months during the simulation. Figure **??** shows this result in the form of bar graphs and tables.

- This load profile was then plotted with the measured power production from Alaska Energy Authority Plant Log to validate that the resultant load profiles are in agreement with measured load (Figure **??**).

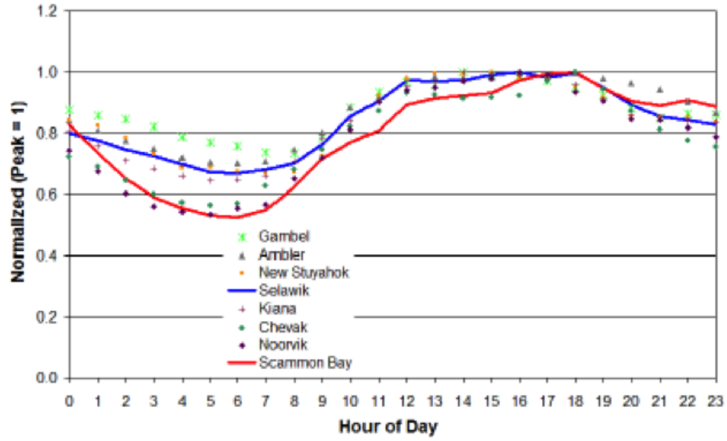


Figure 6.1: Plot of normalized load profiles modified from Devine and Baring-Gould, 2004.

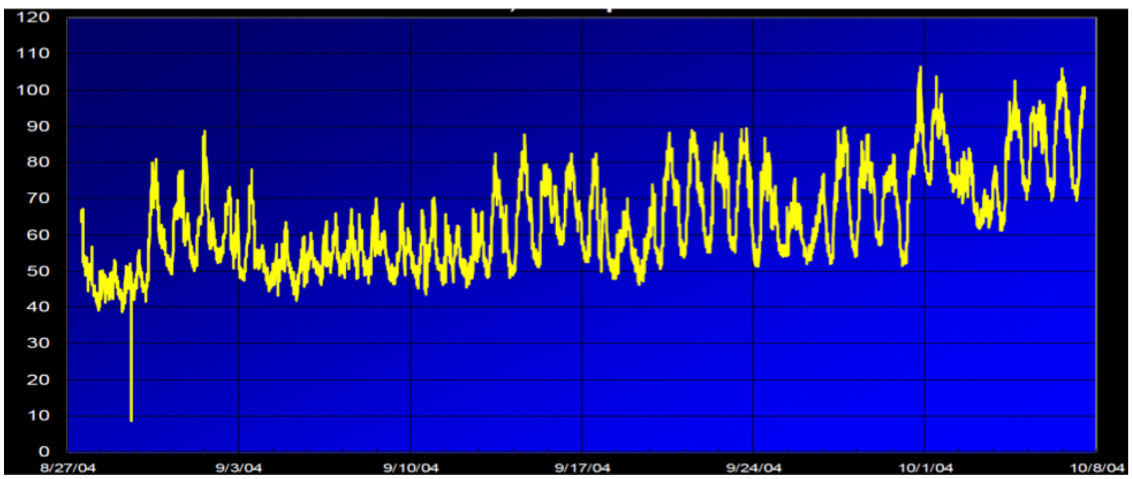


Figure 6.2: Plot of load profiles taken from Whitwell et al., 2004.

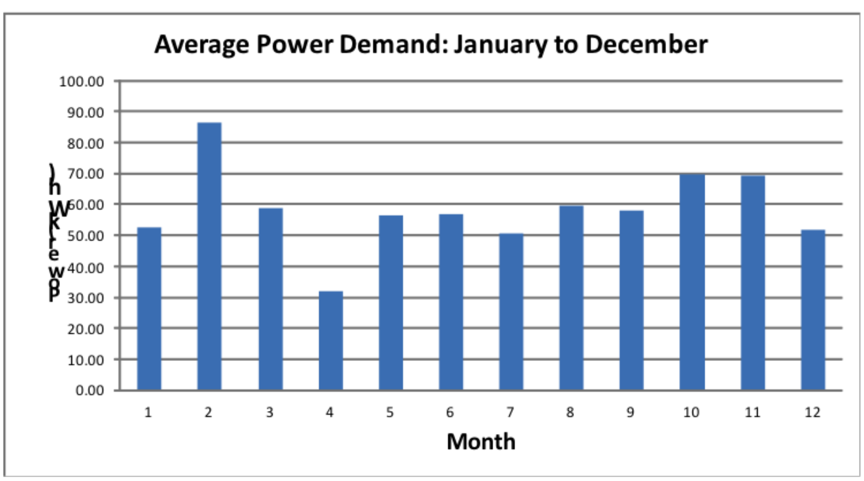


Figure 6.3: Average Monthly Power Demand calculated from the measured Total Monthly Energy (kWh sold) in Table **??**.

6.4 Simulated Load Profile Discussion

Comparisons between the simulated load profile and the measured load profile (Figure **??**), the difference between the Alaska Energy Authority Log and the simulated load profile over the month of April (Figure **??**), and the discrepancy between the reported seasonal peaks (150 kW for winter, 80 kW for spring, 70 kW for summer and 110 kW for fall) and that observed in the simulated load also suggest that the actual load is very complex and underscores the importance of working with actual high quality, high resolution load data. However, the simulated load data, although not accurate in detail, does capture daily fluctuations and monthly trends in a reasonable manner in that the data is consistent with historical and measured loads and with energy accounting records. Thus accuracy of the simulated load profile is sufficient to illustrate the application of consequence modeling specific to the Venetie community.

6.5 Potential Generator Configuration Investigation

A year-long simulation was run with seven generator (genset) configurations to investigate the duty cycles and fuel consumption of each configuration.

1. The first genset configuration is the current set up at the Venetie power plant where a 180kW generator is operated 24 hours around the clock with no consideration for the load.

2. The second genset configuration is a potential set up if the 190kW generator, also present at the site, is brought on line. This generator would also run 24 hours a day with no consideration for the load.

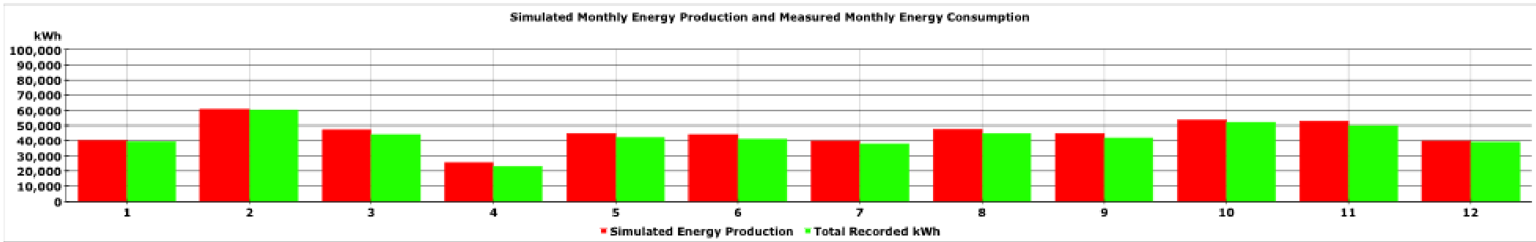
3. For the third genset configuration, a 125kW generator is used to follow the load 24 hours a day. This configuration illustrates the more favorable power production levels of the 125 kW generator over that of the 180 and 190 kW generators.

4. The fourth genset configuration invokes a 125kW generator and a 60 kW generator to meet loads between 185kW and 125kW, the 125kW generator to meet loads between 125kW and 60kW and the 60kW generator for loads below 60kW. This genset configuration illustrates the advantage of a dual generator system with one of the generators being approximately one-half the capacity of the other to prevent low power production from the larger generator.

5. The fifth genset configuration is similar to the fourth, except the 60kW generator is replaced with an 80 kW generator with the load intervals adjusted accordingly.

6. The sixth genset configuration is similar to the fourth, except the 60kW generator is replaced with an 100 kW generator with the load intervals adjusted accordingly.

7. For the seventh genset configuration, two - 60 kW generators are combined with a 30 kW generator to provide generation for loads between 150 kW and 60, the 60 kW generator



40,310 kWh	60,514 kWh	46,994 kWh	25,501 kWh	44,634 kWh	43,775 kWh	39,693 kWh	47,371 kWh	44,617 kWh	53,457 kWh	52,726 kWh	39,567 kWh
39,153 kWh	60,124 kWh	43,841 kWh	22,946 kWh	42,068 kWh	41,010 kWh	37,573 kWh	44,420 kWh	41,735 kWh	51,914 kWh	49,926 kWh	39,000 kWh

Figure 6.4: Plot of simulated results showing the simulated Total Monthly Energy (red) and Venetie's Measured Monthly Energy (green).

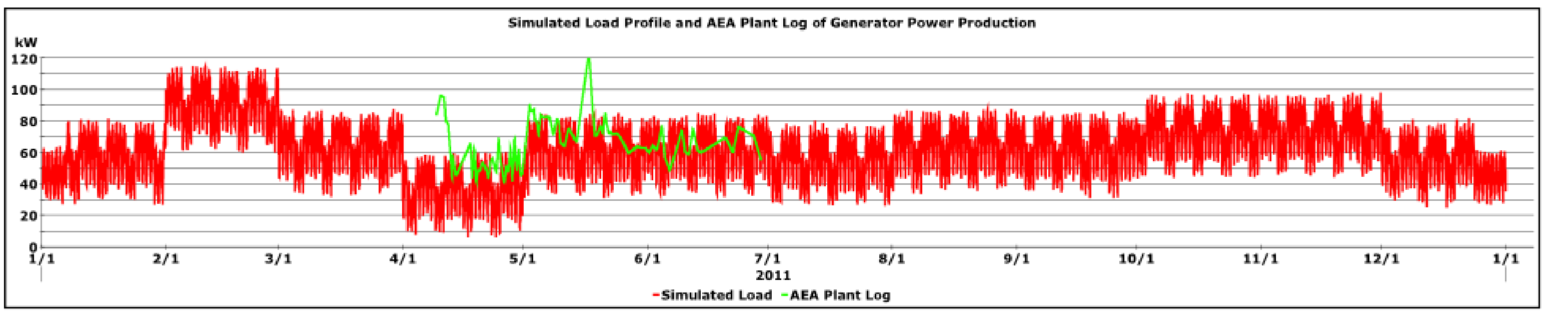


Figure 6.5: Plot showing simulated load profile for a 12 month period with AEA Plant Log Data superimposed.

meets loads down to 30 kW, and the 30 kW generator meets loads down to 12 kW. This configuration illustrates the use of three generators of different sizes to meet the load. The smaller generator provides low power production required if PV is brought onto the system

Below are seven sets of graphs with each set associated with one of the seven cases and arranged in order of increasing genset configuration number. The first plot of each series shows the generator duty cycles and for the strategies where a single generator is used, only one generator is displayed on the duty cycle plot. The second plot shows the power production interval of the generator and if a second generator is present, two power production interval plots are present.

The significance of the generator duty plot is that is allows a visual check to determine if generators are excessively cycling off and on or if the load is greater or less than the range of the generator. In PowerSim Studio® it is a simple matter to build event counting into the model so that events such as these can be quantified and tracked.

The power production plots quantify the power production interval of each generator relative to its rated capacity and in terms of the percentage of the total time the generator spends within each interval. These plots are important because, as mentioned elsewhere in this report, wet stacking can occur if diesel generators run at low power levels. Wet stacking has significant deleterious effects on diesel engines. Additionally, diesel generators are most efficient when operated near their maximum capacity and least efficient when operated at the low end of their capacity. Therefore it behooves diesel generator operators to implement diesel operation strategies that minimize under loading generators.

Following these seven sets of plots is a bar graph and table showing the calculated diesel consumption for each of the scenarios. Each of the seven strategies is discussed independently below each set of graphs. These discussions include a summary of the simulation results.

6.5.1 Load is met by the on-site active 180 kW Generator

This is the current set up at the Venetie power plant where a 180 kW generator is operated 24 hours around the clock with no consideration for the load. In the top plot (the generator duty cycle plot), the 180 kW generator shows cycling between weekend and weekday loads (coarse oscillations) as well as daily loads (fine oscillations). The bottom plot is a Power Production Interval plot that shows the generator production is mostly in the 30% to 50% range (about 60% of the time) and about 30% of the time in the 10% to 30% range. These power production intervals are not desirable as the generator is oversized for this load. Keep in mind that this simulation is based on a simulated load so that these results may be over or understating the actual situation at Venetie.

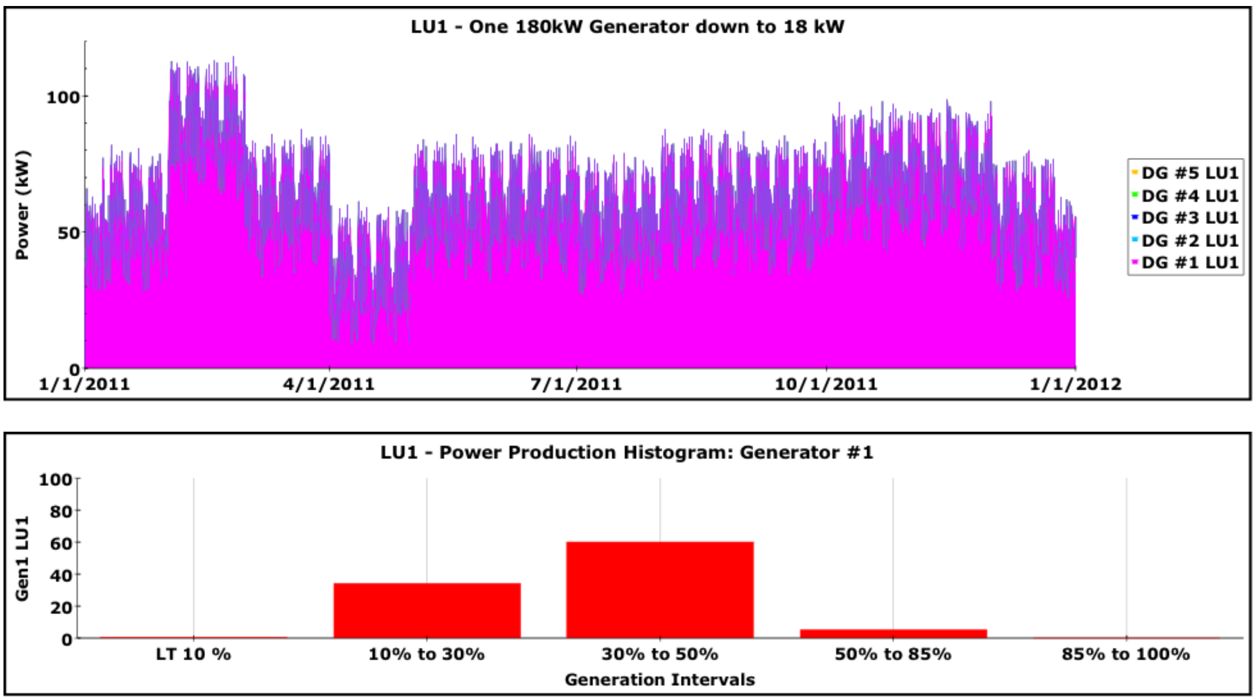
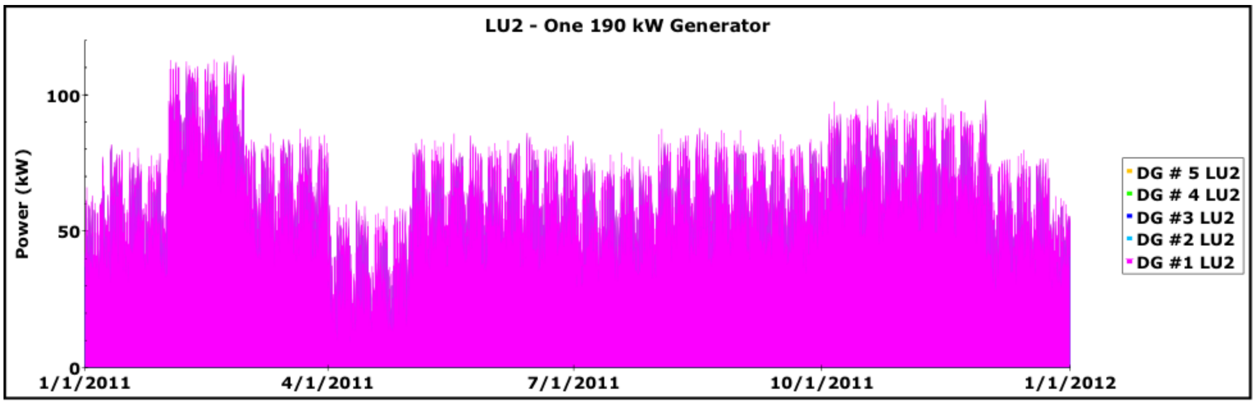


Figure 6.6: Plots showing the generation duty profile (top) and Power Production versus Generation Interval Histograms (bottom) for the current primary generator at Venetie (180 kW generator).

6.5.2 Load is Met by the Current 190kW Backup Generator

The second genset configuration is a potential set up if the 190 kW generator is brought on line. This generator would operate twenty-four hours a day with no consideration for the load. The generator duty cycle plot is a duplicate of the plot in Figure **??** because the generator is serving the same load. However the Power Production Interval Plot shows a slight increase in the percent of time the generator spends in the 10% to 30% range because of the larger capacity of this generator relative to the 180 kW generator. Again, these power production intervals are not desirable as the generator is oversized for this load and the high probability of wet stacking with the accompanying long term maintenance and reliability issues.



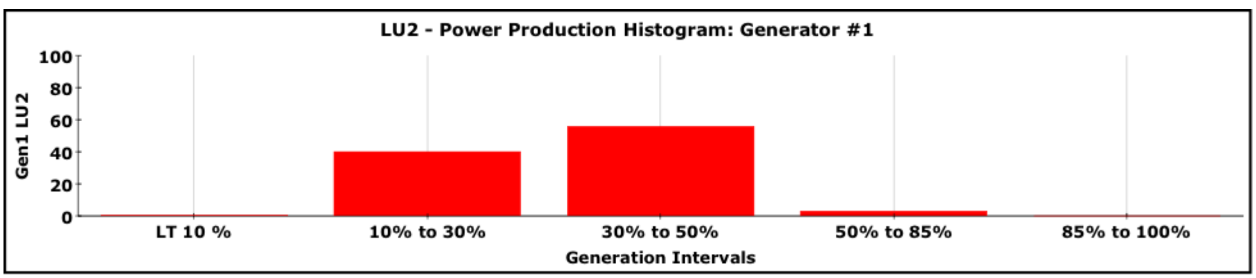
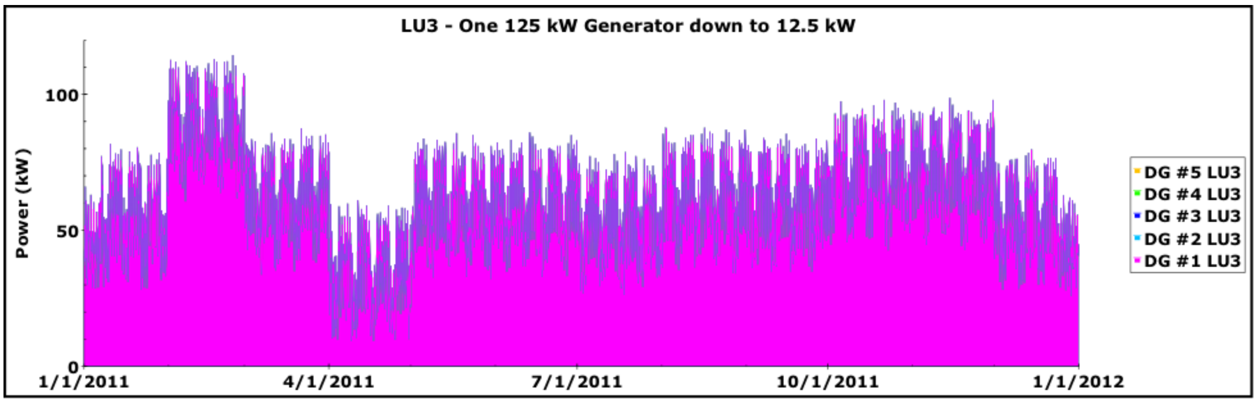


Figure 6.7: Plots showing the generation duty profile (top) and Power Production - Generation Interval Histograms (bottom) for the current backup generator at Venetie (190 kW generator).

6.5.3 Load is Met by a 125 kW Generator

For the third genset configuration a 125 kW generator is used to follow the load 24 hours a day. Once again the generator duty cycle plot is a duplicate of the two other plots because the 125 kW generator is servicing the same load. Here there is marked improvement in the power production intervals as now the generator is producing power in the 50% to 80% range almost 60% of the time. This difference is due to the fact that this capacity is significantly smaller than the previous two cases. However, the generator is still generating significant power in the 30 to 50% range and a smaller percentage in the 10% to 30% range.



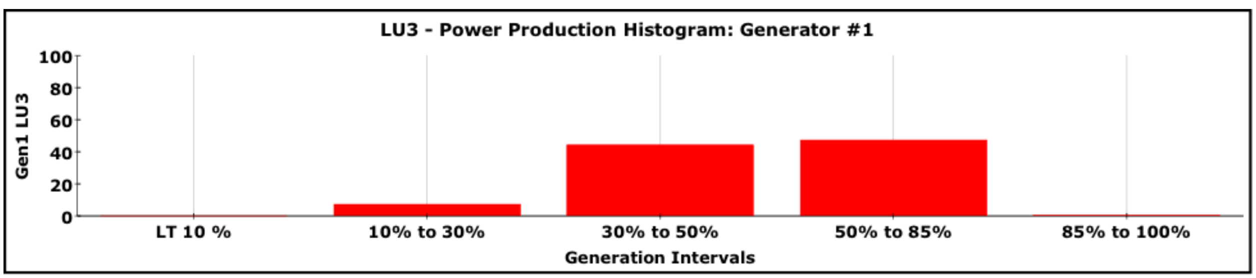


Figure 6.8: Plots showing the generation duty profile (top) and Power Production - Generation Interval Histograms (bottom) for a 125 kW generator at Venetie.

6.5.4 Load is Met by a 125 and a 60 kW Generator

The fourth genset configuration allows matching of loads with either one, or both generators: the 125 kW and the 60 kW generator to meet loads between 185 kW and 120 kW; the 125 kW generator to meet loads between 125 kW and 60 kW; and the 60 kW generator for loads below 60 kW. The load profile is the same as the previous cases, but the different colors show that the generators switching off and on to meet the loads within a specified range. Having generators of two different capacities allows for optimized generator use. This can be seen in the Power Production Histograms where the 125 kW generator power production below 50% is minimized. Note that the generator operation strategy could be adjusted to minimize the rapid switching outside the April and early January.

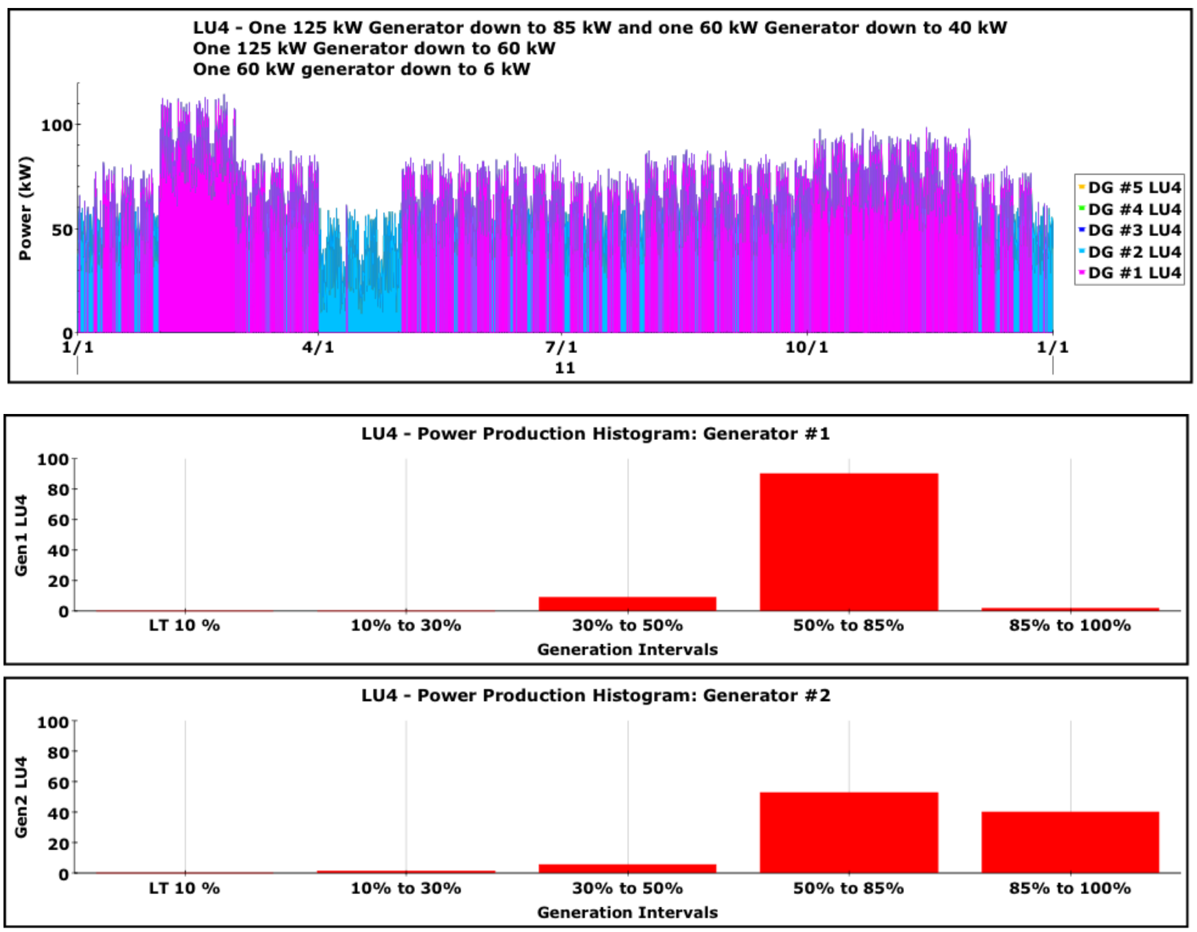


Figure 6.9: Plots showing the generator duty profile (top) and Power Production - Generation Interval Histograms (middle and bottom) for a generator suite consisting of one-125 kW generator (Generator #1) and one 60 kW generator (Generator #2). In this case, the 125 kW generator is allowed to drop to 30% of its rated capacity while the 60kW generator is allowed to drop to 10 to 30% of its capacity.

6.5.5 Load is Met by a 125 and a 80 kW Generator

The fifth genset configuration is similar to the fourth, except the 60 kW generator is replaced with a 80 kW generator with the load intervals adjusted accordingly. The results of this simulation show the importance of matching generator assets appropriately to the load, and hence the importance of having accurate load data. Notice that the generator duty plot shows the two generators (125kW and 80kW) switching back and forth excessively. Also note that the power production of the two generators shows some improvement over the previous case because the 125 kW generator does operate below the 50% range, which shows why it is important to consider the duty cycles.

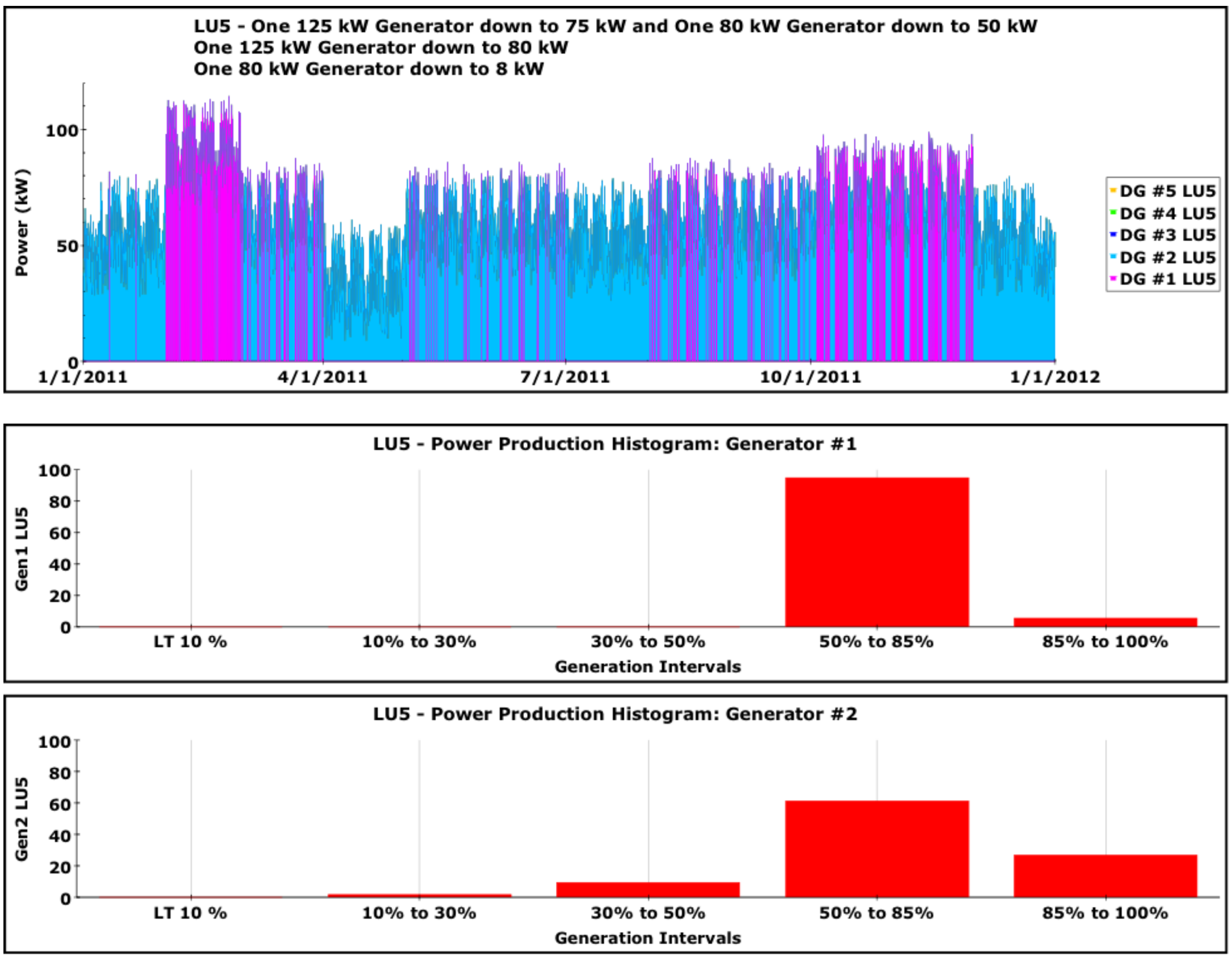


Figure 6.10: Plots showing the generator duty profile (top) and Power Production - Generation Interval Histograms (middle and bottom) for a generator suite consisting of one-125 kW generator (labeled Generator #1) and one 80 kW generator (labeled Generator #2). In this case, the 125 kW generator is prevented from dropping below 50% of maximum capacity whereas the 80 kW generator is allowed drop to 10 to 30% of its rated capacity.

6.5.6 Load is Met by a 125 and a 100 kW Generator

The sixth genset configuration is similar to the fourth and fifth cases, but with a 100 kW generator replacing the smaller generator and with the load intervals adjusted accordingly. Here the generators are not switching back and forth as much as was the case with the 80kW generator, but the 100kW generator is producing significant amounts of power below the 30 to 50% mark. It is very likely that this is occurring in April when the load appears to be at a low for the year.

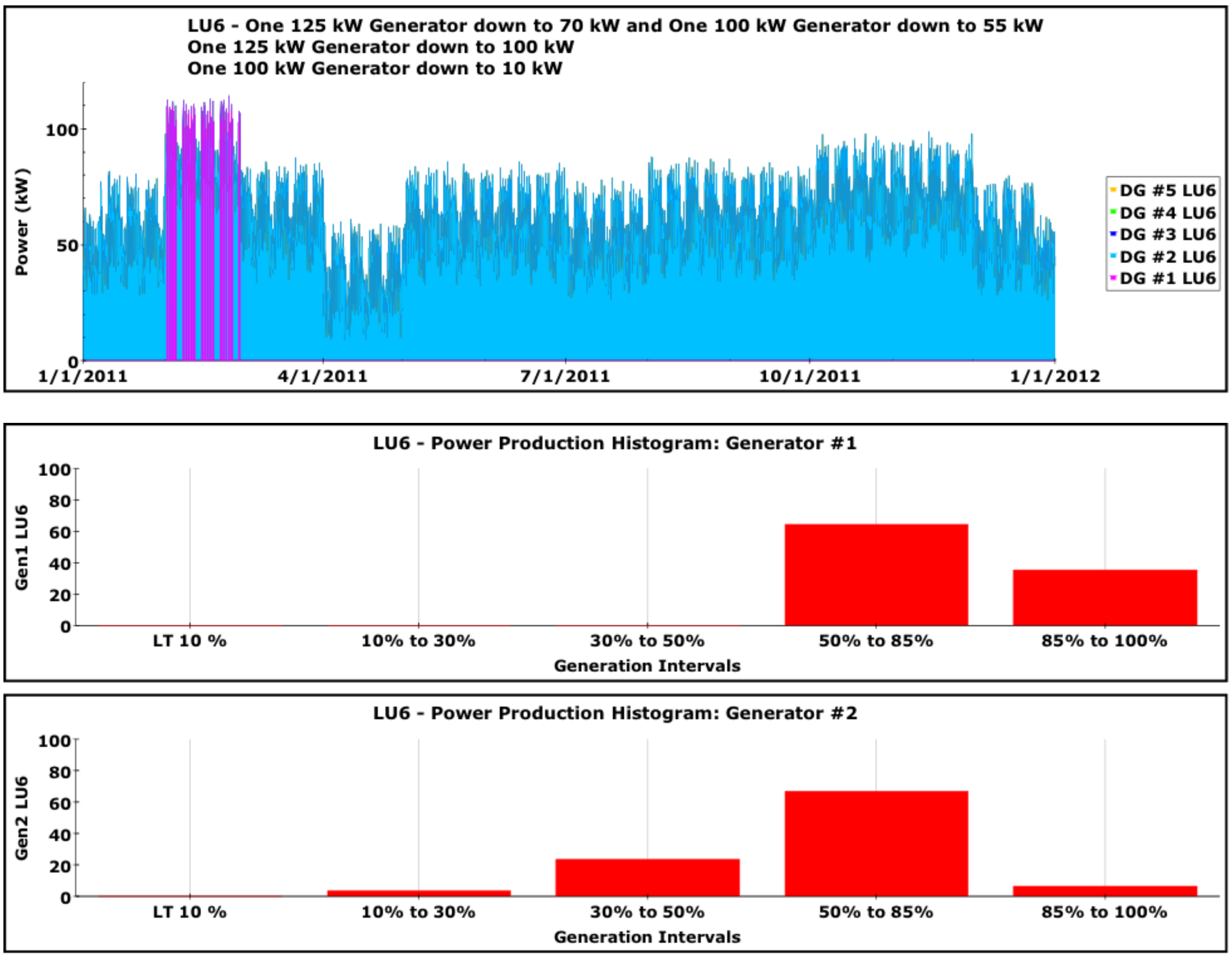


Figure 6.11: Plots showing the generator duty profile (top) and Power Production - Generation Interval Histograms (middle and bottom) for a generator suite consisting of one-125 kW generator (labeled Generator #1) and one -100 kW generator (labeled Generator #2). In this case, the 125 kW generator is prevented from dropping below 50% of maximum capacity whereas the 100 kW generator is allowed drop to 10 to 30% of its rated capacity.

6.5.7 Load is Met by Two 60 kW Generators

For the seventh genset configuration, two 60kW generators are run simultaneously, from 120kw down to 60kW, then one of the generators is run from 60 down to 6 kW. The duty cycle plots and the power production intervals show that both generators would be producing above the 50% interval a significant amount of time so that two 60 kW generators could be an ideal combination if the peak load in never higher than 120 kW.

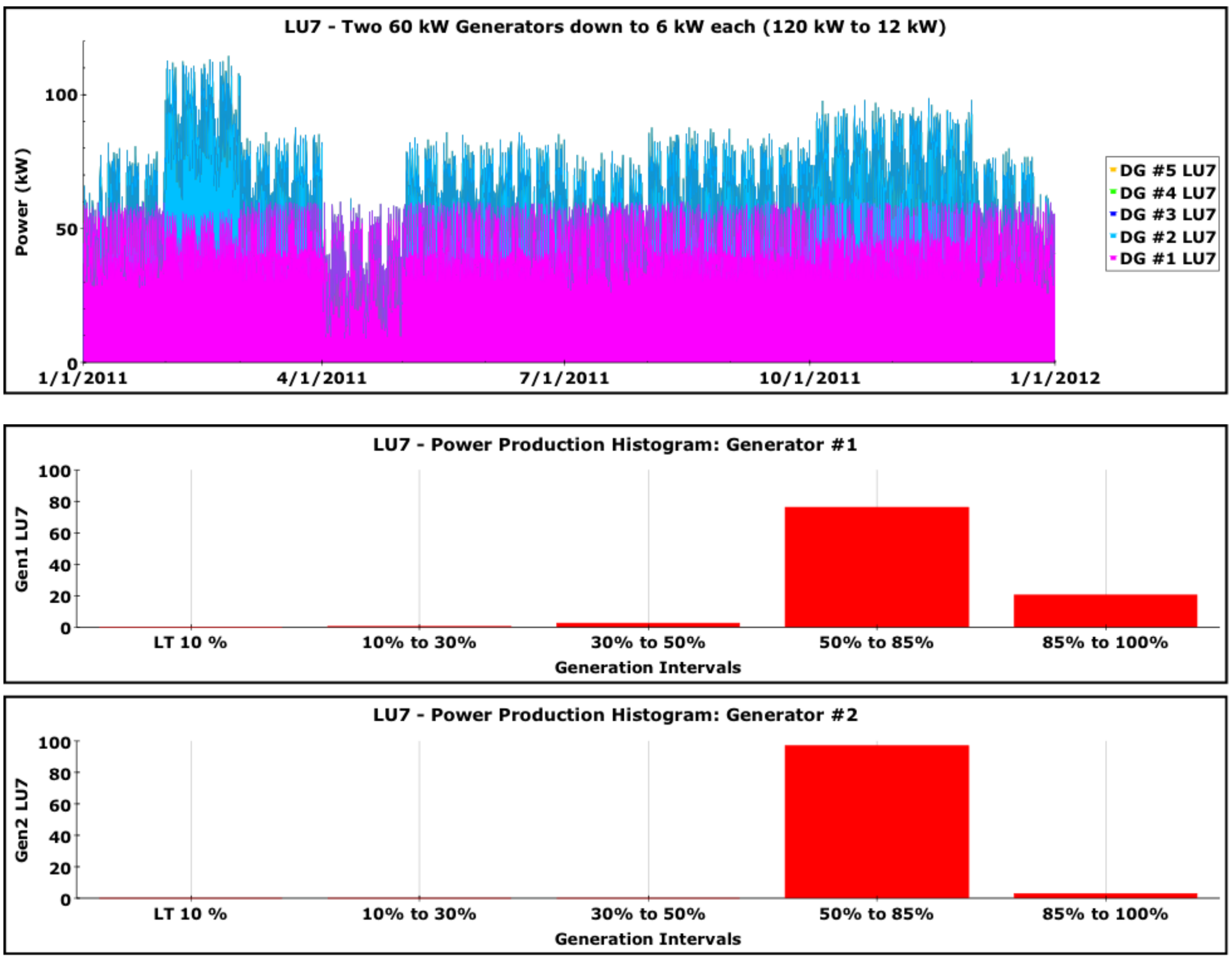


Figure 6.12: Plots showing the generator duty profile (top) and Power Production - Generation Interval Histograms (middle and bottom) for a generator suite consisting of two - 60 kW generators. In this case both generators are allowed to run simultaneously unless the load drops below 60 kW, then one of the generators shuts off and the other continues to run.

6.5.8 Diesel Consumption for Each of the Seven Generator Operation Strategies

Figure **??** is a bar plot and table of the diesel consumption for the seven strategies discussed above. Note that the least efficient scenario is number Six where a 100 kW generator is used in combination with a 125 kW generator. This is a somewhat unexpected result. Not surprisingly the current case and the potential case where the 190 kW generator cover the entire load (scenario 1 and 2 respectively) are markedly less efficient operation scenarios than the more efficient scenarios. The most efficient scenarios are scenario three (where the entire load was serviced by the 125 kW generator), scenario four (where the load was serviced by a combination of the 125kW generator and a 60kW generator), and scenario five (where the load was serviced by a combination of the 125 kW generator and a 80 kW generator) with the scenarios three and five edging out four by about 500 gallons for the year. The three most efficient scenarios have significant fuel savings over the current case; about 3000 gallons. Another important note is that while the diesel savings for scenarios three, four, and five, are similar, the maintenance costs are likely higher for scenario number three due to impacts from wet stacking, resulting from under loading the generator. Table **??** shows the efficiencies used to compute the diesel consumption.

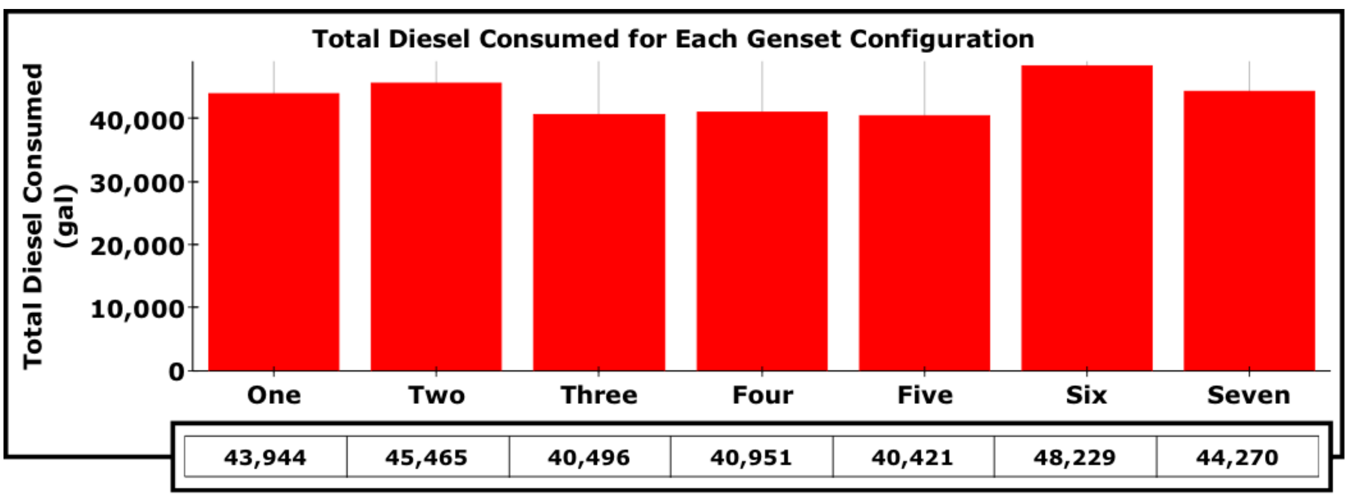


Figure 6.13: Bar graphs and table showing the diesel consumption for each of the seven generator strategies discussed above.

6.6 Photovoltaic Generation Considerations

In this section, simulation results showing the impact of various PV penetrations on generator operations given the fourth generator configuration presented above (see Section **??**). The fourth configuration had a 125 kW generator and a 60 kW generator where these generators either shared the load or ran alone depending on the magnitude of the load. Seven PV penetration levels were simulated using the consequence model. The levels of PV generation were 7, 22, 43, 65, 108, and 130, kW - AC which corresponds to 7%, 20%, 40%, 60%, 80%, and 100% penetration given a peak load of 115 kW used in the simulation. Three of the seven penetration levels are presented below for the purpose of illustrating the operational impacts of introducing PV to a microgrid.

The PV generation data was derived from NREL's PVWatts® Version 1 Calculator (NREL-1) a site specific calculator that calculates PV output based on typical meteorological year (TMY) data from NREL's Solar and Wind energy Resource Assessment Program (NREL-2). PVWatts® has several user selectable inputs including choice of location for the TMY data. Bettles, AK is a community located 140 miles west-southwest of Venetie, AK. Bettles was chosen as a surrogate for Venetie because both villages are located significantly inland and are just south of the Brooks Range, a major east- west mountain range separating Alaska's Interior geographic region from that of the Arctic Region. Hence the two villages share similar climates and likely would have similar PV production curves. Other inputs include DC rating of the PV System, DC to AC Derate Factor (.77), Array Type (Fixed), Array Tilt (66.9), and Array Azimuth. The data used for the simulations here are based on a fixed array configuration with the default selected for the DC to AC derate factor (.77) and Array Tilt (66.9 degrees).

6.6.1 Photovoltaic Generation and Generator Performance

The first series of plots are stacked plots showing the generator operation during the month of June for four cases, 0%, 20%, 60% and 80% penetration (Figure **??** through Figure **??**). The load data used in these simulations is the same load data used in the previous section, hence the case without PV has been run, but for the entire year.

Comparisons between the PV penetration plots illustrates the impact of increasing PV penetration that range from beneficial at the lower penetration levels where switching of generators on the weekends is minimized with a slight trade-off of having the 60 kW generator run below the 50% of capacity interval, to severe at the higher levels where excess generation occurs and the 60 kW generator is forced to run significantly below the 50% of capacity level (see the figure captions for details). Energy storage can mitigate the impacts of high penetration of PV on generation operations. For instance, the excess energy can be stored then released at later times to reduce generator switching and can also be used on shorter time intervals to reduce the variability in the load due to PV generation variability. The generators can also charge and, when needed, discharge the energy storage devices to keep the generation levels above 30% or 50% to minimize switching.

The excess power, generated in the simulated PV Penetration cases above, was accumulated over time to obtain bar plots comparing the maximum excess daily energy from each case (Figure **??**). The plot shows an increased energy storage requirement with increased PV penetration; the 20 kW requires very little storage whereas the 80 kW case requires about 200 kWh of storage capacity. This stored energy is energy that would otherwise be dumped to maintain system stability and thus, the cost of this gain in energy availability includes capitol costs for the system and maintenance costs, and does not include efficiency losses that would occur from diesel generation. The savings in diesel fuel the stored energy would replace offsets these costs. These diesel fuel savings are investigated in the next section.

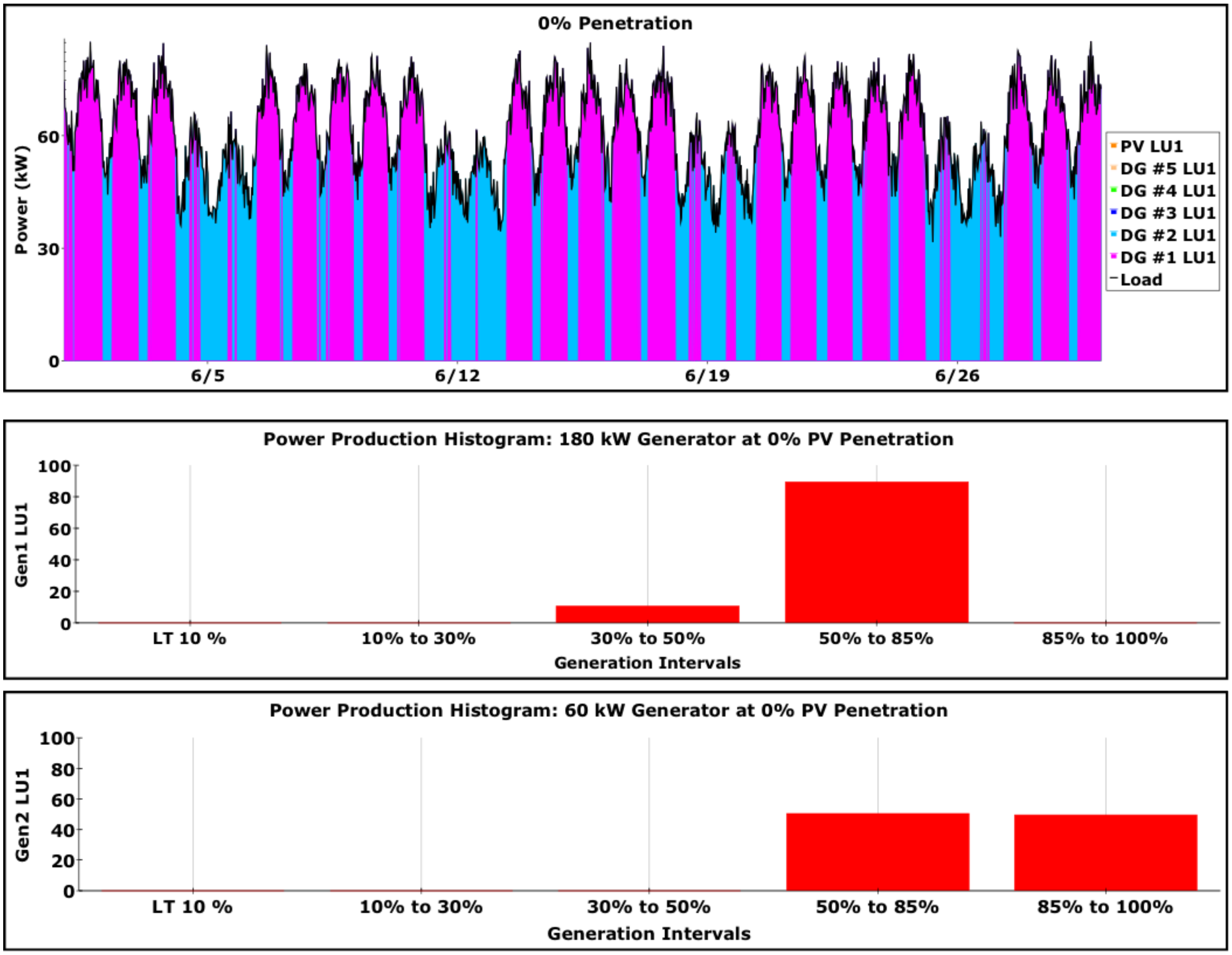


Figure 6.14: Plots showing the generator duty profile (top) and Power Production - Generation Interval Histograms (125 kW middle and 60 kW bottom) for the 0% PV Penetration Case. In contrast to the year-long simulation presented in the previous section this plot shows reveals more detail regarding the switching of the generators. The 60 kW generator starts during off-hours during the weekday and runs the majority of the weekend except at weekend peak load where the 125kW generator is used.

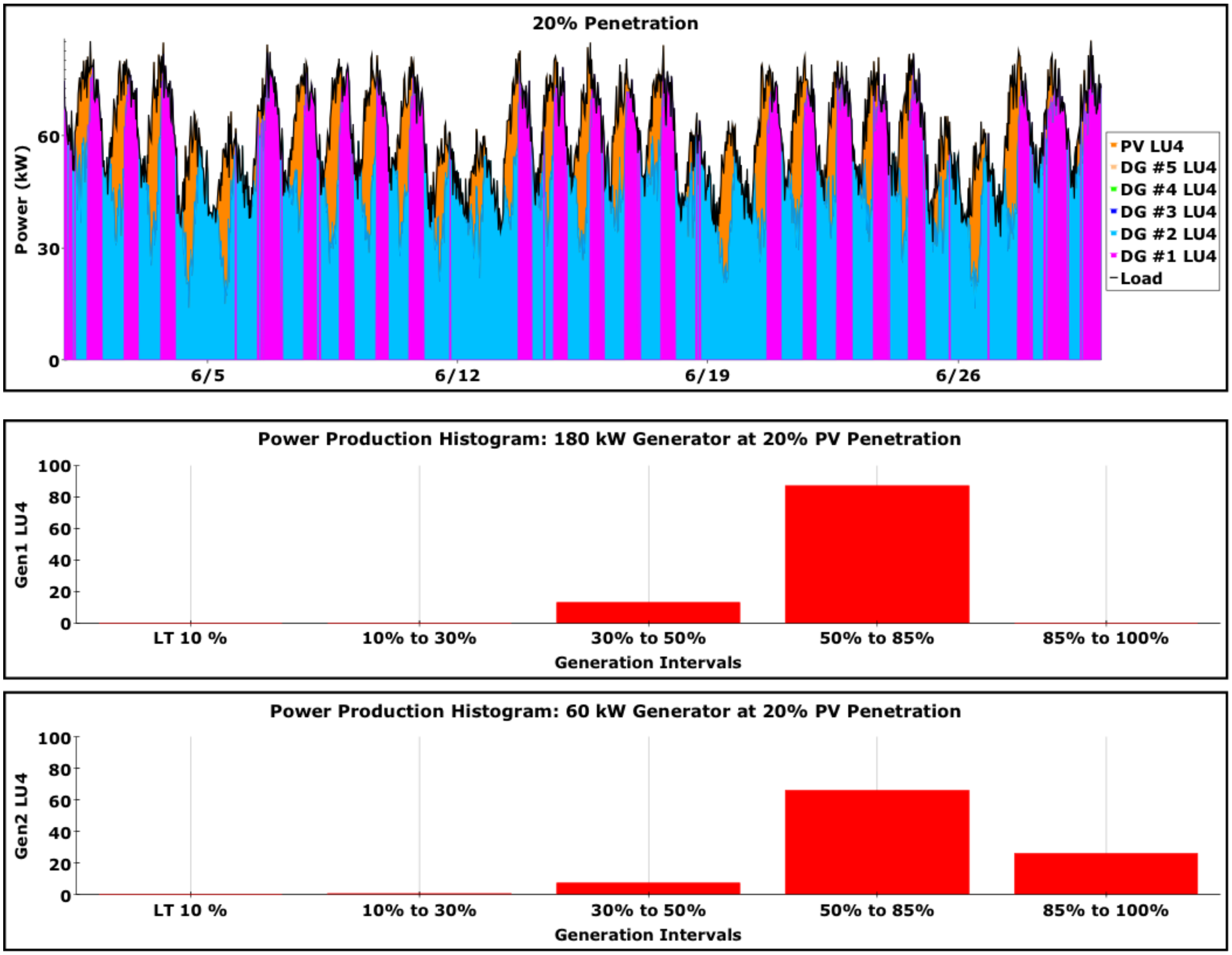


Figure 6.15: Plots showing the generator duty profile (top) and Power Production - Generation Interval Histograms (125 kW middle and 60 kW bottom) for the 20% PV Penetration Case. Contrasting this plot with the previous shows that the PV generation significantly reduces the switching of the 60 and 125 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.

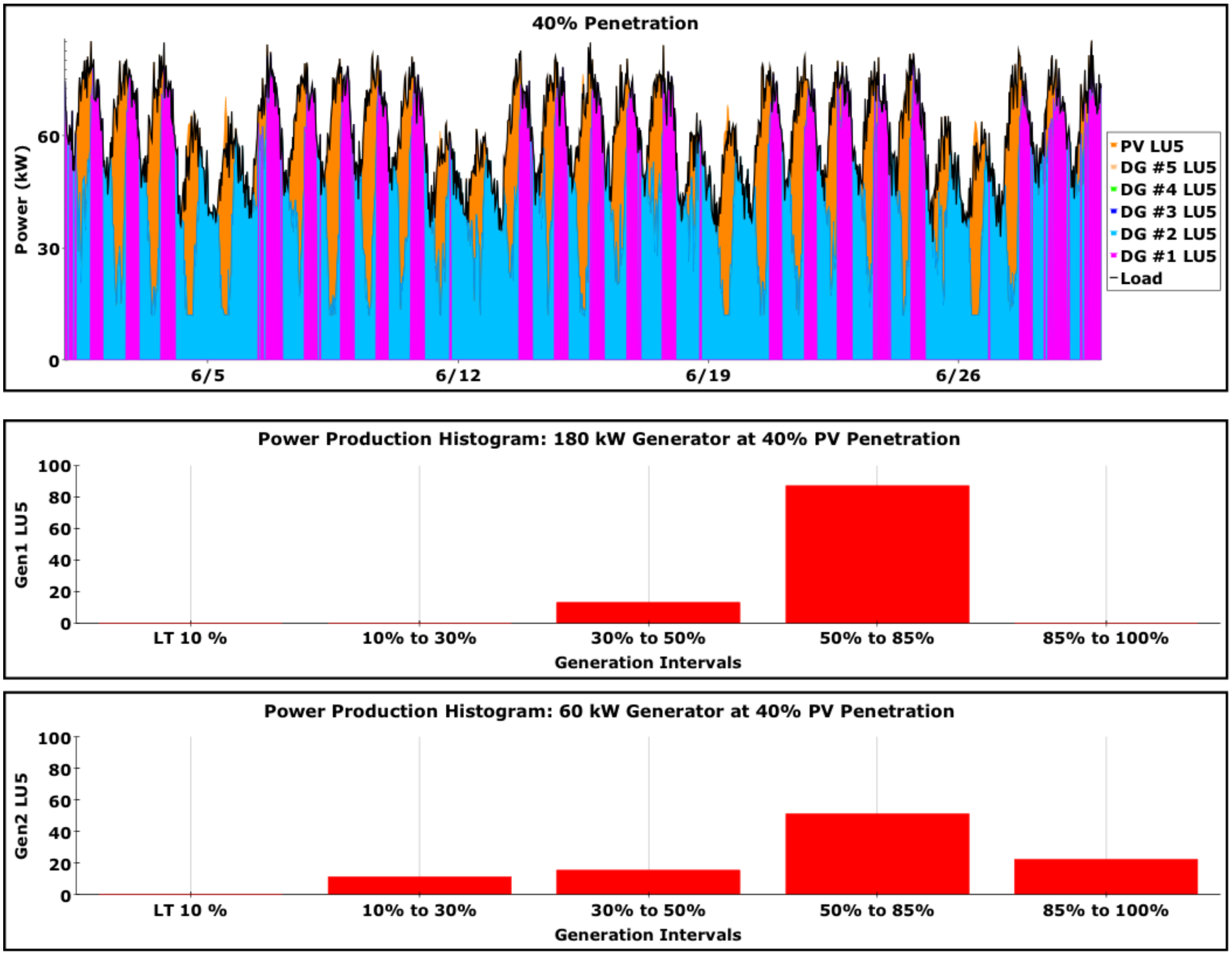


Figure 6.16: Plots showing the generator duty profile (top) and Power Production - Generation Interval Histograms (125 kW middle and 60 kW bottom) for the 40% PV Penetration Case. With further PV penetration, the 60 kW generator slightly increases the percentage of time generating between 30% and 50% and is required to generate power in the 10% to 30% of capacity range. Note also that excess generation occurs on 6/4, 6/5, 6/20, and 6/26 where the yellow spike appears above the black load line.

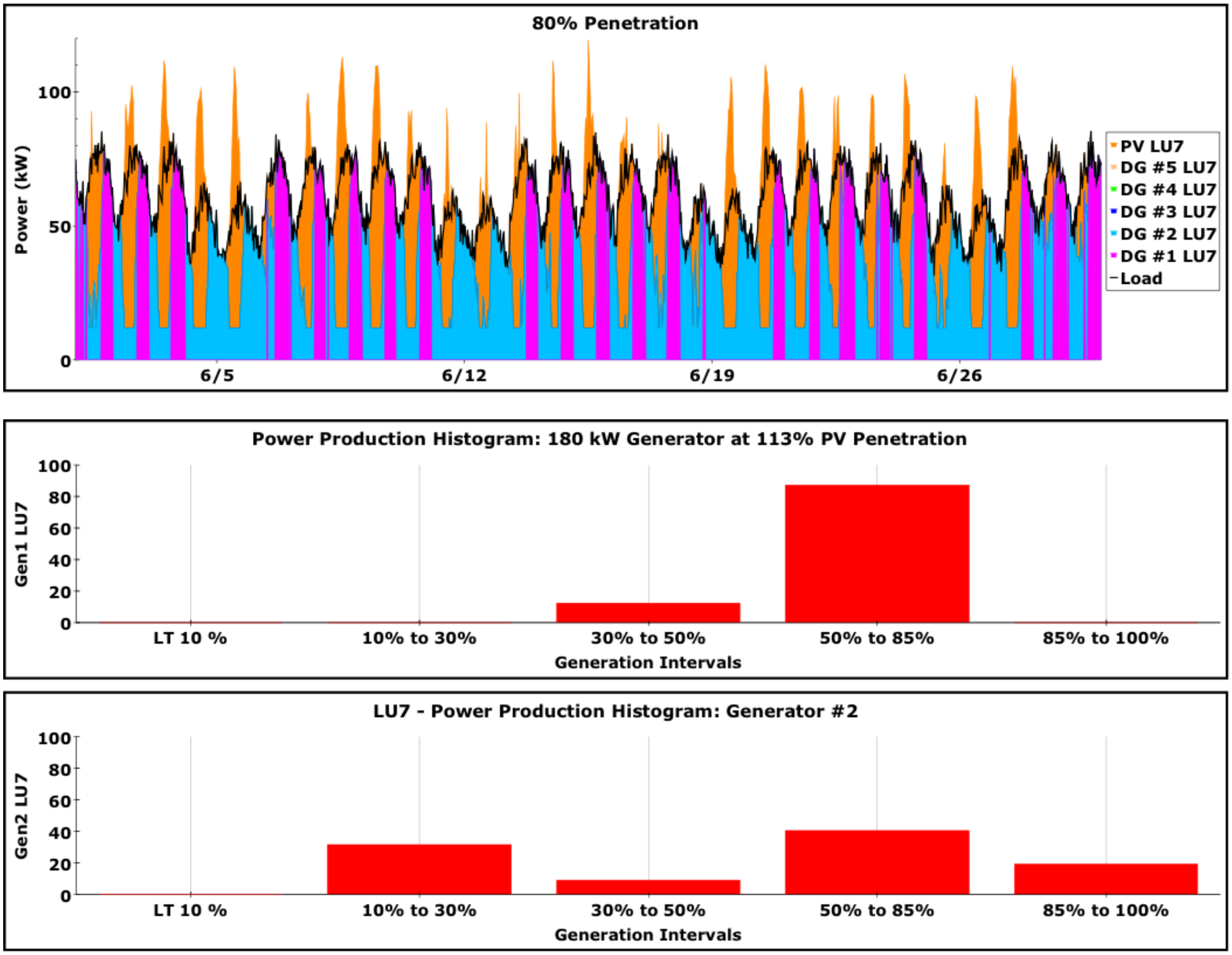


Figure 6.17: Plots showing the generator duty profile (top) and Power Production - Generation Interval Histograms (125 kW middle and 60 kW bottom) for the 80% PV Penetration Case. PV levels of 80% further increases the amount of time the 60 kW generator spends in the low power production mode and also increases incidents of over generation.

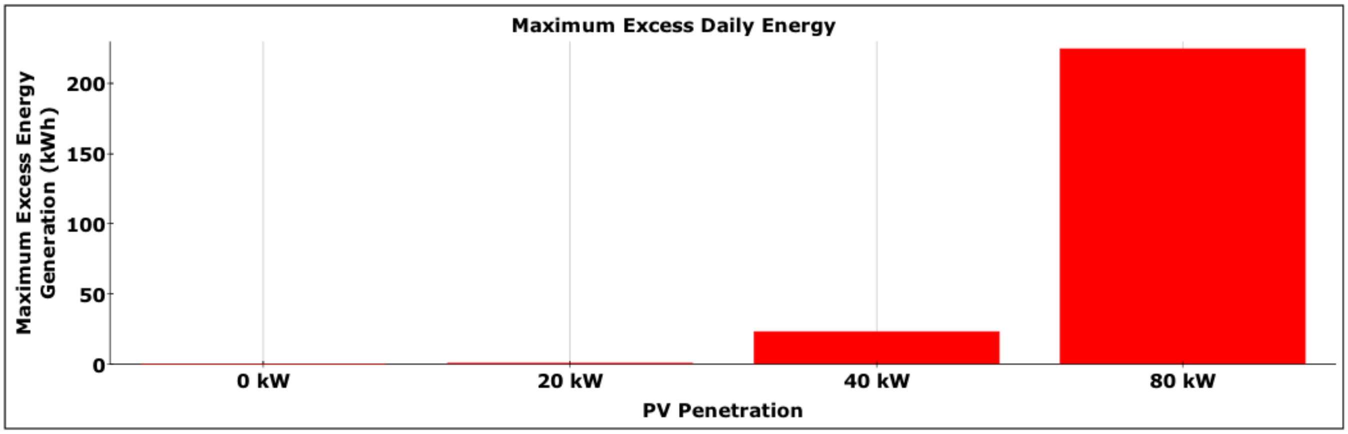


Figure 6.18: Bar plot showing the excess energy generated for the nominally 0%, 20%, 40%, and 80% penetration cases simulated.

6.6.2 Diesel Fuel Savings with PV and Storage

The potential for offsetting diesel fuel consumption with PV is the reason for incorporating this technology into a microgrid and holds promise for cost savings at Venetie. Diesel fuel savings were calculated during a one-year simulation (as seen in section **??**) for a variety of diesel generator suites. A comparison between the diesel consumption from case one (Section **??**) where current generator setup was used (180 kW generator), and from case 4 (Section **??**) with new generators more matched to the observed loads (125 kW and a 60 kW) shows a savings of 2993 gallons per year (43944gal - 40951gal = 2993 gal, see Figure **??**). The addition of PV results in additional fuel savings as shown in Figure **??**. Fuel and correlating cost savings resulting from PV generation are presented in Table **??** assuming the fuel cost savings calculated from the Consequence Model.

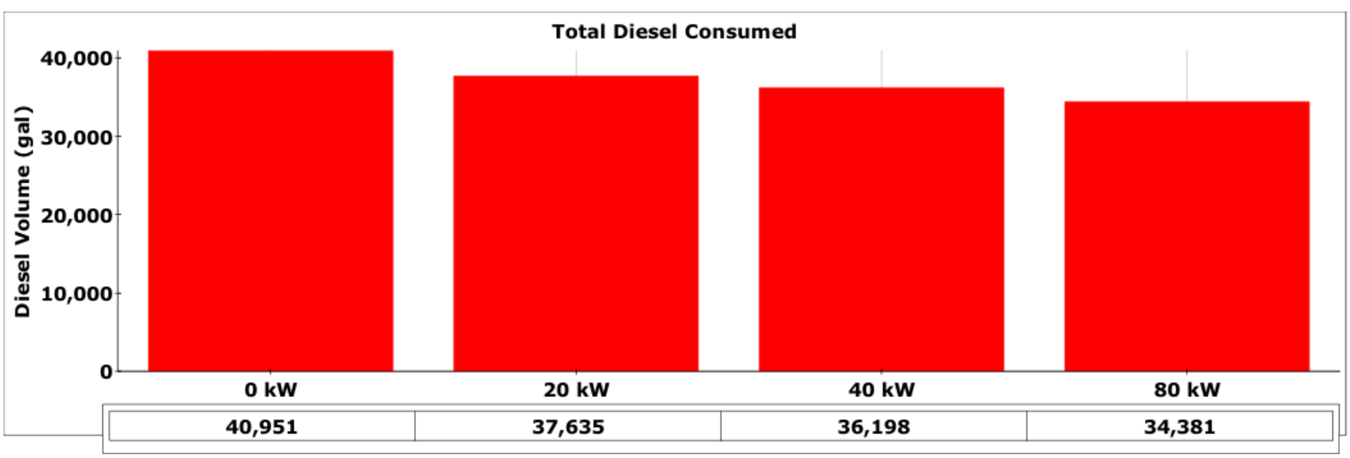


Figure 6.19: Plot showing results from a one year simulation for the four PV penetration levels discussed above.

6.7 Consequence Model Summary

The consequence model we used to obtain the results presented in this report was built on a generator dispatch model developed for other microgrid projects. The consequence model has many additional capabilities that were not illustrated here. Of significance is a more complete battery storage module, which uses battery performance data to account for losses associated with charge-discharge cycles. This component of the model could be used to identify optimal battery sizes for different genset configurations and operation strategies.

As shown in the text above, energy storage allows for systems with high PV penetrations through storage of excess generation during times of maximum solar generation. This stored energy can be used to smooth the load and therefore reducing generator ramping and associated wear and tear, to minimize switching of generators when the load is swinging back and forth across a switching threshold, and for peak load shifting to avoid brining a second generator on line or to avoid generator switching. With accurate and high temporal resolution load and PV data, the consequence model could be used to investigate these possibilities and provide quantitative measures needed for evaluating a value proposition for a coupled PV and Energy system. Additionally, the consequence model could be used to identify optimal genset configurations and operation strategic through quantified performance measures.

Other positive aspects of the consequence model is that it provides a way to illustrate issues associated with small community power systems and design options in a manner that is easy for non-electrical engineers to grasp. Thus the consequence model benefits both the project teams charged with investigating and implementing microgrid designs and administrative personnel charged with overseeing project funding and evaluating the paybacks and tradeoffs of the various available options. Thus the consequence modeling can be an integral part of the microgrid design project.

Table 6.1: Tabulated fuel savings for different PV penetrations, assuming the fuel savings calculated from the Consequence Model. The 0 kW configuration assumes savings due to improved efficiency of generator utilization.

PV Penetration/ Configuration (kW)	Savings from Implementation of PV (gal)	% Savings of Configuration Four with PV	Savings/year due to PV assuming $5.53/gal ($/year)	Total Savings over Current Genset Configuration (gal)	% Savings of Configuration Four with PV over Current Genset (%)	Total Savings/year assuming $5.53/gal ($)
0	NA	NA	$0	2,993	NA	$16,551
20	40,951 - 37,635 = 3316	8%	$18,531	2,993 + 3,316 = 6,309	14%	$34,889
40	40,951 - 36,198 = 4,753	12%	$26,284	2,993 + 4,753 = 7,746	18%	$42,835
80	40,951 - 34,381 = 6,570	16%	$36,332	2,993 + 6,570 = 9,563	22%	$52,883

Chapter 7

Cost Estimates

7.1 Estimating Costs for Option 1

The costs for the new generation facility involve costs associated with the additional equipment and services necessary to implement the new generator facility as shown in Figure **??**:

The following are the components of upgrading the electrical production system

- New generator facility building
- New generators and associated switchgear and controls
- Upgrades/replacement of bulk diesel storage facility for generators
- Relocation of 3-phase step up transformers and structure to new generation facility
- Upgrade and extend 3-phase distribution line from new generator facility to village center distribution
- Need to account for costs for subsequent engineering analysis, and detailed design and construction of facilities
- Need to account for any additional costs associated with labor at remote sites and airlifting equipment into remote sites

Using our cost estimate approach, Table **??** show the cost estimates associated with option 1. Table **??** shows an estimated cost of approximately $2284K for option 1, including a 25% contingency factor. In 2006, the cost of building the new generation facility at Arctic Village, which would be comparable in size to the size needed in Venetie, was approximately $2000K (Denali Commission Expense Category Summary, project #350151, 2006). Taking into account the increase in cost due to inflation, this estimate is in line with what would be expected.

7.2 Estimating PV Benefits and Costs for Option 2

Another way to analyze PV costs and benefits is to compare the expected return on investment (ROI) for a given PV installed cost, and a given capacity factor. If installed costs are constant for a given amount of penetration, which should be generally true for small systems, the PV installed costs as a function of ROI should be the same whether 10% -50% of PV penetration is used, since costs and benefits will rise proportionally to the amount of PV installed.

7.2.1 Simple Payback and Return on Investment analysis for Option 2

Figure **??** plots the return on investment, assuming simple payback. A system with a $5/W PV cost and a 30% capacity factor will have a payback in about four years. Our assumption for Venetie for a PV system with a cost of $10/W and a capacity factor of 15% would have an expected payback in approximately 15 years.

Another approach for looking at the costing of the upgrades is through internal rate of return and benefit/cost ratios. In Table **??**, the cost of a system, assumed to be 20 kW, was calculated assuming three different unit costs, $10.00/W, $12.00/W, and $14.00/W. The cost of large-scale PV systems located in rural Alaska was difficult to estimate due to the lack of previous projects. According to the NREL OpenPV website `http:\www.openpv.nrel.gov`, the average cost of installed PV is in the neighborhood of $7/watt. Conversations with personnel at Alaska Energy Authority and at the University of Alaska-Fairbanks, indicated that the installed cost would be greater than this average due to the remote location of Venetie and the need to air freight all of the materials and most of the labor. A range of $10 - $14/watt is fall within this range (personal communication, 2012). Due to the uncertainty, a range of values was calculated. The net annual savings in Table **??** was calculated using the assumed fuel replaced assuming a capacity factor of a PV system to be 15%, see Table **??**. For the assumed cost of $10/W, this gives a simple payback of 17 years and a benefit to cost (B/C) ratio of 0.87. A project is usually considered viable when the B/C is greater than 1.0, which is the present value of the net annual savings divided by the cost of the project.

If the net annual savings are assumed to be the values determined by the consequence model (see Table **??**), the viability of the project increases. The net savings calculated by the consequence model are greater because it more closely tracks the daily variation instead of assuming a composite profile. These values can be seen in Table **??**. Because of the higher net annual savings as seen in Table **??**, the simple payback is reduced and the B/C ratio is greater than 1.0 for both the $10/W and $12/W installation price. This indicates that a 20 kW PV system (20% penetration compared to the summer loads) may be economically viable. This is due in part because there is no additional cost requirement from energy storage.

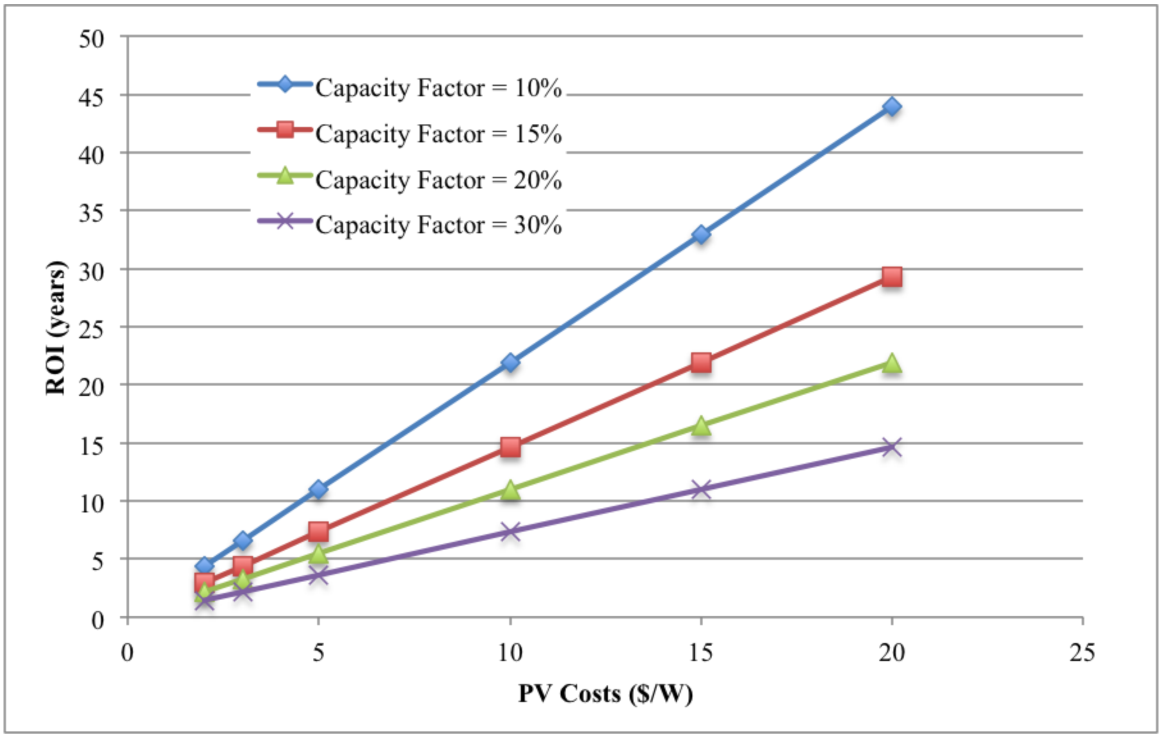


Figure 7.1: Plot of PV cost versus ROI for different PV capacity Factors.

7.2.2 Simple Payback and Return on Investment analysis for Option 3

For option 3, an energy storage system must be included in the cost. For these estimates, it was decided to look at the cost of a battery. The budgetary cost of a deep-discharge lead-acid type battery will run approximately $874/kWh. From the CM, two PV systems with batteries are illustrated in Section **??**, a 40 kW PV system and an 80 kW system. As can be seen in Figure **??**, the 40 kW PV system needs a 40 kWh battery and the 80 kW system needs a 250 kWh battery. As can be seen in Table **??**, despite the increased savings from the larger PV system, when compared to the 20 kW PV, the increased upfront investment cost, including the battery, offsets the savings and makes it a less economically viable proposition. The simple payback is, at best 18.7 years, with a B/C ratio of 0.80.

The larger the PV system, the less economically viable the option is. As can be seen in Table **??**, the simple payback increases to nearly 32 years and has a B/C ratio of 0.47. An 80 kW system is about the maximum size that could be installed in the village due to the fact that the peak load is generally less than 80 kW during the peak PV production months.

Table 7.1: Cost estimates for Option 1 - New Generator Facility

Equipment	Equipment/ Installation Costs ($K)	20% Construction Overhead ($K)	12.5% Design Overhead ($K)	12.5% Engineering Overhead ($K)	Total Costs ($K)	Total Costs with 25% Contingency ($K)
Generator Facility Building	400	80	50	50	580	725
Generators and Controls	300	60	38	38	435	544
Bulk Diesel Storage	300	60	38	38	435	544
Line Upgrades	50	10	6	6	73	91
Total w/ Generation	1050	210	131	131	1523	1903
Total w/ 20% Freight						2284

Table 7.2: Cost analysis assuming savings computed using savings computed based on Capacity Factors (see Table ??).

System Size (kW)	20	20	20
Cost/W ($/W)	$10.00	$12.00	$14.00
Contingency	0%	0%	0%
Investment cost ($)	$200,000	$240,000	$280,000
Annual Savings ($)	$13,710	$13,710	$13,710
Annual Maintenance ($)	$2,000	$2,000	$2,000
Net Annual Savings ($)	$11,710	$11,710	$11,710
Simple Payback (yrs)	17.08	20.50	23.91
Discount Rate (%)	3%	3%	3%
Time (yrs)	20	20	20
Net Present Value of Annual Savings ($)	$174,215	$174,215	$174,215
Internal Rate of Return	1.09%	-0.75%	-2.20%
Benefit to Cost Ratio	0.87	0.73	0.62

Table 7.3: Cost analysis assuming savings computed by Consequence Model (see Table ??).

System Size (kW)	20	20	20
Cost/W ($/W)	$10.00	$12.00	$14.00
Contingency	0%	0%	0%
Investment cost ($)	$200,000	$240,000	$280,000
Annual Savings ($)	$18,531	$18,531	$18,531
Annual Maintenance ($)	$2,000	$2,000	$2,000
Net Annual Savings ($)	$16,531	$16,531	$16,531
Simple Payback (yrs)	12.10	14.52	16.94
Discount Rate (%)	3%	3%	3%
Time (yrs)	20	20	20
Net Present Value of Annual Savings ($)	$245,940	$245,940	$245,940
Internal Rate of Return	4.99%	2.85%	1.18%
Benefit to Cost Ratio	1.23	1.02	0.88

Table 7.4: Cost analysis assuming savings computed by Consequence Model for 40 kW PV system with a 40 kWh battery for energy storage.

System Size (kW)	40	40	40
Cost/W ($/W)	$10.00	$12.00	$14.00
PV Cost	$400,000	$480,000	$560,000
Battery Size (kWh)	40	40	40
Battery cost ($/kWh)	$874	$874	$874
Battery Cost ($)	$34,960	$34,960	$34,960
Contingency	0%	0%	0%
Investment cost ($)	$434,960	$514,960	$594,960
Annual Savings ($)	$26,284	$26,284	$26,284
Annual Maintenance ($)	$3,000	$3,000	$3,000
Net Annual Savings ($)	$23,284	$23,284	$23,284
Simple Payback (yrs)	18.68	22.12	25.55
Discount Rate (%)	3%	3%	3%
Time (yrs)	20	20	20
Net Present Value of Annual Savings ($)	$346,407	$346,407	$346,407
Internal Rate of Return	0.17%	-1.47%	-2.80%
Benefit to Cost Ratio	0.80	0.67	0.58

Table 7.5: Cost analysis assuming savings computed by Consequence Model for 80 kW PV system with a 250 kWh battery for energy storage.

System Size (kW)	80	80	80
Cost/W ($/W)	$10.00	$12.00	$14.00
PV Cost	$800,000	$960,000	$1,120,000
Battery Size (kWh)	250	250	250
Battery cost ($/kWh)	$874	$874	$874
Battery Cost ($)	$218,500	$218,500	$218,500
Contingency	0%	0%	0%
Investment cost ($)	$1,018,500	$1,178,500	$1,338,500
Annual Savings ($)	$36,332	$36,332	$36,332
Annual Maintenance ($)	$4,000	$4,000	$4,000
Net Annual Savings ($)	$32,332	$32,332	$32,332
Simple Payback (yrs)	31.50	36.45	41.40
Discount Rate (%)	3%	3%	3%
Time (yrs)	20	20	20
Net Present Value of Annual Savings ($)	$481,018	$481,018	$481,018
Internal Rate of Return	-4.61%	-5.81%	-6.81%
Benefit to Cost Ratio	0.47	0.41	0.36

7.3 Levelized Cost of Energy Assessment

Another way to assess the cost of generating energy is through a leveled cost of energy assessment (LCOE). The LCOE is a method that computes the unit price at which energy must be sold for the project to break even. It can also be used as a means to compare the economic benefits of one project over another, based on unit cost (the project with the lowest unit cost being the more economically favorable). The LCOE is computed based upon the following (Equation **??**):

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \tag{7.1}$$

where

- $LCOE$ = Average lifetime leveled electricity generation cost
- I_t = Investment in year t
- M_t = Operations and maintenance cost in year t
- F_t = Fuel cost in year t
- E_t = Electricity generated in year t
- r = discount rate
- n = life of the system (number of years) [**?**]

The LCOE calculated for PV systems can be very sensitive to factors such as the inflation rate, the capacity factor of the system, etc. Table **??** lists the various parameters used in calculating the LCOE. The base assumed life of the systems was 25 years. All of the costs of operating the systems, such as maintenance and fuel, were adjusted to account for the increased costs due to inflation. Additionally, it was assumed that the 30% Federal tax incentives would discount the installation cost of the PV [**?**]. Based on several runs of the NREL LCOE program SAM (`https://sam.nrel.gov/`), a capacity factor of 10% seems to be the most reasonable value when assuming that Bettles, AK is a comparable analog to Venetie with regards to PV production. Tables **??**, **??**, and **??** show the LCOE for the three basic PV options (as discussed in Section **??**):

- a 20 kW PV arrray
- a 40 kW PV array with a 40 kWh battery (note: in order to fully utilize the larger PV arrays, an energy storage system is required)
- an 80 kW PV array with a 250 kWh battery

Two of the parameters that have a significant effect on the LCOE and that have a large degree of uncertainty are the cost of installing the PV system and the capacity factor of the PV system. In order to get an idea of how the LCOE changes with the changes in these parameters, three tables have been compiled. Due to the uncertainty of the installed costs of PV in rural Alaska, a range of costs per watt was chosen (see Section **??**) to investigate how the economic viability of the project changes with cost. The LCOE calculated in Table **??** assumes a cost of installing the PV to be \$10/W and a capacity factor of 10%. As can be seen in this table, if inflation rises at the a rate of 1% per annum (the first column), the cost of producing power using the 20 kW PV, is comparable to the status quo of doing nothing to the existing diesel gensets and producing electricity as they are now configured. If inflation increases at a rate of 2% per annum (the second column), the LCOE of the 20 kW PV is more favorable than the status quo. Regardless of the inflation rate, the LCOEs of the larger PV arrays are quite a bit higher than the status quo. This is a function of the need to include energy storage to take advantage of the higher production capacity.

If the capacity factor of the PV system is increased to 15%, the favorability of the PV arrays is increased by a sizable amount, as can be seen in Table **??**. In this case, both the 20 kW and the 40 kW PV arrays are more favorable than the status quo.

If the cost of installing the PV system is \$13/W, while keeping the capacity factor at 10%, the economic viability of using a PV system, when compared to the status quo, is greatly diminished. This can be seen in Table **??**, where all of the PV systems have a much higher LCOE than does the status quo.

The last comparison made was to see how including the cost of the PV would effect the LCOE of a newly installed diesel genset. As mentioned previously in this assessment, the existing diesel gensets and powerhouse are substandard and should be replaced. The cost of replacement was assumed to be \$2.5 million, which is comparable to the cost of the new powerhouse in Arctic Village. It was also assumed that the installation cost of the PV system would be \$10/W and the capacity factor would be 10%. Using these parameters, it can be seen in Table **??** that the cost of producing a unit of electricity with a new powerhouse with no PV is comparable to the unit cost of producing electricity from a new powerhouse that includes a 20 kW PV array. The added cost of needing energy storage makes the larger PV arrays less economically viable.

Table 7.6: Parameters used in calculating the pricing for the PV systems and the LCOE.

Nominal Discount Rate	3.0%
PV Operation and Maintenance Rate	100 $/kW-yr
Fuel Cost	5.53 $/gal
Electric Power Generation Rate for New Diesel Genset	11.4 kWh/gal
Electric Power Generation Rate for Old Diesel Genset	10.6 kWh/gal
Diesel Genset Operation and Maintenance Rate	0.04 $/kWh
Battery Cost	874 $/kWh
Battery Operation and Maintenance Rate	50 $/kWh-yr

Table 7.7: LCOEs comparing PV systems to the status quo (leaving the existing diesel generators as is) assuming a unit cost of installing the PV system to be $10/W and the capacity factor to be 10%. The life of the system is also assumed to be 25 years. See Table **??** for the other parameters used in the calculations. The first column assumes that O&M and fuel costs increase at a rate of 1% per annum due to inflation (i). The second column assumes that O&M and fuel costs increase at a rate of 2% per annum due to inflation (i).

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

Table 7.8: LCOEs comparing PV systems to the status quo (leaving the existing diesel generators as is) assuming a unit cost of installing the PV system to be $10/W and the capacity factor to be 15%. The life of the system is also assumed to be 25 years. See Table **??** for the other parameters used in the calculations. The first column assumes that O&M and fuel costs increase at a rate of 1% per annum due to inflation (i). The second column assumes that O&M and fuel costs increase at a rate of 2% per annum due to inflation (i).

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

Table 7.9: LCOEs comparing PV systems to the status quo (leaving the existing diesel generators as is) assuming a unit cost of installing the PV system to be $13/W and the capacity factor to be 10%. The life of the system is also assumed to be 25 years. See Table **??** for the other parameters used in the calculations. The first column assumes that O&M and fuel costs increase at a rate of 1% per annum due to inflation (i). The second column assumes that O&M and fuel costs increase at a rate of 2% per annum due to inflation (i).

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

Table 7.10: LCOEs comparing systems with new Diesel Gensets and varying PV systems assuming a unit cost of installing the PV system to be \$10/W and the capacity factor to be 10%. The cost of installing the replacement diesel gensets and powerhouse was assumed to be \$2.5M. The life of the system is also assumed to be 25 years. See Table **??** for the other parameters used in the calculations. The first column assumes that O&M and fuel costs increase at a rate of 1% per annum due to inflation (i). The second column assumes that O&M and fuel costs increase at a rate of 2% per annum due to inflation (i).

LCOE (\$/kWh)		
	i=1	i=2
New Diesel Genset	0.828	0.898
New Genset + 20 kW PV	0.829	0.898
New Genset + 40 kW PV + 40 kWh Battery	0.843	0.911
New Genset + 80 kW PV + 250 kWh Battery	0.876	0.944

7.4 Recommendations

Three design options were given. The first option was to relocate the powerhouse to near the airport and the existing bulk fuel storage area. This would require a new powerhouse and attendant electrical power generation equipment as well as an upgrade of the distribution line from a single-phase, 7.2 kV medium voltage distribution line to a three-phase 12.47 kV medium voltage distribution line from the village to the airport. To match the electrical power demand of the village more closely, the best combination was found to be one 125 kW diesel generator and two 60 kW diesel generators. This combination gives redundancy as well as allows for the seasonal peak demand to be efficiently met. The annual reduction in fuel used, solely through more efficient operation, is nearly 3000 gallons. The approximate cost for replacement will be between $2.25 and $2.5 million dollars.

The second and third options start from the basis that the existing electric power generation will be replaced. Design option two calls for addition of PV but without energy storage, which means a system of 20 kW in size. The installed unit cost of the system was assumed to be $10/W, which gives a cost of the system at $200,000. At that cost point, assuming the consequence model calculated net annual savings of $16,531, a simple payback was twelve years and a benefit to cost ratio of 1.23. However, $10/W cost is very uncertain and could easily be higher.

Design option three assumed a PV system with energy storage incorporated. A system with 40 kW and a 40 kWh battery was determined to have an investment cost of $435,000, based on $10/W for the PV and $874/kWh for the battery. Under this scenario with a net annual savings of $23,284, the simple payback was nearly 19 years with a B/C ratio of 0.8. The larger system of 80 kW PV and a 250 kWh battery had a cost of greater than $1 million with a net annual savings of $32,332, resulting in a simple payback of 31.5 years and a B/C ratio of 0.47.

Additionally, levelized cost of energy analysis was done on the three options and compared to the existing diesel genset system and to a new diesel genset and powerhouse. This analysis showed that based on the total cost of operations, the cost of adding a 20 kW PV to a new system is neutral. Installing such a system could have valuable long term benefits in the form of increased understanding of how well a larger-scale PV system, tightly coupled with diesel generators, works in a rural Alaskan village.

Based on these numbers, the most cost effective system would be the 20 kW PV system without any energy storage. Caution needs to be taken to ensure that any system installed would have adequate support from the community and that the community is willing and capable of assuming the responsibility for the system, both financially and technically. Additionally, for any installed system to have long-term benefit to the community, it should match the community's ability to operate and maintain the system.

Chapter 8

Ongoing Activities

Data collected during a site visit the first week of July 2012 was used as a basis for the models and initial estimates for the preliminary design. Ideally, data would be collected for at least one year. The more data available, the better the load forecasting and the more optimized the overall design will be. In February 2013, a PQiaB-200V 480V L1-L2-00 electric power meter, manufactured by Power Standards Laboratory (PSL) was installed at the Venetie power facility and a system set up to record the load data over the course of the following year. The meter is recording both the power quality (Voltage dips, swells, and interruptions, over-, under-frequency events, voltage unbalance, etc.) and the energy usage (Watts, VA, VAR's, power factor, Watt-hours, peaks, etc.). Data being collected in Venetie is one minute resolution data of voltage and current at the power plant on the main bus and sub-cycle resolution for abnormal conditions. The trending of power consumption is being developed along with transient analysis to better assess the optimal generation needed to meet load demand. In 2014, the load data from the preceding year, obtained from the meter, will be compiled into a dataset, by SNL. After the load data has been compiled and a thorough, year long load profile has been compiled, a more precise model can be created and more accurate simulations can be run.

This data will be useful for an engineering design/detailed design, which would include the details of equipment specifications and requirements and detailed engineering drawings from which the upgraded grid is constructed.

Chapter 9

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