Noorvik, Alaska
Solar PV Analysis

Noorvik aerial photo: Doug Vaught

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Background

Northwest Arctic Borough (NAB) has contracted V3 Energy, LLC to evaluate the power production potential and power system control implications of installing approximately 45 kilowatts (kW) of new solar photovoltaic (PV) capacity in the village of Noorvik, Alaska. This new capacity would be in addition to the 10 kW of existing PV capacity presently operational in the community. The purpose of this analysis is to demonstrate that 45 kW of new PV capacity will not require special system control features.

Summary

Forty-five kilowatts of new solar PV capacity would yield a very low (less than 3 percent) average renewable energy penetration and only approximately 35 percent maximum instantaneous power penetration. This project can be constructed without need of power system control equipment or measures such as secondary load control and/or dispatch control.

Noorvik Power System

Alaska Village Electric Cooperative, Inc. (AVEC) is the electric utility for Noorvik, Alaska. The water plant is operated by Alaska Native Tribal Health Consortium (ANTHC). At the present time, a heat recovery system to transfer waste jacket water heat from the diesel generators to the nearby village school is planned and will be constructed in 2016.

Noorvik solar PV panels on the roof of the ANTHC water plant

Diesel Generators

The Noorvik powerplant is equipped with three diesel generators: a 363 kW (electrical generator capacity) Detroit Diesel S60K4c, a 499 kW Cummins K19G4, and a 710 kW MTU 12V2000, all operating at 277/480-volt station voltage. The powerplant is considered relatively old. Besides the age of the generator units themselves, the generator switchgear is manual control and the plant lacks even data logging capability. For this reason, renewable energy input must be maintained at a sufficiently low instantaneous penetration to avoid system instability, or additional control and mitigation measures would be necessary.

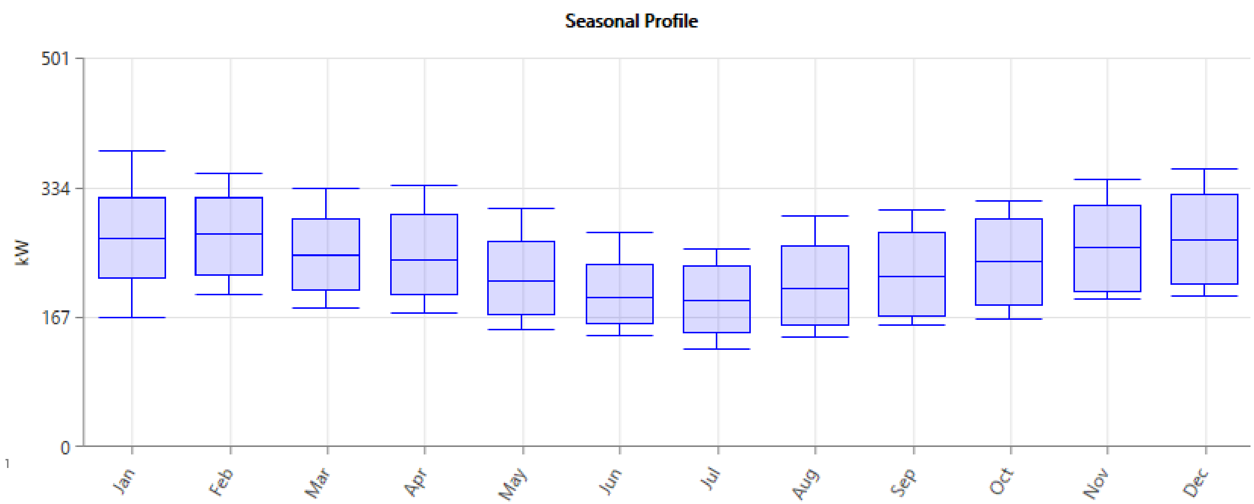
Existing Solar Power

The ANTHC water plant is presently equipped with 10 kW of solar PV capacity mounted on the roof of the building. This solar capacity is "behind the meter" with respect to usage, but its power generation is grid-connected and hence interacts with diesel generators, albeit at very low penetration.

Electrical Load Demand

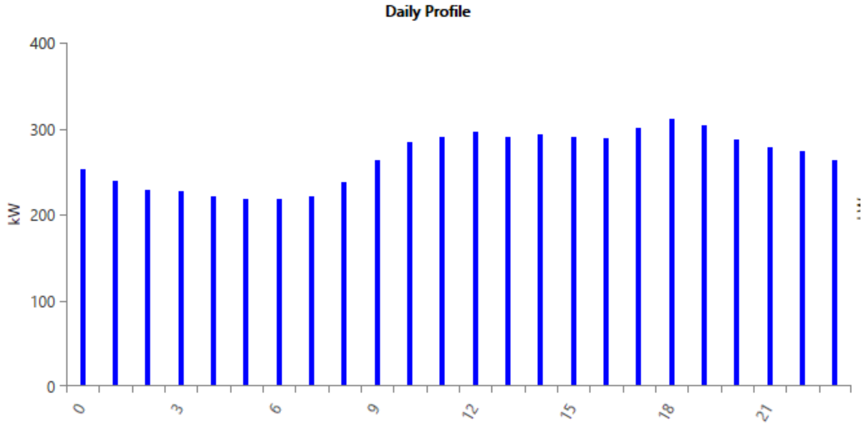
Hand logging of power demand and cumulative energy delivered is accomplished by the powerplant operator a few times per day, but without automatic logging of electric load demand, precise or even approximate diurnal and seasonal variation of load demand from these logs cannot is not reliable. But, broad parameters of the Noorvik load are known, such as average load, peak load, and annual energy generated, hence a load profile can by synthesized. For this, the Alaska Village Electric Load Calculator Excel file, developed by AEA in 2005, was used to create a virtual hourly Noorvik load. From this, a 234 kW average load, an approximate 380 kW peak load, and a 150 kW minimum load were generated and matched to 2015 data documented in AVEC's annual generation report. This synthesized data yields an average daily load demand of 5,625 kWh and an average annual load demand of 2,055 MWh. As one would expect, highest load demand occurs during the cold mid-winter months of December, January and February and lowest load demand occurs during the mid-summer months of June and July.

Noorvik seasonal load profile



The (synthesized) diurnal load is also as one would expect of a typically residential or non-industrial load profile with minimum loads demand during the early morning hours and peak loads during the late afternoon and early evening hours.

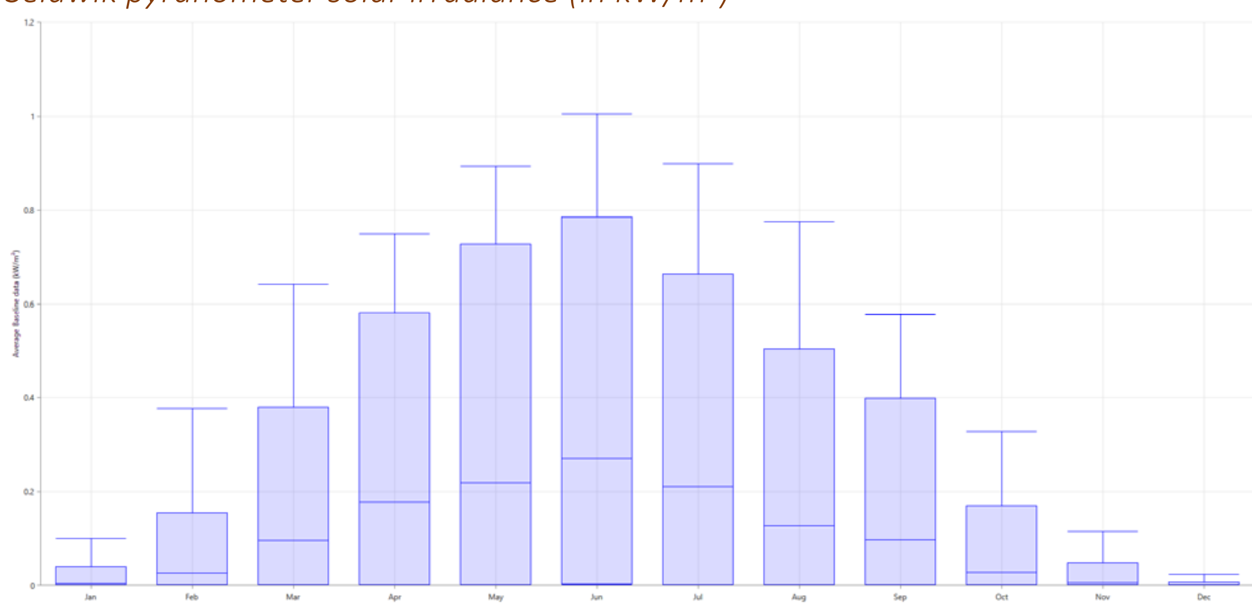
Noorvik diurnal load profile



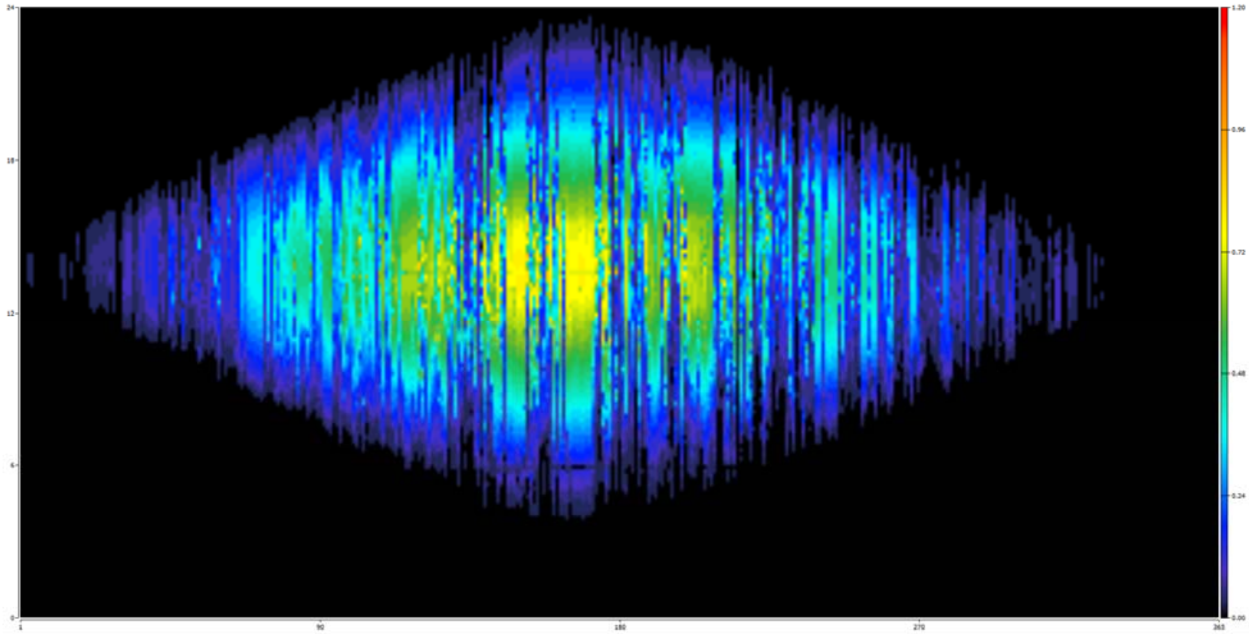
Solar Resource

HOMER software enables one to download from a NASA database solar irradiance and clearness index for Noorvik, which is valuable data and fine for this analysis, but because the nearby Selawik met tower was equipped with a pyranometer (solar resource sensor) for its 14-month operational life of early November 2014 through late December 2015, that sensor data was instead used for this analysis. The advantage of the Selawik pyranometer data is that this sensor was located at about 2.5 meters height in an open field, hence it includes ground reflectance (that is, sunlight reflected off of snow, which accurately mirrors the intended construction method of a new Noorvik solar PV system). Hence, the recently collected Selawik pyranometer data is superior to the NASA database in that for the latter one must manually adjust for ground reflectance to account for snow reflectance whereas for the Selawik data it is already included. Graphic representations below describe the Selawik (and by extension, nearby Noorvik) solar power resource.

Selawik pyranometer solar irradiance (in kW/m^2)

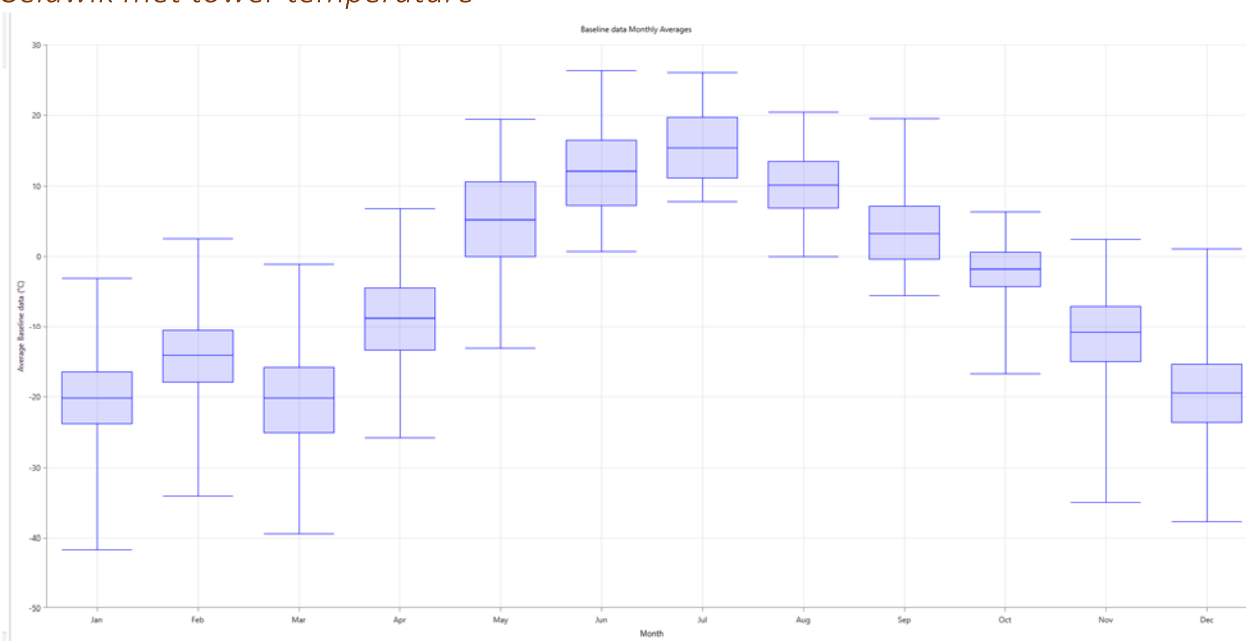


Selawik pyranometer Dmap (day of year vs. hour of day; color code, kW/m²)



Because solar PV output is dependent on ambient temperature (solar panels are more efficient at colder temperatures), Selawik met tower temperature sensor data is used for this Noorvik analysis to complement the met tower pyranometer data. Selawik (and nearby Noorvik too of course) was quite cold during the late 2014 to late 2015 measurement period with a measured low temperature of -42° C (-44° F) and an annual average temperature of just -4° C (24° F).

Selawik met tower temperature



Solar PV Project

The planned project is to install approximately 40 kW of additional solar PV generation capacity to the Noorvik power grid, in addition to the 10 kW of existing capacity at the water plant. The new capacity would be installed at ground level near the AVEC powerplant. NAB has indicated their preference to split the new solar PV capacity into three parts so that one third of the capacity can be oriented to the southeast, one third to the south, and one third to the southwest to mitigate the peak solar generation power. With this in mind, the analysis in this report is 45 kW of new capacity as 40 divided by 3 is not a whole number while, of course, 45 divided by 3 is. As such, three panels of 15 kW each are evaluated.

Note that the existing 10 kW solar PV system at the water plant is also a three panel array with a 90-degree spread, although it is not clear to this writer if the capacity is an even 1/3, 1/3, 1/3 split. For conservatism with respect to instantaneous power penetration, the water plant array is modeled as a single 10 kW unit facing due south.

Analysis Inputs

The analysis for this report was accomplished with HOMER software programmed at a 10-minute time step interval for 52,560 evaluation steps per year. This time step interval matches the granularity of the measured solar irradiance and temperature data from the Selawik met tower. This analysis is accomplished with the following constraints and assumptions:

- Diesels-on operation
- Minimum diesel loading of 20% (of rated capacity; for each 10-minute time step)
- Load-following dispatch strategy
- Operating reserve of 10% load and 15% solar power in each step
- Southeast and southwest-facing solar PV panels evaluated at 0, 22.5, 30, and 45 degrees offsets from south-facing
- Solar PV panel de-rating of 20% for annual power production and economic analyses; de-rating of 0% for instantaneous power penetration analyses
- Solar PV panel slope (degrees from horizontal) of 66.8° (default value for Noorvik's latitude)
- Solar PV panel efficiency of 15%
- Temperature effect on solar PV power production of -0.5%/°C considered

Results

Summary results indicate that 45 kW of new solar PV capacity supplying the Noorvik power grid would yield a very low average renewable energy penetration of less than 3 percent (with a 20 percent de-rating to account for soiling, ice on panels, wire degradation, etc.) and more importantly from a system control perspective, acceptable instantaneous penetration, even during periods of maximum solar PV power output with minimal load demand. Note in the table below that it is most beneficial for all solar panels to face due south and clearly there are diminishing returns when azimuth variation is employed, especially beyond a 60 degrees southeast-to-southwest spread.

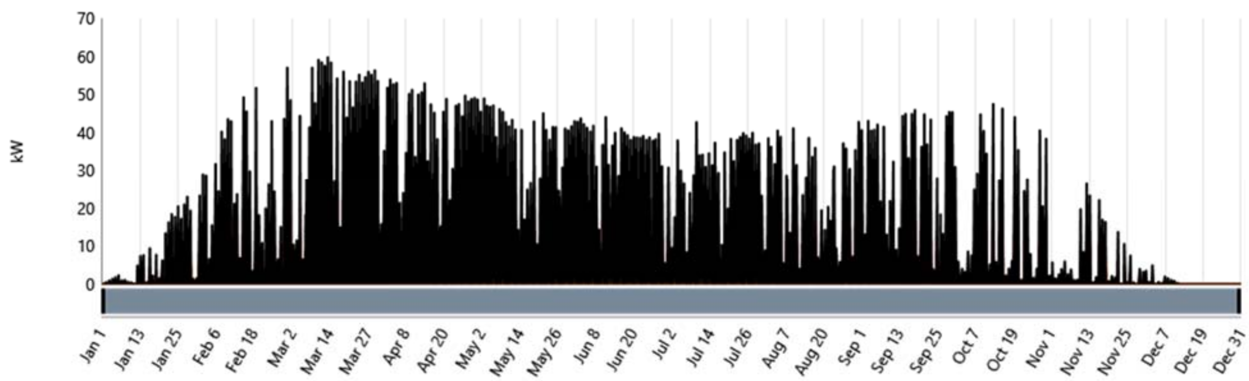
Solar PV energy production results

Azimuth (°W of S)			PV Production (kWh/y)				Penetration (%)	
SE	S	SW	SE	S	SW	Combined	Average	Instant
0	0	0	14,722	25,537	14,722	54,981	2.68	36.0
-15	0	15	14,532	25,537	14,551	54,620	2.66	35.5
-22.5	0	22.5	14,308	25,537	14,345	54,190	2.64	34.9
-30	0	30	13,999	25,537	14,062	53,598	2.61	34.0
-45	0	45	13,130	25,537	13,251	51,918	2.53	31.6

Instantaneous Penetration

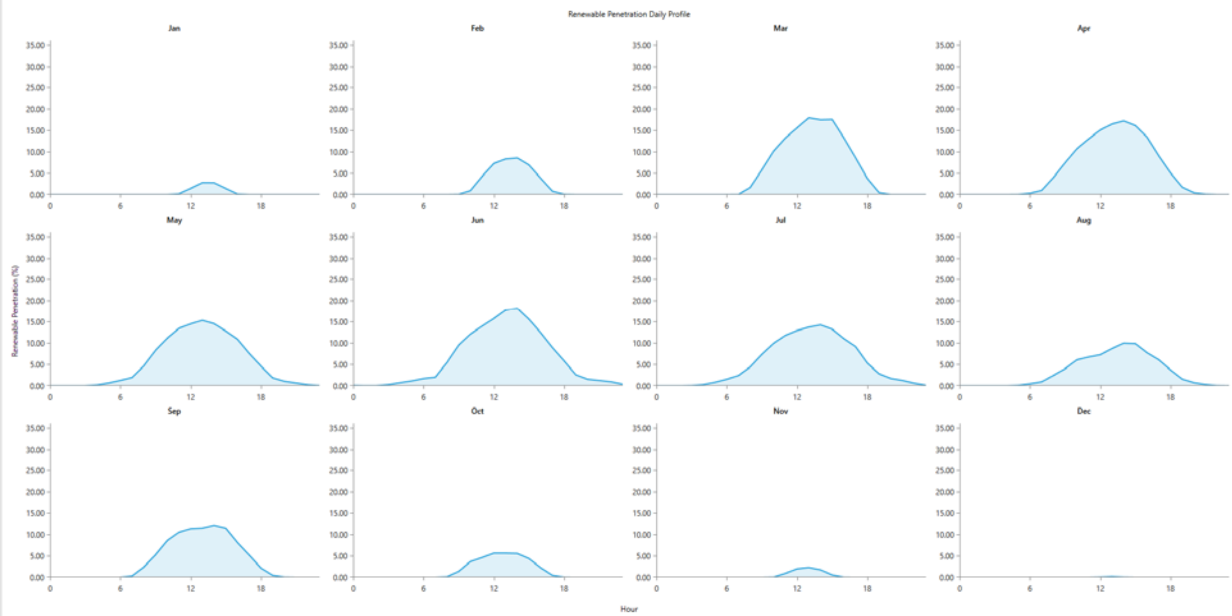
A view of solar PV output over the course of a year indicates that the highest energy production would occur in late winter and spring when the sun begins has climbed higher in the sky but there's still snow on the ground, and early autumn while there's still many hours of daylight and the first snows of winter have arrived. In both seasons, solar PV energy production benefits from direct irradiance and ground reflection of light from the snow-covered ground. Additionally, besides loss of ground reflection, summer solar PV energy production is lower compared to spring and autumn due to the commonly cloudy skies of summer in northwest Alaska.

Solar PV energy production (55 kW installed capacity), 20% de-rating



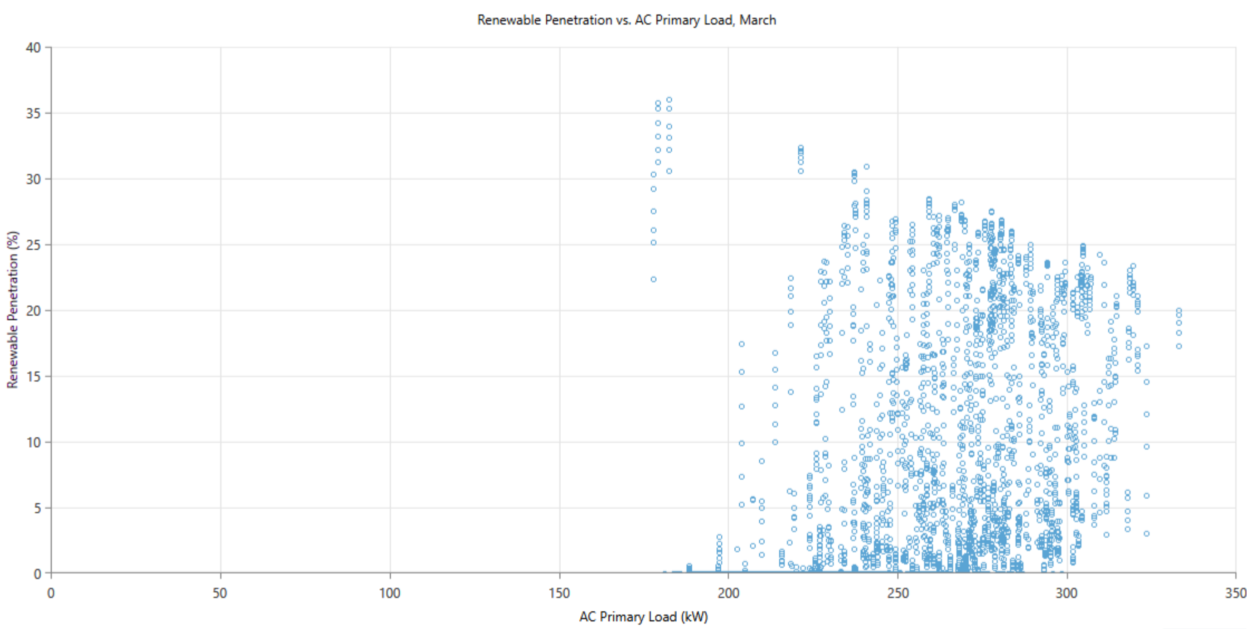
For analysis of instantaneous power penetration, de-rating is not considered. With this, one can see that solar PV power production can under particularly advantageous circumstances such as all panels facing south, bright mid-day sun, and a smooth, even snowfield south of the arrays reflecting light, produce well above the rated power capacity, to as high as 77 kW. It can be understood then that with a maximum 77 kW solar PV power output and minimum 150 kW load demand, instantaneous penetration can never exceed approximately 51 percent, which would be acceptable by itself, but HOMER modeling demonstrates that in reality maximum instantaneous penetration is lower than this as highest instantaneous solar PV power, which occurs at local apparent noon (actually about 3 p.m. in Noorvik from March through October because Alaska Daylight Time is 8 hours from UTC, not 11 hours as Noorvik's longitude would dictate), and minimum load demand, which typically occurs between 3 and 6 a.m., do not occur simultaneously. Hence, in reference to the solar PV production results table, maximum instantaneous penetration is only approximately 36 percent, not 51 percent.

Renewable penetration daily average profiles per month, 0% de-rating



The preceding graphs indicate that maximum instantaneous solar PV power penetration occurs in March, as one might expect. A more detailed view of March can be seen in the scatterplot below, which illustrates the several instances of maximum modeled renewable penetration of up to 36 percent. Typically though, instantaneous penetration well under 30 percent is the norm.

Scatterplot of solar PV power penetration for March



Doubled New Solar PV Capacity

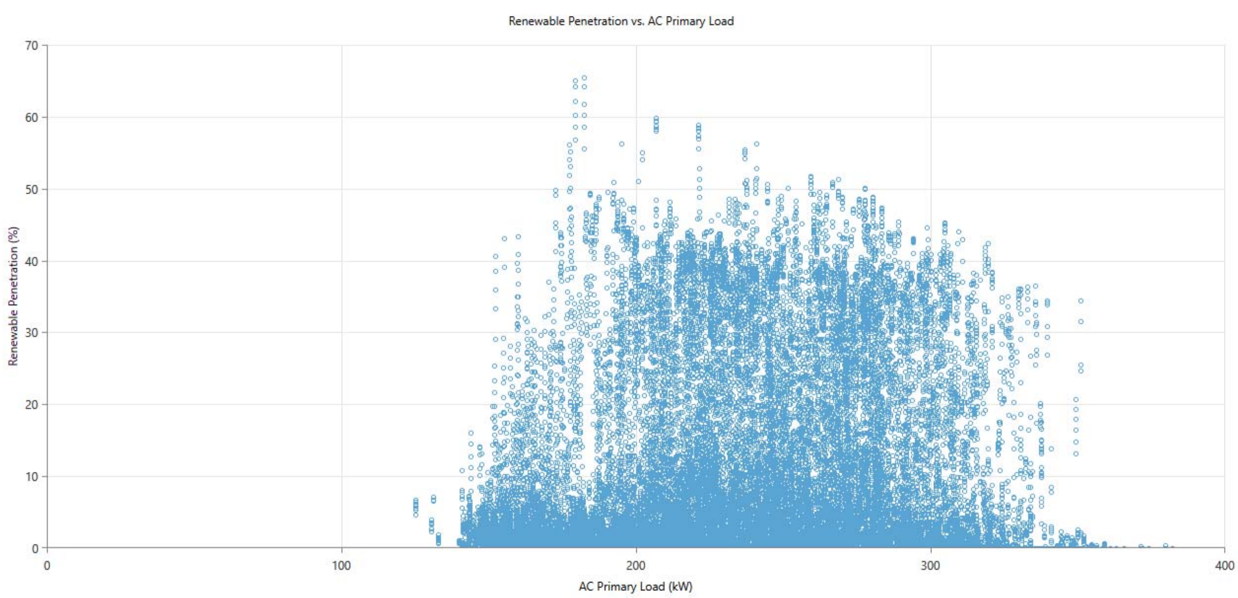
Should a larger solar PV capacity be considered; for example, doubling the planned 45 kW capacity to 90 kW, then possibly instantaneous solar power penetration might be sufficiently high to lead to system frequency instability and the need for control measures such as a secondary load controller and/or dispatch controller. This penetration potential is indicated in the table below.

Solar PV energy production results, doubled proposed capacity

Azimuth (°W of S)			PV Production (kWh/y)				Penetration (%)	
SE	S	SW	SE	S	SW	Combined	Average	Instant
0	0	0	29,444	39,259	29,444	98,147	4.78	65.5
-15	0	15	29,064	39,259	29,103	97,426	4.74	64.5
-22.5	0	22.5	28,617	39,259	28,691	96,567	4.70	63.2
-30	0	30	27,998	39,259	28,123	95,380	4.64	61.5
-45	0	45	26,259	39,259	26,503	92,021	4.48	56.6

Clearly, even with 90 kW of new solar PV capacity in addition to the existing 10 kW of capacity at the Noorvik water plant, instantaneous penetration would almost always be sufficiently low that the diesel generator(s) could maintain power system quality and stability. Renewable penetration daily profiles again illustrate that peak instantaneous penetration would occur during March, but an annual view of penetration vs. load demand (see below) demonstrates that 65 percent penetration would not be typical. Generally, solar PV instantaneous penetration would be 50 percent and less, even under optimal solar PV power-producing conditions.

Scatterplot of solar PV power penetration, annual, 0% de-rating



Economic Analysis

NAB indicates that capital costs for a 45 kW solar PV system in Noorvik will be $7,000 per kW installed, for a total project cost of $315,000. This is expensive by Lower 48 standards of course, but reflects the high cost of shipping and labor logistics in northern Alaska. For an economics analysis, the following assumptions are made:

- All solar panels face due south, 20% de-rating, 54,981 kWh/year energy production
- Diesel generator fuel efficiency of 12.5 kWh/gallon for usage offset
- Project life of 20 years
- Average fuel cost of $6.00/gallon over 20-year project life
- O&M cost of $250/year starting in Year 2 with a $2,500 cost in Year 10 for repairs
- Discount rates of 0, 3 and 6 percent

The proposed 45 kW solar PV project is economically beneficial at all three assumed discount rates and would have a simple (non-discounted) payback period of 12.0 years.

Solar PV project benefit

Discount Rate (%)	Project net NPV	NPV Cost	NPV Benefit	B/C Ratio
0	$219,818	$308,000	$527,818	1.71
3	$91,955	$300,674	$392,630	1.31
6	$9,420	$293,282	$302,701	1.03