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Project Title: School Sisters of Notre Dame Solar Park

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Congressional District, Corporate Office: Minnesota 3rd

Congressional District, Project Location: Minnesota 1st

FINAL REPORT

Overview/Executive Summary

The School Sisters of Notre Dame (SSND) Solar Park is an 849.12 kW_{dc} ground mounted fixed axis multi-crystalline photovoltaic (PV) solar system located on the SSND campus in Mankato, Minnesota that was commissioned on September X, 2015. At the time of commissioning, it was the third largest solar project in the State of Minnesota.

The project was the first large-scale solar development that demonstrates the use of 1,000 Volt, direct current, (V_{dc}) platform, versus a commonly used 600 V_{dc} platform. By switching to a 1,000 V_{dc} platform, the project realized approximately \$32,000 in savings (\$0.038/Watt) during installation. The savings resulted from a reduction in wire quantity and wire size, other Balance of System (BOS) DC components and reduced installation time. In addition there is projected better system performance over the life of the system. The project confirms that higher design voltage platforms will reduce the cost of future solar installations in Minnesota.

The array faces at an angle of 190 degrees from North, rather than the more typical 180 degrees (or directly South) realizing an increase in the amount of energy produced in the afternoon where typically more electrical power is required in the region. Due to this change, the system produces it's maximum power 40 minutes later in the day resulting in an estimated 4% more energy in the afternoon compared to the same system orientated directly South. However, this shift in orientation does result in an estimated 0.4% reduction in annual energy produced.

This project provided many benefits, some during the construction of the project and others that will be achieved over time. By producing approximately 1,182 MWh's of renewable energy each year, the addition will reduce carbon dioxide emissions by approximately 1,245,000 pounds per year. The project will result in a significant reduction in other air pollutants such as sulfur dioxide (1,891 lbs.),

nitrogen oxides (1,537 lbs.) and mercury (0.019 lbs.)¹.

While the interconnect process with Xcel Energy was time consuming, frustrating, and expensive, we believe that Xcel Energy has learned a lot in this process to better serve solar projects in the future.

The SSND Solar Park provided one of the best values in total resource costs (Grant \$/kW) in this round of RDF funding.

By demonstrating the use of a higher voltage in the solar array, inspectors will better understand the different code requirements and solar developers will understand how they can continue to drive down the cost of solar as even higher voltage platforms move into the market.



The Completed Array

General performance data of the array can be found on the following link:

XXXXXXXXXXXXXXXXXXXXXXXXXXXX.com

¹ Source: Xcel Energy 2014 Corporate Responsibility Report upper Midwest Xcel owned facility comparison

System Description:

Project Size:	849.12 kW _{dc} multi-crystalline photovoltaic solar 4.85 acres within the 84" high fence
Orientation:	190-degrees from North
Design Voltage:	1,000 V _{dc} , all equipment UL listed
Est. Annual Generation:	1,182,000 kWh (first year)
Racking (RBI Solar):	Static ground mount, 35-degree, 2- high portrait 24" minimum ground clearance
Panels (Renesola):	2,784 72-Cell 305W Virtus II
Inverters (SMA):	29-24000TL-US

Project Size

One of the project goals in our response to the RDF Request for Proposals (RFP) in September of 2013 was to build a 907 kW_{dc} solar system that would produce approximately 1,138 MWh's in the first year of operation. Due to a large number of variables, it is very difficult to build an efficient PV system to an exact size sometime in the future without final design details being fully developed. At the time of the RFP, a preliminary design was completed using aerial topography and a list of equipment that was available at the time. We concluded then that a 907 kW_{dc} system would be feasible.

The final product of 849.12 kW_{dc} (6% less than originally proposed) resulted from several design decisions based on available land (constrained due to an existing CRP contract), available equipment, row spacing, specific equipment ratings, and RDF contract language that required the system not to exceed 907 kW_{dc}. However, due to more efficient equipment, panel angle, spacing between rows, and the 1,000 V_{dc} design platform, we are estimating that the installed facility will generate 1,182 MWh in the first year of operation. That is 44 MWh (4%) more than the 1,138 MWh originally proposed.

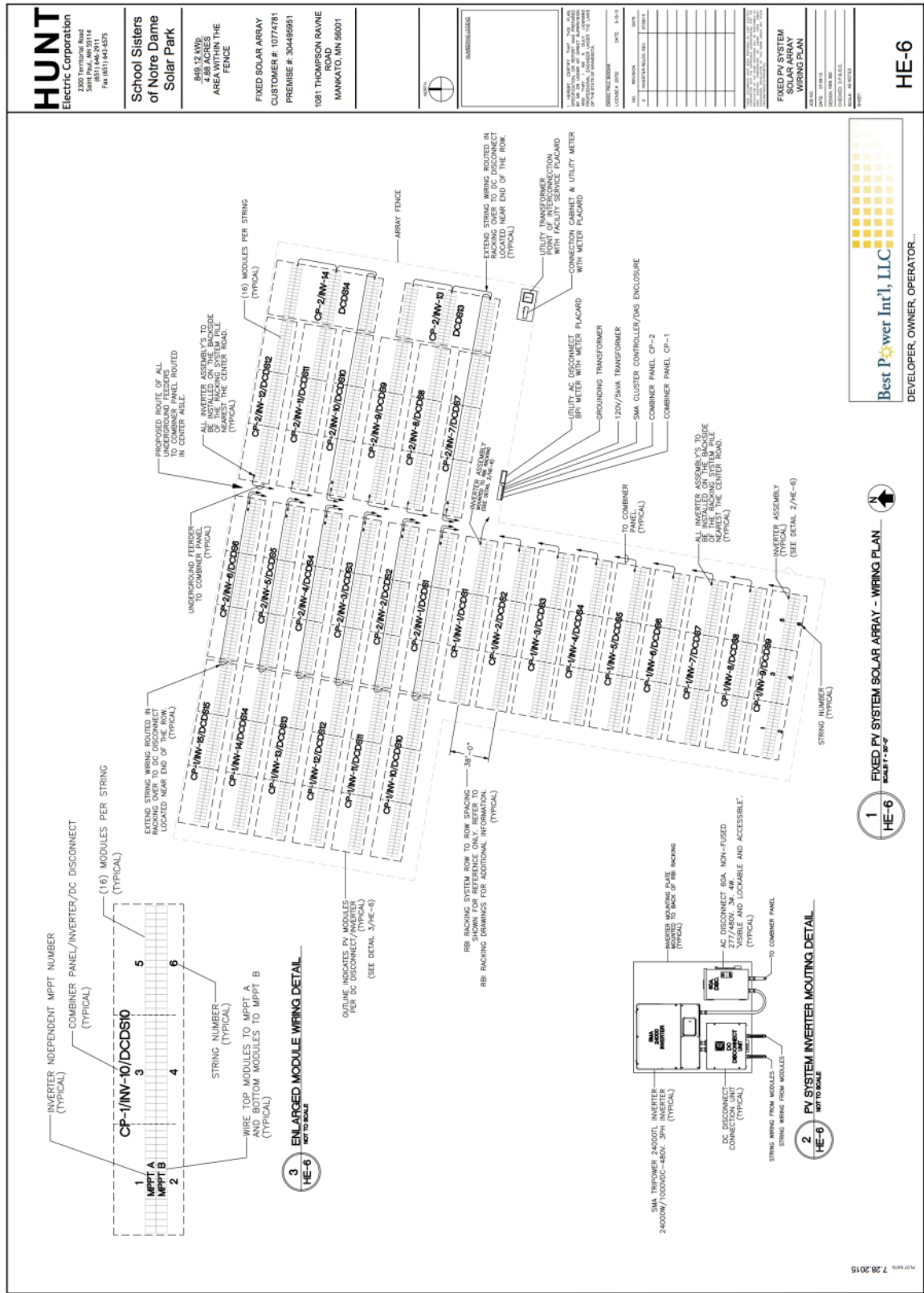


RBI Solar Racking



SMA String Inverter/Combiner Box and AC Shutoff

Construction Plans



Project Benefits:

The project proposal contemplated benefits in four major areas: Economics, Energy Pricing, Environmental, and to Xcel Energy electric ratepayers. The benefit goals in all of these major areas have been accomplished with the following outcomes in both immediate benefits and benefits to be realized over time:

Immediate benefits realized at completion of the project

1. Taxable Income will be generated based on fees paid to contractors and suppliers in the amount of approximately \$1,600,000.
2. This project provided one of the lowest resource costs (Grant \$/kW) compared to other projects awarded during this RDF cycle.
3. Local construction jobs were created. Approximately 12-full-time people worked on the project site for 8 weeks. Approximately 6-full-time people worked on the project site for an overlapping 8 weeks.
4. The purchase of over \$800,000 (50%) of materials and services to install the facility were obtained from Minnesota suppliers and contractors providing economic stimulus to the Minnesota economy.
5. Information to make better decisions learned from this project can be utilized to lower the cost of solar energy in the future.
6. The project has provided local electrical inspectors experience with electrical code issues on solar projects and specifically working with a 1,000 V_{dc} platform.
7. Press coverage in print, radio, and television helps to educate people in the Mankato area about solar energy.
8. Two local presentations to the District 9 Renewable Energy Task Force and a project “thank you” event have brought increased knowledge about solar energy to the local Mankato area.
9. The practical knowledge relating to solar development and construction obtained through this demonstration project has allowed the project team to expand their service offerings and their ability to deliver similar solar projects in Minnesota. By adding this knowledge, better decisions about design and construction of future facilities will lower the cost of future solar projects.
10. Data from the project has concluded that there are opportunities to reduce the cost of a solar system by using a 1,000 V_{dc} platform. Taking advantage of 1,000 V_{dc} efficiencies will depend on the design of the system, and the goals of the entity using the power as well as the entity producing the power.



Local Jobs



Sister Marjorie at the thank you event

Benefits realized over time

1. Taxable income in the amount of approximately \$2,170,000 will be generated based on the grant amount and electricity generated during the first 15 years of operation.
2. During the 15 years of production under the initial power purchase agreement, the facility will produce approximately 15,470 MWh's of renewable energy, all of which will count towards Xcel Energy's Renewable Portfolio Standard.
3. The project produces more energy during afternoon periods due to shifting the array 10 degrees to the West. In this region, electrical energy is more valuable later in the day so it will provide long-term value to the ratepayers.
4. The project will be available for tours and educational opportunities that will be administered by The School Sisters of Notre Dame.
5. The project will produce the following annual environmental benefits² during its first year while producing 1,182 MWh of energy:
 - The equivalent of 1,245,828 pounds of carbon dioxide (CO₂) not released
 - The equivalent of 1,891 pounds of sulfur dioxide (SO_x) not released
 - The equivalent of 1,537 pounds of Nitrogen oxides (NO_x) not released
 - The equivalent of 0.019 pounds of Mercury not released
 - Approximately 874,456 pounds of coal not used

Project Lessons Learned:

1. **Site Issues** - An early understanding of boundaries, soil conditions, and storm water management is critical to the success of a project during construction. One of the strengths of BPI is their ability to understand the site and potential constraints that may exist. Even with thorough homework, Mother Nature continued to challenge us during construction with several rain events over 2 inches during the 12-week construction period. Understanding the site conditions limits delays and mitigation measures that can increase project costs.
2. **Contractor Experience** - More work is needed for construction contractors to gain experience installing commercial scale PV so that costs can come down. There was a considerable improvement in experience since 2014 from local contractors. Most of the experience has been on paper and has lacked real world applications, but nonetheless, experience is being gained in the Minnesota region. While local crews do not have hands on experience, the parent company typically does and can provide valid direction.
3. **Interconnection Process** –Solar Developers need be cognizant of the time necessary to complete the interconnection process. Xcel Energy lacks process and experience to effectively process interconnect applications. It took over 20 months to get the Interconnect agreement completed even though the Tariff outlines a process that should take less than a few months. The process added over \$80,000 in additional costs that were not revealed during initial approvals. This process raises the cost of energy to ratepayers in Minnesota and needs to be improved. Also, the interconnect forms required work well for traditional energy generators such as natural gas or coal, but are not conducive to solar plants due to different power characteristics and number of inverters that may be needed. We would encourage Xcel

² ² Source: Xcel Energy 2014 Corporate Responsibility Report upper Midwest Xcel owned facility comparison

Energy to review this process and make improvements.

4. **Completion of Design and Engineering** - An update is needed to the Tariff that will allow designers and developers to follow a defined set of rules. Having three large Xcel territory solar projects built, BPI was confident of the rules and regulations required for construction even though requirements for solar design is changing rapidly and there are still several code interpretations that are not particularly clear. It was clear that Xcel Energy wanted more information than what current rules require in order to approve our plans. During the process to get an interconnect agreement finalized, Xcel Energy created several new and undefined steps in the process to get a design approved.
5. **Procurement of Equipment** - The selection of a specific solar panel drives the design of the entire system and therefore the selection needs to be made early. Selecting a product is the beginning of a 20+ year relationship and demands critical review of the product specification, warranty and overall company viability. All other components of the plant depend on the specifications of the panel. Because the panel pricing has been moving dramatically for the past several months, it was financially difficult to commit to a panel early. Because the interconnection process takes so long, and the interconnect application needs a system design, making the commitment to a specific panel has to be well thought out.
6. **Obtain Permits and Licenses** - Solar Developers need be cognizant of possible permitting and licensing requirements. This process went well and was easy to do. The State inspectors were available and knowledgeable. The city of Mankato was supportive and helpful so approvals went very well. The fact that the city required a “building permit” for the facility came as a surprise. While the process was relatively simple, it was cost and a timing issue that was not planned on.
7. **Rack Design** - Solar designers need to be cognizant of how changes to typical designs for this latitude may affect pricing. The fixed racking industry has gone through major changes in the last 18 months with a major price war. Getting early quotes on racking with limited site information can be misleading because racking companies are assuming the best site conditions so that early quotes are competitive. We learned that having very good soil information and understanding snow and wind loading is important to reliable pricing quotes. This project has a 35-degree rack that is ideal for maximum energy production at this latitude. Initially we were concerned with the cost to go from a 30-degree tilt to a 35-degree tilt. With some racking designs tilt angle will greatly impact the post spacing due to wind loads. The greater the degree of tilt, the more wind stress and more posts are required. The more posts, the higher the costs. Snow loading can also govern the design of the post spacing. Each racking company has significantly different structural members to consider. Based on the same site conditions, one racking company had 500 posts in the design compared with less than 300 for another due to the strength of the lateral members. In our case, snow loading was governing the design so it was prudent to chose a rack with stout lateral members to reduce the number of vertical posts. Because of this, there was very little cost increase to go from a 30-degree tilt to a 35-degree tilt.
8. **Equipment Delivery** - Communication with trucking firms for delivery to the proper location and to identify the appropriate unloading equipment is critical for the smooth delivery of project equipment. Even though the site needed a driveway for long-term maintenance, access for construction was an early consideration. The proposed permanent site access to be built is steep, a potential erosion control issue, and it does not provide easy turning radius for semi deliveries. We were able to gain access through a neighboring parcel, which was more accommodating to large trucks and heavy loads. While we learned in earlier projects that communication with trucking firms for delivery is critical, we still had issues with trucks

showing up at the wrong time and without proper unloading equipment.

9. **2014 Code Issues** - The National Electric Code (NEC) has been adopted in Minnesota and there are several changes that impact the design of a 1,000 Vdc system. A major code issue for this project, that was not discovered until an inspector pointed it out, was a change in where the combiner box can be in relationship to the inverter. With the previous version of the NEC, it was permissible to have the combiner box out of sight of the inverter as long as it could be locked out prior to servicing. The new code requires the combiner box to be visible from the inverter. That required us to make a major design change in the field, moving ganged inverters to each individual row.



Crews working on underground wiring



Crews wiring the AC Panels






The new Access Road



New Panels are in









Technical Progress:

The technical goals for this project are as follows:





-  **Reduce the system's overall costs** and stimulate new product rollout by shifting from a 600 V_{dc} platform to a 1,000 V_{dc} platform.
-  **Increase the amount of energy produced during higher value time periods** in Xcel's system (1:00pm to 7:00pm)
-  **Provide a process for local electrical inspectors to understand the 1,000 V_{dc} system** requirements for future solar projects.

Reduce the system's overall costs

The continuous drive to lower the installed price and improve the efficiencies of solar energy includes the process of increasing voltage in the system in a safe way to create benefits. The following benefits are produced when increasing the voltage in the system design:

-  More modules and thus more power per string
-  Fewer strings for the same array capacity
-  Fewer Balance of System (BOS) components, including overcurrent protection devices, combiners, disconnects, etc.
-  Reduced labor costs
-  Less wire in the DC system
-  Reduced wire losses (doubling voltage reduces wire loss to ¼ for the same power level)
-  Increased power conversion efficiency at the inverter
-  All of which leads to a lower cost per watt and a lower levelized cost of energy

With changes also come disadvantages. The following are the disadvantages when moving from 600 V_{dc} to 1,000 V_{dc} platforms:

-  Some equipment choices are limited due to lack of UL listing
-  Fencing requirements are greater
-  Greater setbacks to metal equipment such as fencing
-  Specific wiring types (greater insulation) that can cost more.

At the release of the Renewable Development Fund (RDF) request for proposals (9/2013), the concept of 1,000 V_{dc} PV systems was just gaining attention in America. While very much the standard in Europe for commercial applications, America was entrenched in the 600 V_{dc} platform. Because most electrical codes require UL listed equipment in America, most equipment at the time was not UL rated at 1,000 volts and thus not available for use. Inspectors were also slow to embrace the concept due to 2011 National Electric Code (NEC) interpretation resulting in the lack of 1,000 V_{dc} acceptances. Since then, manufacturers have certified almost all new commercial equipment to meet 1,000 V_{dc} UL standards and the 2014 NEC specifically allows for 1,000 V_{dc} for commercial applications. While beginning to be the standard now in America at 1,000 V_{dc}, equipment manufacturers are now certifying to 1,500 V_{dc} and will be soon pushing for NEC acceptance.

The SSND Solar Park project allowed us to build the largest PV solar system in Minnesota with 1,000 V_{dc} technologies giving us a good opportunity to discover local design and application constraints in our region. It also gave local electrical inspectors their first opportunity to provide

code interpretations for such applications.

Cost Comparison

Using the 1,000 V_{dc} platform allows designers and developers to realize increased energy production, material cost savings and a lower levelized cost of energy (LCOE) when compared to the 600 V_{dc} platform. In general, the change from 600 V_{dc} to 1000 V_{dc} means that the cost of the DC components of the system could be reduced by 40%. Some of the advantageous are not realized due to our cold climate (# of panels per string is reduced) and code issues. Code issues include more expensive 1,000 V_{dc} rated wire from the combiner boxes to the inverter and site fencing that needs to be 84" in height rather than simply a fence. There are also other design choices that lead a designer to make tradeoffs that reduce the impact of the voltage change. In our case, the use of string inverters instead of central inverters reduced the advantages that were possible. The use of string inverters reduced the DC wiring compared to what a central inverter system would realize. A central inverter would have much more DC wiring operating at higher volts than AC wiring which is more efficient. We estimate that we reduced the DC Balance of System (BOS) costs on the project by approximately 25% due to the utilization of the 1,000 V_{dc} platform.

The following table illustrates the details of the savings generated on this project:

Table 1 – Cost Comparison

Item	600 V	1,000 V	Difference	Value
Modules per string	11	16	7 (31%)	N/A
Watts per string (305 W Panels)	3,355	4,880	1,525 (31%)	N/A
Parallel connections	253	174	-79 strings (31%)	N/A
Combiner box	32	29	-3 (9%)	\$1,200
24kW Inverter	32	29	-3 (9%)	\$12,705
AC Shutoff	32	29	-3 (9%)	\$990
Conduit/AC Wiring, Etc.	NA	NA	NA	\$10,000
12/10 AWG DC wire (panel to combiner)	37,670 ft.	21,710 ft.	- 15960 (42%)	\$3,990
Est. labor (Hours)	80	0	-80	\$6,000
Fencing	\$9,000	\$12,000	\$3,000 (25%)	-\$3,000
Total				\$31,885
			1.8% of Total Cost	\$0.038/Watt

Note: A 1,000 V_{dc} system compared to a 600 V_{dc} system will be more efficient by approximately 0.5% in the wiring and 0.5% in the inverter resulting in more energy over the life of the system³. As designed, because the 600 V_{dc} system requires additional inverters due to string length issues, the 600 V_{dc} system will produce approximately 1% more energy over the life of the array compared to the 1,000 V_{dc} system causing the cost/benefit to be equal.

Increase the amount of energy produced during higher value time periods

³ "The Commercial Promise of 1,000 VDC Design, SMA America, LLC"

Xcel Energy defines their peak electrical energy period from 9:00 am through 9:00 pm not including weekends or holidays. In our Midwest region, the peak electrical use occurs in the summer at approximately 4:30 pm. Because Xcel Energy needs to dispatch more capacity during the peak times, the electricity generated is more costly (or has more value). In the month of July, a fixed solar array that faces directly south produces energy from approximately 6:15 am to 8:15 pm with the peak occurring at about 12:00 noon. By shifting the array to the West, the peak will occur later in the day and the system will produce more energy in the afternoon getting closer to matching the regions electrical load. However, the array will experience a reduction in annual energy production.

By shifting the array 10 degrees to the West, we moved the peak power of our system 40 minutes later in the day. By modeling the system with the PVWatts design software under both a 180-degree and a 190-degree orientations, by shifting the array 10 degrees to the West, on a sunny day in July, the system will produce about 4% more energy between the hours of 1:00pm and 8:00pm.

At the 190-degree orientation, the model showed that it reduced the annual energy produced by the array by approximately 0.4%.

When the penetration of solar is low in the area, the goal to date has been to maximize the amount of renewable energy of the system. So most systems are facing South to maximize energy production throughout the year. As the penetration of solar energy increase over time, it may be more valuable to shift solar arrays to the West to more closely match the load needs of the region.

Energy Comparison 180 degrees versus 190 degrees

180 degrees = 1,187,267 kWh/Year

190 degrees = 1,182,492 kWh/Year (0.4% less annual energy)

Process for local electrical inspectors to understand the 1,000 Vdc system requirements

Two State electrical inspectors were at the site on several occasions during construction. They had design conversations with our engineer and that collaboration proved to be valuable for both parties. The inspectors identified a 2014 NEC issue that required a design change regarding the location of the inverters, and the engineer was able to educate them on other pertinent design issues leading to a safe system design. Both parties learned from the experience.

Usefulness of Project Findings:

The project findings in benefits, lessons learned, and technical progress have been valuable during this RDF reporting period. Understanding the complexities of providing energy based on the vast amount of technical choices is important and this study has provided more clarity to those complexities. While increased voltage is a definite advantage for solar design and installation, it is hard to take advantage of all of the efficiencies due to competing needs and the choices of equipment. While 1,000 V_{dc} system will soon be surpassed by 1,500 V_{dc} systems, this process at 1,000 V_{dc} provided clues for the future.

Project funding provided by customers of Xcel Energy through a grant from the Renewable Development Fund.

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