

North Dakota Renewable Energy Council  
Interim Report  
**Portable Solar Array Modules**

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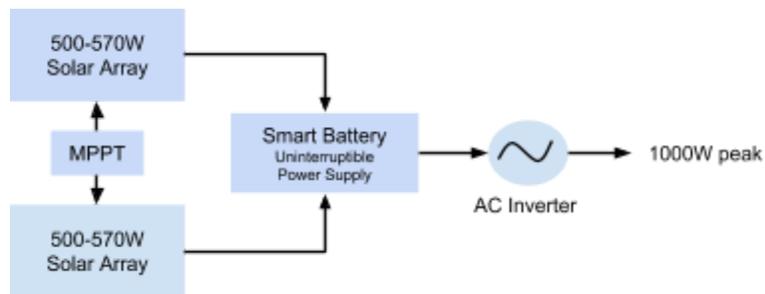
May 2018

## Introduction

This document describes the accomplishments and current status of projects during the Portable Solar Array Modules project. These activities took place at Packet Digital's facilities in Fargo, ND as well as at the Naval Research Lab (NRL) facilities. Progress has been made on the objectives. A status update of each deliverable is listed below.

## Objective:

To develop and commercialize transportable solar power generation modules capable of delivering up to 1kW for remote military installations, emergency shelters and camps, and a variety of commercial uses; and to eliminate the fuel requirement and noise and reduce the life cycle cost of standard electromechanical power generation.



**Figure 1: System Overview**

## Schedule

The performance period is February 27, 2018 through December 31, 2018. This interim report covers the progress made through May 31, 2018.

## Deliverables

- Power electronics and hardware for a portable up to 1 kW solar power system, including smart batteries and Maximum Power Point Tracker (MPPT);
- Innovative MPPT algorithm for extracting maximum charging capacity from the solar cells;
- Custom enclosures for individual electronic components and integrated system;
- Documented results of system testing;
- Manufacturing ready for commercially viable, portable up to 1 kW solar power system;
- Commercialization partners and distribution.

## Status Updates

Below are summaries of the progress made during this period for each of the objectives.

### Objective 1: Specify, select and test a 1kW inverter

A high reliability AC inverter is an integral part of the system by the converting the DC battery voltage to a usable AC voltage. The inverter should have the following capabilities:

- A wide DC input voltage to accommodate varying battery voltages
- Built in cooling (albeit a weakness to dust and moisture)
- A high (>80%) conversion efficiency
- A pure sine wave output

With the following capabilities being highly desirable:

- A high IP rating for dust or water resistance
- Variants with 110V or 220V outputs
- Built in MPPT
- Small or compact in form



**Figure 2: Meanwell TS-1000 series inverter**

The following is a list of nine inverters selected to fulfill the requirement.

1. This one is made by KD which is a Chinese made unit. The model number is WVC-1200 and sells for around \$280. The specifications are as follows:
  - a. Input voltage: 22-50VDC
  - b. Output voltage: 80-160VAC
  - c. Output power: 1200W

Unable to find the datasheet for this inverter, the maximum efficiency cannot be reported at this time. It does state that the output is a pure sine wave, a built in MPPT algorithm, and has a IP65 rating. With only passive cooling, it would suggest this unit could suffer from overheating and longevity would be compromised. Aside from the questionable construction quality and durability, it does possess many of the qualities that are desirable for the chosen unit.

2. The Solinba grid tie inverter is a highly configurable unit that comes from somewhere in Asia. The model number is based on the selected features and carries a price tag of

\$200. The built in cooling prevents the unit from overheating and it's available in multiple input/output configurations. With features such as built in MPPT, reverse polarity sense, over temperature, undervoltage, and overcurrent, the Solinba is a compact unit with sensible safety protection.

- a. Input voltage: 11-28, 22-56, 44-112VDC (selectable at time of order)
- b. Output voltage: 110, 220VAC (selectable at time of order)
- c. Output power: 920-970W, max of 1000W

One downfall of this inverter is that it is probably susceptible to dust and moisture with the cool vents on each end of the casing. The reliability and durability of this unit are unknown but it boasts some favorable features and has a high 85-90% efficiency.

3. The Meanwell TS-1000-112/124/148/212/224/248 is an offering from a well respected company in the power industry. The 1000W has surge protection up to 2000W and a high efficiency of 92%. The pure sine wave output will ensure that all electric devices will have reliable power without the concern for damaging sensitive electronics. The unit has several smart safety features built in such as a low battery alarm, low battery shutdown, over voltage, over temperature, over load, output short and reverse polarity.
  - a. Input voltage: 10.5-15, 21-30, 42-60 DC (12/24/48 selectable at time of order)
  - b. Output voltage: 110, 220VAC (selectable at time of order)
  - c. Output power: 1000W, surge to 2000W

This power inverter boasts one of the highest efficiencies in the list but is lacking a MPPT and any weather protection. At \$295, it's towards the upper end of the price range but coming from a reputable company in the power industry, it's reliability and construction quality are of lesser concern.

4. The GWL/Power SUN-1000G2 is perhaps the most versatile inverter in the list. Offering a wide input voltage along with built in cooling, an MPPT, greater than 90% efficiency, and safety features such as over current, over temperature and reverse polarity. Outputting a pure sine wave, delicate electronics won't have an issue. With an IP40 it can withstand dry debris but is susceptible to moisture. At \$274 it's an affordable option on the list.
  - a. Input voltage: 22-65VDC
  - b. Output voltage: 185-265VAC (230VAC)
  - c. Output power: 1000W

The SUN-1000G2 is from a United Kingdom company so currently the only output voltage is 230VAC which may be an issue. But the list of features and integrated LCD screen to change settings and view current system status make this a strong finalist.

5. The Xantrex PROsine is a commercial offering that also carries a commercial price. At \$550, it's the most expensive in the list and lacks some of the features (such as an MPPT) that would ideally be included at that price. Available in two input configurations and a single output configuration, the 89/90% efficiency is in expected range.
  - a. Input voltage: 10-16, 20-32VDC (12, 24VDC)

- b. Output voltage: 120VAC
- c. Output power: 1000W, surge to 1500W

An additional feature is an optional interface panel that can be remotely mounted in a more convenient location for monitoring the inverter. Most of the features on this model appear fairly basic and at the price point, more would be expected. For a better investment, the GWL/Power or Meanwell options should be looked at.

6. The Snaterm SCI1000W is a hefty inverter weighing in at 50lbs. All that weight delivers a ruggedized inverter that is available in three input voltages, two output voltages, and protection against over temperature, over load, over voltage or shorted outputs. The built in MPPT and pure sine wave output ensures the connected electronics will receive conditioned power that won't cause issues with operation. The unit itself is >85% efficient when running on batteries but lacking any weather protection may cause premature failure due to environmental exposure.

- a. Input voltage: 10-16, 20-32, 40-64 DC (12/24/48 selectable at time of order)
- b. Output voltage: 110, 220VAC
- c. Output power: 1000W, surge to 3000W

The SCI1000W is a robust unit in terms of offering, but the lack of weather protection, its massive weight and unknown price tag leave this inverter trailing against some of the other competitors.

7. Mustpower's PH30-1KW PRO appears to be a well put together unit featuring built in cooling, selectable output voltage, two input voltage options, a pure sine output and efficiency of >88%. The built in LCD display is an added bonus that displays important information such as input and output voltage, output frequency, system temperature, load and battery capacity.

- a. Input voltage: 12-15.7, 20-31.4, 40-62.8VDC (12/24/48VDC)
- b. Output voltage: 110-120, 220-230VAC
- c. Output power: 1000W (surge to 3000W)

The PH30-1KW PRO has lots of desirable features but lacks a MPPT and appears to require an AC input for the output to lock onto. The price is also unknown as it requires a request to Mustpower.

8. The second offering from Mustpower is the EP20-1KW. This inverter is similar to the other Mustpower offering in that it has two input voltage options, two output voltage options, built in system protection and an optional LCD screen. Mustpower's website does not have a technical datasheet for this inverter which makes finding specifications, aside from the brief overview, very hard to find.

- a. Input voltage: 12/24VDC
- b. Output voltage: 100-120, 220-240VAC
- c. Output power: 1000W

Like the previous Mustpower inverter, the price on this unit is not known and with the units being manufactured in Shenzhen, China, other units should be considered before these.

9. The ultra-cheap option in the list is the Suoer GTI-H1000B. Coming in at \$70, the expectations would be low but this unit provides built in cooling, an MPPT, an optional remote monitoring display, parallel connections to other units, and an efficiency of 87%. It lacks any weatherproofing and has a single output voltage, but does include a slew of protection features to prevent damage to the unit.
  - a. Input voltage: 35-39VDC
  - b. Output voltage: 190-260VAC
  - c. Output power: 1000W

Additional information from a missing datasheet would be required to place this unit in the top three but with the cost, and other included features, it may be the surprise in the list.

Looking through all the inverters on the list, most include a similar set of features such as built in safety features and varying input range. Outputs seem to be dependant on which country the unit is manufactured in, 120VAC for the U.S., 220VAC for the rest of the world. Having high efficiency, an integrated MPPT, and some level of weather protection are expected. The two standouts from the list are the GWL/Power and the Meanwell offerings. The GWL/Power SUN-1000G2 is the standout but if the 220VAC output is restricting, the Meanwell would be the other inverter to consider. Both come from reputable manufacturers and are available from multiple resellers.

## **Objective 2: Evaluate and/or modify a smart battery**

In this task, a formal overview of secondary batteries was performed to assess the available options for the portable power system. The batteries are a critical part to nearly every aspect of the system. This section contains a summary of those findings.

Table 1 shows the key metrics for common secondary or rechargeable battery chemistries. Cell voltages are not terribly significant as cells will be assembled in series to obtain the proper voltage, likely 24 or 48V. Energy density, on the other hand, is extremely important for a portable system. LiNiMnCoO<sub>2</sub> (NMC) is the clear winner as it has 5x the density of lead acid and approximately 2x NiMH and LiFePO<sub>4</sub>. Number of cycles relates to the lifetime or maintenance costs of the system. Both lithium battery types boast significantly better lifetimes than lead acid and NiMH. Safety is also a key factor and the one area where the NMC is at a disadvantage. Safety concerns can be mitigated with the use of a proper battery management system (BMS). Packet Digital has designed multiple BMSs and will design a custom BMS to increase the safety of the lithium batteries.

Chemistry	Cell Voltage (min/nom/max)	Energy Density (Wh/kg)	# cycles	Safety
Lead Acid	1.75/2.1/2.32	30-40	500-800	Best
NiMH	0.9/1.2/1.3	100	300-800	Best
LiFePO4	2.0/3.2/3.65	90-130	7000	Better
LiNiMnCoO2(NMC)	2.5/3.6/4.2	205	5000	Good

**Table 1: Key metrics for primary chemistries**

The requirements for a reliable and portable system exclude the use of the lead acid and NiMH batteries. Table 2 compares commercially available cells of each chemistry. These cells are representative of the chemistries in general.

	LiFePO4 (model 87122200L, <b>x2 to get comparable capacity</b> )	Farasis NMC (model IMP06160230P29)
Capacity (nominal)	30000mAh	29000mAh
Cycle life	>1000	2000
Voltage (nominal)	3.2V	3.7V
Charge current (max)	1.0C	1.0C
Discharge current (max)	2.0C	4.0C
Cutoff voltage	2.4V	2.75V
Impedance	<4mΩ	?
Weight	764g	485g
Energy Density (Wh/kg)	125.6	221
Volume (mm3)	431250	222180
Cost (qty 1)	\$39.95	?

**Table 2: Specifications for LiFe and NMC Cells**

Table 3 shows the size, weight, volume, and estimated cost of a 1kWh battery bank based on the cells from table 2. It is seen that the NMC cells are approximately half the weight and volume of the LiFePO4 option.

	LiFePO4 (model 87122200L)	Farasis NMC (model IMP06160230P29)
Number of cells needed	21	10
Weight (g)	8022	4850
Volume (m3)	0.0045	0.0022
Cost	\$839	

**Table 3: Specifications for 1kWh battery bank**

### **Objective 3: Modify the MPPT**

Multiple configurations are available for the Maximum Power Point Tracker (MPPT). In this effort, the focus was on calculating the performance/cost tradeoff of different configurations. The two primary configurations under evaluation are listed below.

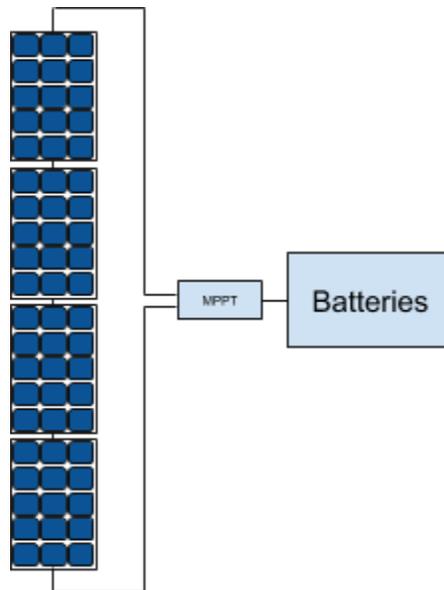
#### **Configuration 1: 4 panels connected in series with a single MPPT**

Pros:

- Lowest cost
- Very high efficiency under ideal conditions

Cons:

- Lower efficiency in the presence of non-ideal conditions (shading, damaged panel)
- Requires high voltage compatible MPPT



**Figure 3: 4 Panels in Series Configuration**

#### **Configuration 2: 4 panels connected in parallel, each with their own MPPT**

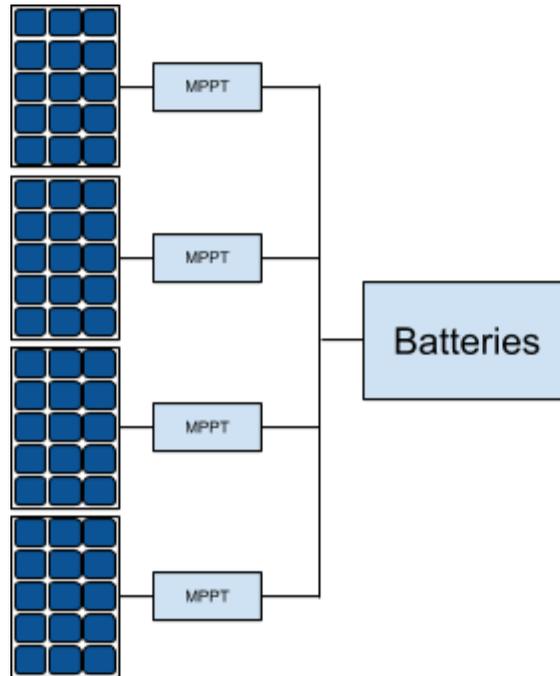
Pros:

- Better efficiency under non-ideal conditions
- Lower voltage MPPTs
- Allows more system flexibility

Cons:

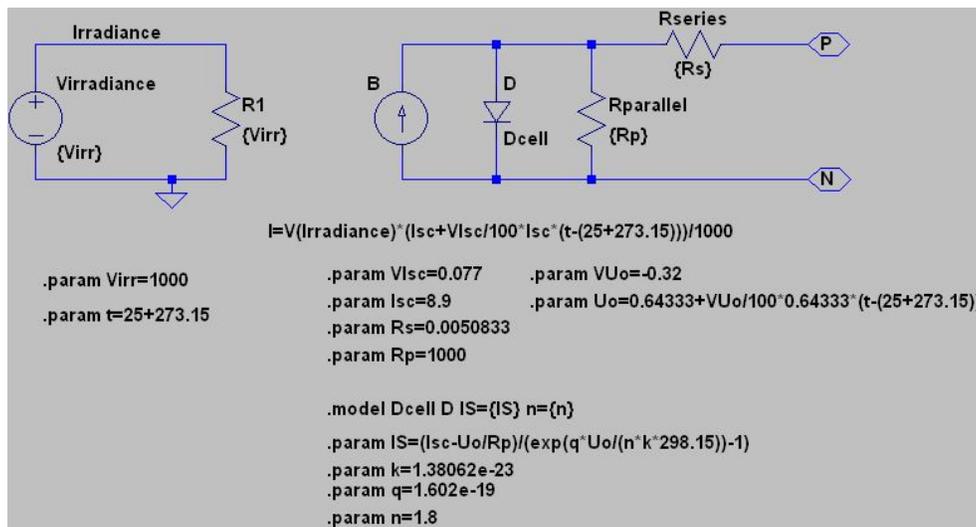
- Higher component count increases cost

- Requires diodes to prevent back-feeding



**Figure 4: 4 Panels in Parallel Configuration**

To help evaluate the two configurations, a simulation models were created. While there are multiple commercial software packages that simulate solar panel performance in the presence of various environmental conditions (temperature, location, shading), most were designed for residential housing applications. A solar cell including irradiance can be modeled using electronic components. A spice model of a single solar cell and also an entire panel were developed and shown Are shown in the figures below.



**Figure 5: Individual Solar Cell Model**

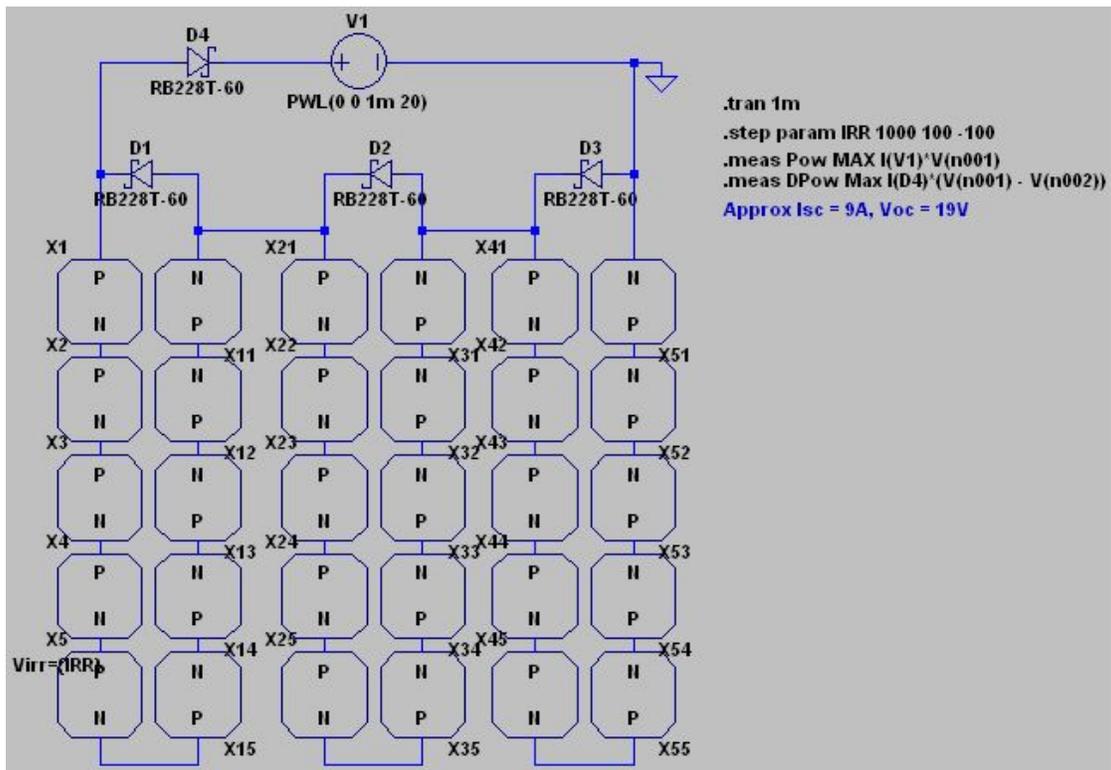


Figure 6: Full Panel Model

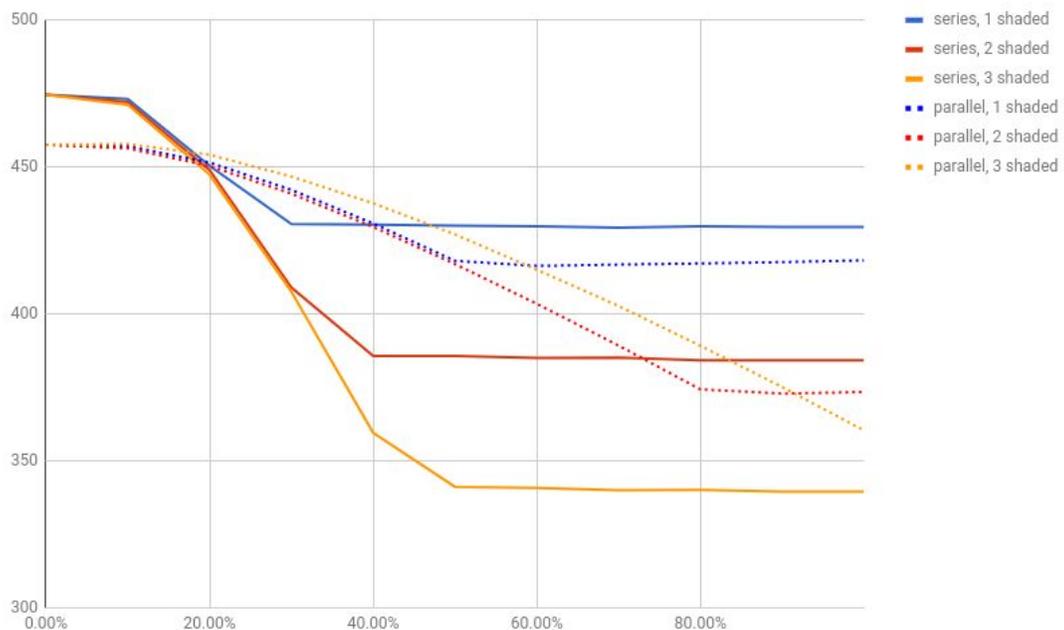


Figure 7: Comparison of series and parallel panel configurations

Also being evaluated during the period is a solar cell string optimizer integrated circuit from Maxim. This device claims to replace bypass diodes with a more efficient ideal diode and MPPT. Maxim currently only allows solar panel OEMs access to this technology. We are currently in discussions with Maxim on whether or not we qualify for access.

**Objective 4: Evaluate and develop additional hardware, custom enclosures and transport cases**

This objective will be executed once objectives 1-3 are complete.

**Objective 5: Final system integration and testing**

This objective will be executed once objectives 1-4 are complete.

**Objective 6: Develop, document, transition and implement the manufacturing plan**

This objective will be executed once objectives 1-4 are complete.

**Other activities:**

No other significant activities in during this period.

**Budget**

Total project cost is expected to be \$1,000,000, of which \$500,000 is provided by NDIC. Matching funds of \$500,000 will be provided. \$75,000 by Nishati and \$425,000 by the Naval Research Lab as matching funds. Table 2 lists the budget status as of May 31, 2018.

<b>Project Associated Expense</b>	<b>NDIC's Share</b>	<b>Nishati Share</b>	<b>Naval Research Lab Share</b>	<b>Packet Digital Share</b>	<b>Total</b>
Total Personnel Costs	\$90,106.89	\$0.00	\$167,344.42	\$0.00	\$257,451.31
Software Costs/Materials	\$0.00	\$295.00	\$4,211.45	\$0.00	\$4,506.45
Total	\$90,106.89	\$295.00	\$171,555.87	\$0.00.	\$261,957.76

**Table 2: Interim Budget Status as of May 31, 2018**

**Summary**

Significant progress has been made thus far on the project. Both inverter and battery market research has been completed. Several viable options are available depending on the end customer's requirements. Solar panel simulation models have also been created that will enable

system configurations to be evaluated prior to physically constructing the systems. The groundwork has now been laid to begin prototyping the system.