Global LEAP Solar Water Pump Test Method

Version 3

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Context

This document includes test methods for evaluating small-scale (less than or equal to 2.2 kilowatts of PV power input) solar water pumping systems (SWPs) intended for deployment in stand-alone applications. The tests include procedures for evaluating the performance and durability of SWPs and methods to assess overall system quality. The test bench setup, required equipment, and testing constraints are also presented.

The methods were originally developed by the Schatz Energy Research Center (Schatz Center) to evaluate the performance and durability of 27 SWPs that were submitted to the 2019 Global Lighting and Energy Access Partnership (Global LEAP) Awards Solar Water Pump (SWP) Competition – a program implemented through the Efficiency for Access Coalition. The methods have also been used since the 2019 awards competition to assess additional SWPs, and several procedures were added following additional research, such as the Solar Water Pump Durability Research Memo. Where applicable, the procedures draw from existing international standards and technical specifications, including *IEC 62253: 2011, IEC 62257-9-5:2018,* and *IEC 62257-9-8:2020.*

When revising this test method, the Schatz Center worked in close collaboration with CLASP as part of VeraSol, a quality assurance program that provides a suite of quality assurance services for the off-grid sector, including test methods development, quality standards, appliance testing and certification and test lab capacity building among others.

VeraSol is managed by CLASP in collaboration with the Schatz Energy Research Center at Humboldt State University, with foundational support from the World Bank Group, the United Kingdom's Foreign, Commonwealth & Development Office, the IKEA Foundation, and Good Energies Foundation under the Efficiency for Access Coalition umbrella.

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Contents

1 Scope

This document defines methods to evaluate the quality, performance, and general durability of small-scale (less than or equal to 2.2 kilowatts of power input required) off-grid solar water pumping systems (SWP) used mainly for agricultural purposes.

The test method consists of the following major components:

- Overall **product quality** inspection both internal and external as well as an evaluation of the user manual and company provided information
- Evaluation of **performance**
- General assessment of various **durability** metrics

The following international test procedures and standards have been referenced in the preparation of this document:

- *IEC 62253: 2011: Photovoltaic pumping systems – Design qualification and performance measurements*
- *IEC 62257-9-5: 2018 Integrated systems – Laboratory evaluation of stand-alone renewable energy products for rural electrification*
- *IEC 62257-9-8:2020 Integrated systems- Requirements for stand-alone renewable energy products with power ratings less than or equal to 350 W*

2 Testing and evaluation definitions

2.1 Centrifugal Pump

Pump system that uses rotating impeller(s) to impart kinetic energy (velocity) by centrifugal force to a fluid and stationary diffuser to convert the kinetic energy to potential energy (pressure). [SOURCE: ISO 15551:2023, 3.22]

2.2 Positive Displacement Pump

Machine in which liquid is trapped in confined volumes and transported from an inlet connection to an outlet connection by the reciprocating movement of pistons or plungers. [SOURCE: ISO 12809:2020, 3.1]

2.3 Surface Pump

A pump that draws water from surface sources, including streams and ponds, and is designed to be installed outside of the water source. A surface pump's inlet is situated under the surface of the water and needs to be primed before operating (i.e. air needs to be removed). A surface pump has a suction lift limit, which is the maximum vertical distance the pump can draw water through its inlet hose before pumping it out through the outlet hose. A surface pump may be classified as centrifugal or positive displacement.

2.4 Submersible Pump

Pump designed to be operated completely immersed in water. [SOURCE: ISO 8849:2020, 3.3]

2.5 Maximum Power Point Tracking (MPPT)

A charge controller algorithm that searches for the maximum power point along the PV array's I-V curve in order to maximize the power utilized from the PV array.

2.6 Pulse width Modulation (PWM)

Pulse control in which the pulse width or frequency or both are modulated within each fundamental period to produce a certain output waveform. [SOURCE: ISO 15118-1:2013, 3.46]

2.7 Inverter

Device powered by a DC source, designed primarily to provide AC power at a required voltage and frequency. [SOURCE: ISO 13297:2020, 3.31]

2.8 Charge Controller

A device that controls the power (either current or voltage) going into a pump from a power source. Most charge controllers can detect operational faults and signal this to the user.

2.9 Photovoltaic Array

Two or more photovoltaic modules at one location that together provide a photovoltaic solar energy system [SOURCE: ISO 6707-3:2022, 3.3.7]

2.10 Standard Testing Conditions (STC)

Test or operating conditions that have been predetermined to be the basis of the test in order to have reproducible and comparable sets of test data. [SOURCE: IEC 60050:2022, 485-22-08]

– Cell temperature: 25 °C. [SOURCE: IEC 61853-1:2011, 7.2]

– Irradiance: 1000 W/m^2. [SOURCE: IEC 61853-1:2011, 7.2]

2.11 Solar Array Simulator

DC power supply that has I-V characteristics equivalent to a PV array.

2.12 Temperature Coefficient of V_{oc} (%/°C)

Temperature coefficient of the open-circuit voltage; quotient of change in open-circuit voltage of a cell or battery by the corresponding change in temperature. [SOURCE: IEC 60050:2004, 482-03-33]

2.13 Float Switch

Mechanism used for sensing water level. A float switch works by either opening or closing a circuit by the movement of some kind of instrument within, such as a metal ball, being lifted or dropped by water level.

2.14 Head (m)

The vertical distance fluid may be lifted by a pump from the surface of the source water to the delivery point. This metric is usually specified in meters. Note that during testing, head is simulated by controlling the pressure in the pump's outlet hose; pressure and head are directly correlated in relation to SWPs.

2.15 Normal Solar Irradiance (W/m^2)

Irradiance produced by direct sunlight on a surface on the Earth that is perpendicular to the direction of irradiation by the Sun
Note 1 to entry: Normal solar irradiance is not the same as direct solar irradiance, which is measured on a horizontal surface on the Earth, not necessarily perpendicular to the direction of irradiation by the Sun.
Note 2 to entry: The normal solar irradiance is expressed in watt per square metre (W/m^2).
[SOURCE: IEC 60050:2004, 845-29-134]

2.16 Hydraulic Power (W)

Power converted by a motor to the flow of a liquid over a vertical distance.

2.17 Hydraulic Energy (Wh)

Hydraulic power over time.

2.18 Wire to Water Efficiency (%)

Hydraulic power generated by a pump divided by the measured input power.

2.19 Simulated Solar Day (hr)

Function of solar irradiance (w/m^2) with respect to time used to simulate a typical day of solar charging. Details on each simulated solar day and their assumptions can be found in the Volume Moved over Three Different Solar Days Test Method (4.6).

2.20 Slew Rate (V/ms or A/ms)

Rate of change of an output per unit time.

2.21 Battery-integrated SWPs

Some SWP systems include integrated batteries. These pumps cannot be fully assessed using these current test methods. SWPs may include batteries to achieve one or more objectives, and the batteries may be integrated with the controller or the pump itself. For example, a battery may be used to support powering and/or charging additional appliances, eliminating issues with the pump’s cold start, or extending the time a pump is able to run by providing power to the pump at times when the solar resource is insufficient to meet the load. Because there are various designs and objectives for integrating a battery into a SWP system, testing requirements may vary from one system to the next and will differ in some respects from the test methods described in this document for non-battery integrated SWPs. As more battery-integrated SWPs become available for testing, validation work should be done to develop and assess test methods for common battery-integrated SWP designs.

3 Test Setup

3.1 Test Station Description and Layout

The test station design draws from *IEC 62253: 2011*.

A general layout of the test station can be seen in Figure *1*, and solar array simulator recommendations can be found in Table *1*. Note that Figure 1 depicts a submersible pumping system. The layout for a surface pumping system would be the same with the exception that the pump would be placed outside of the water tank.

In most cases, a solar array simulator must be used as a PV input for testing[1]. The test station used to evaluate the solar pump systems that informed development of these methods includes the *Chroma 62150H-600S-220V PV solar array simulator*, with the following specifications:

Table 1. Chroma 62150H-600S-220V Specifications

Accuracy	Voltage: 0.05% + 0.3 V Current: 0.1% + 0.025 A
<u>Programming Response Time</u> **Rise Time 50%F.S. CC* Load [ms]** **Fall Time: 50%F.S. CC* Load [ms]**	 30 100
Output Voltage [V]	0-600
Output Current [A]	0-25
Output Power [W]	15000
Voltage Slew Rate Range [V/ms]	0.001-20
Current Slew Rate Range [A/ms]	0.001-0.1
Minimum Transition Time [ms]	0.5

*CC is constant current

[1] Because many SWPs utilize MPPT controllers/ inverters when supplying power to the SWP, a solar array simulator must be used (as opposed to a DC power supply). The minimum specifications for a solar array simulator that would ensure the interaction between the controller/ inverter and the solar array simulator reflects what would be observed when using the SWP with its included or advertised PV array have not yet been established. In some cases, a cost-effective solution may not yet be available. Currently, this test method recommends testing with a solar array simulator that has a programming response time of no more than 30ms. However, in rare cases, some pumps may require a shorter response time and must be tested using the Alternative Test Method, which is described in this test method. It is recommended using nothing slower than the response times and slew rates listed in Table *1*.

It is assumed that over the normal operating range of the pump, the pressure drop due to frictional losses between the pump outlet and the pressure sensor will be negligible.

Any pressure sustaining device can be used such as a ball valve which creates back pressure by restricting flow.

The discharge pipe should be beneath the water surface to prevent splashing to prevent air bubbles from entering the pump inlet and affecting performance. If this setup is not possible, a vertical baffle shall be installed between the pump intake and the return pipe so that the water can pass under the baffle.

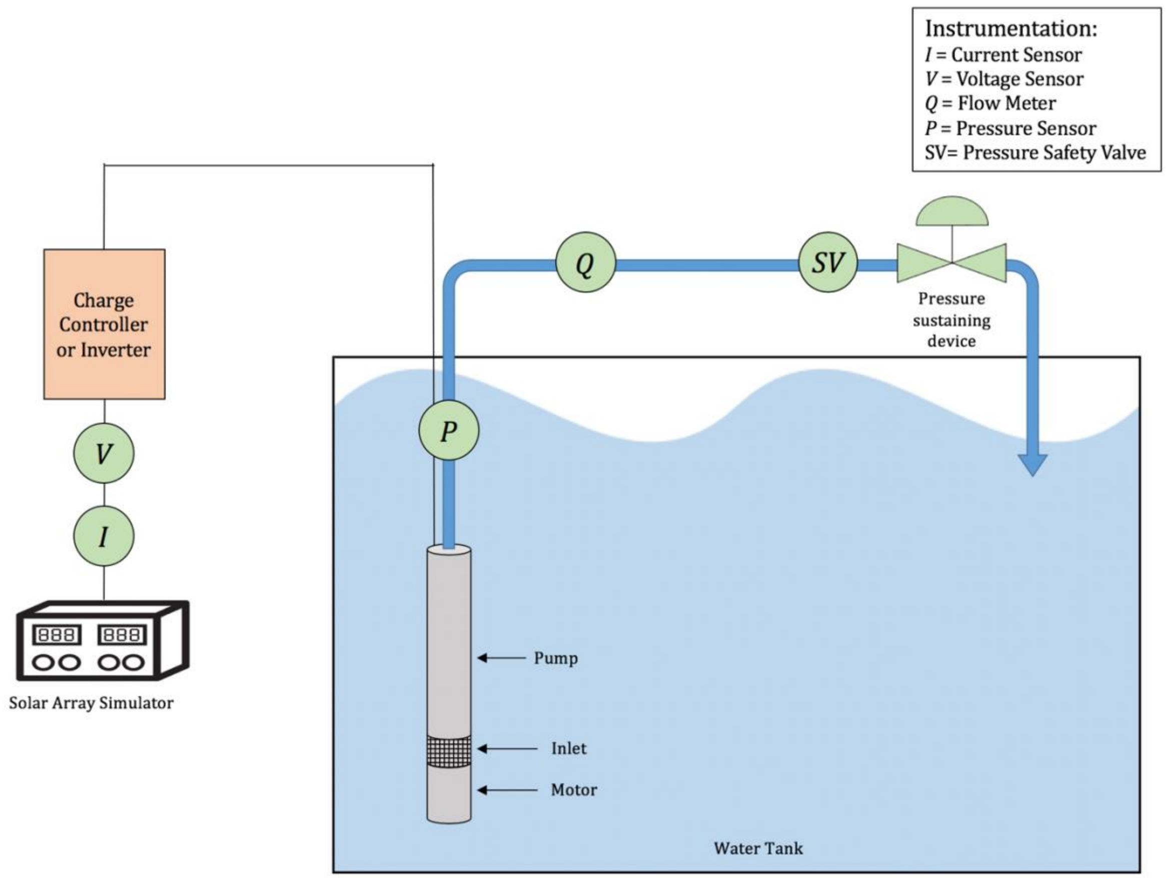

Figure 1. Test station diagram.

3.2 PV Array Simulation

This section details how to determine the power settings for the solar array simulators. All PV arrays are simulated at a 50° C cell temperature (to simulate the typical module operating temperature) by the solar array simulator during testing [2].

a) Procedure

i) Determine the recommended PV array size (W) and PV module material from the submitting entity. If the submitting entity does not specify the material, the PV modules are assumed to be polycrystalline PV modules.

ii) From the PV array size and manufacture/ company guidance, determine the STC V_{mp} and I_{mp} values of the array. For the Chroma solar array simulator software, the V_{mp} and I_{mp} are the required inputs to generate an IV curve used for testing.

iii) Unless the manufacturer/ company specifies a temperature coefficient, the temperature coefficients noted in section 4.1.5b will be used.

iv) For simulation purposes, the effect of temperature on the current is considered negligible. Therefore, when determining $I_{mp,50°C}$, the $I_{mp,STC}$ is equal to the $I_{mp,50°C}$.

v) To determine $V_{mp,50°C}$, use the following equation:

$$V_{mp,50°C} = V_{mp,STC}\left[1 + T_{C,Voc}(T - T_{STC})\right]$$

where

V_{stc} is the PV module's voltage at STC, in volts (V)

V_{mp} is the PV STC rated Vmp, in volts (V)

$T_{c,VOC}$ is the PV module's temperature coefficient for the voltage, per degree Celsius (1/°C)

T_{stc} is the cell temperature at STC, 25 °C

T is the simulated cell temperature, 50 °C

vi) Enter the $V_{mp,50°C}$ and PV power at 50° C into the solar array simulator software to generate an IV curve for the recommended PV array.

(1) For the *Chroma 62150H-600S-220V PV solar array simulator* it is recommended to use the Sandia PV Array Performance Model setting (from Annexes A1 and A2 of the Sandia Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems)

[2] It is standard for PV modules to be rated in Standard Operating Conditions (STC), which assumes a PV cell temperature of 25 degrees Celsius. Because most PV cell temperatures stabilize under the sun at temperatures closer to 50 degrees Celsius, this test method converts PV STC ratings to Typical Module Operating Temperature (TMOT) ratings at an assumed 50 degrees Celsius to use as an input during testing.

(2) After inputting the parameters into the software that comes with the solar array simulator, ensure that the V_{OC} and I_{sc} automatically calculated in the software do not exceed the maximum rated voltage and current. If the voltage or current inputs exceed the ratings, the controller/ inverter or pump could be damaged by even brief exposure to high voltage or current. Specifically, double-check input voltages before operating the pumping system.

4 Test procedures

4.1 Visual Screening

The purpose of this section is to guide the Visual Screening process. Each of the following subsections (4.1.1 through 4.1.7) correspond to physical components for a SWP apparatus/system. For each component, follow the provided guidance to describe and record each of the listed features in the test report. The information gathered here will also help inform the Qualitative Assessment. This procedure draws from *IEC 62257-9-5: 2018, Annex F: Visual Screening*.

1) **External Photographs**
   a) A photograph shall be taken of the entire system — the controller, pump component, PV module (if included), and all included items, such as the user manual, tubing, spare parts, etc. that have been received by the test lab. This photograph should be representative of what a consumer would expect to receive upon purchase. This photo shall be neatly laid out with either a grid or plain background. It is recommended to use a placard with identifying information such as the product model, company name, brand name and the date testing started.
   b) During the Visual Screening, additional individual photographs shall be taken of the exterior of the controller, pump component and any other included accessories, the PV module, the product packaging, and the user manual/ warranty card (if applicable). These photographs should capture each side of the components and accessories as well as any ratings or product information. Photos should be in color taken at close enough range that ratings and product information are legible when the photos are included in the test report. A more extensive, in-depth internal inspection shall be done once testing has been completed. Should any defects be noted, high-resolution photographs shall be taken that clearly show the defect, and the defect shall be documented in the test report. Note and document if there are any stickers on the controller that specify that the warranty is void if the product is opened, if applicable.
2) **General Information**
   For each SWP apparatus/system describe the following (if applicable):
   a) Company Information (Entity who provided the product for testing; can be the maker of the product, supplier, importer, distributor, reseller, etc.)
      i) Address
      ii) Phone number

   iii) Website
b) Manufacturer information (The manufacturer is the entity that manufactures the SWP apparatus/system. The manufacturer is the business who produces finished goods from raw materials.)
   i) Address
   ii) Phone number
   iii) Website
c) Brand Information (The brand name is the product brand name as listed on consumer-facing materials, such as product package, nameplate, or product specification sheet.) This information is only required if the brand name is different from the company name.
   i) Brand name
   ii) Address
   iii) Phone number
   iv) Website
d) Product name
e) Model number
   i) Some products do not have a model number
f) Sampling information for the samples received in the test lab
   i) Sampling information includes the serial numbers of the pump samples, PV modules, controllers, and any included components (accessories such as cables may not have serial numbers)

3) Pump component Screening

For each pump, record the following information and the source of the information. Sources of information can include: the user manual; product packaging; pump manufacturer, company, or other marketing entity website; markings or labels on the component itself; the pump specification sheet from the manufacturer or company; a measured value; characteristics observed during an inspection; or “other”. Note that if “other” is chosen for the test report, the tester must further describe what “other” means. Note in the test report if there are any discrepancies between any rated or measured/ observed values.

a) Pump category: submersible or surface
b) Pump type (*e.g*., centrifugal, helical rotor, positive displacement)
c) Motor type (*e.g*., brushed DC, brushless DC, AC)
d) Materials used for the pump housing
e) Ingress protection (IP) rating for pump body
f) IP certifications (if provided for the pump body)
g) Dimensions [length * width * height] (cm) rated and measured
h) Minimum voltage input (V)
i) Maximum voltage input (V)
j) Minimum current input (A)
k) Maximum current input (A)
l) Minimum power input (W)
m) Maximum power input (W)
n) Power rating (W)

o) Wire gauge of the pump cable (mm^2)
p) Rated maximum flow rate (m^3/h)
q) Rated head range (m)
r) Rated Hours of operation (h)
s) Rated Volume of water moved per day (m^3/day)
t) Type of pipe included
u) Length of pipe included (m)- rated and measured
v) Diameter of included pipe (cm)- rated and measured
w) Indicators (indicators are listed in the functionality section of the visual screening section of the test report)
x) Ports (if applicable)
   i) Port name
   ii) Receptacle type
   iii) Number of identical ports
   iv) Nominal port voltage (V)
   v) Is the port intended to be used for charging mobile devices?

4) Controller or Inverter Screening

For each controller or inverter record the following information (if applicable) and note the source of the information. As with the pump component, sources of information can include: the user manual; product packaging; website (manufacturer, company, or other marketing entity); markings or labels on the pump, controller, or inverter itself; the pump, controller, or inverter specification sheet from the manufacturer or company; a measured value; characteristics observed during an inspection; or "other". Note that if "other" is chosen for the test report, the tester must further describe what "other" means. Note in the test report if there are any discrepancies between any rated or measured/ observed values.

a) Inverter or controller (an AC pump would include an inverter; a DC pump would include a controller)
b) MPPT or PWM
c) Description: Integrated or separate (controllers/inverters can be integrated into the pump, or provided as separate components that are electrically connected to the pump during use)
d) Dimensions for separate controllers/inverters [length * width * height] (cm)-rated and measured
e) Minimum input voltage (V)
f) Maximum input voltage (V)
g) Maximum input current (A)
h) Minimum input power (A)
i) Maximum input power (W)
j) Rated Minimum wire gauge input (mm^2)
k) Rated Maximum wire gauge input (mm^2)
l) IP rating for controller/inverter body
m) Remote monitoring present?

n) Indicators (this is listed in the functionality section of the visual screening section of the test report)
o) Ports (if applicable)
   i) Port name
   ii) Receptacle type
   iii) Number of identical ports
   iv) Nominal port voltage
   v) Is the port intended to be used for charging mobile devices

5) PV Module Screening

PV modules are not required to be sampled or tested unless the Alternative Method for Testing Solar Water Pump Performance (test procedure 4.9.1 Alternative PV Array Simulation Method- Option 1 or 4.9.2 Alternative PV Array Simulation: Option 2) is carried out. Documentation including the required information listed below, however, must be provided for the PV module and PV array advertised or included in the system.

For each PV module included or advertised with the pump system, record the following information (if applicable), and note the source of the information. As with the pump components, sources of information can include: the user manual; product packaging; website (manufacturer, company, or other marketing entity); markings or labels on the PV module itself; the pump system or PV module specification sheet from the manufacturer or company; characteristics observed during an inspection; or “other”. Note that if “other” is chosen for the test report, the tester must further describe what “other” means. Note in the test report if there are any discrepancies between any rated or measured/ observed values.

a) Required Information
   i) Maximum power P_{mpp}
   ii) Open circuit voltage V_{oc}
   iii) Short-circuit current I_{sc}
   iv) Voltage at maximum power point V_{mpp}
   v) Current at maximum power point I_{mpp}
b) Optional Information
   i) Active solar material
   ii) Voc Temperature coefficient: (if not provided the following values will be used)
      (1) Monocrystalline silicon: -0.30%
      (2) Polycrystalline silicon: -0.33%
      (3) Copper indium gallium selenide: -0.26%
      (4) Cadmium telluride: -0.28%
   iii) Other listed certifications (*e.g.,* UL, CE, etc.)

6) User Manual Screening and Evaluation

a) Screening: Record if the following information is provided and note the source of the information. Sources of information can include: the user manual, product packaging, details on the component itself, website (manufacturer, company, or other marketing entity) or manufacturer or company provided documentation.

- i) PV operation
  - (1) do not damage the back of the PV module
    - (a) how to connect PV module to unit
  - (2) maximum distance between PV array and controller or pump
  - (3) face PV module surface toward the sun
- ii) Installation
  - (1) any required pre-use steps described (e.g., insert supplied fuse, if applicable)
  - (2) instructions on how to prime the pump before use (if applicable)
  - (3) instructions for how to make all wire terminations or connections (PV array, controller/ inverter, etc.)
  - (4) extension cable specifications
  - (5) install securely
  - (6) controller location requirements
  - (7) is professional installation by company that sells the system and/or trained technicians required (and if so, if technician training documentation or other detailed installation instructions are provided to professional installers)
  - (8) temperature restrictions for air temperature or source water temperature
  - (9) instructions regarding wire or cable connections (e.g., warnings to prevent shorting connections, directions on stripping the wires and instructions to securely screw down the wires
  - (10) dry run warnings
  - (11) other warnings
  - (12) minimum water level above the pump
  - (13) minimum distance between the bottom of borehole and intake of the pump (if applicable) (m)
  - (14) source water sediment-level requirements
  - (15) pump placement or orientation
  - (16) instructions on how to set up remote monitoring
- iii) Product operation
  - (1) display instructions if display is included
  - (2) warning not to cut or heat cable
  - (3) descriptions of error indicators and troubleshooting instructions

- iv) Maintenance
  - (1) warning to keep PV module surface clean
  - (2) specifications for components that may require replacement (*e.g.,* fuses, electrical connectors, PV)
  - (3) instructions for replacing components that may require replacement (*e.g.,* fuses, electrical connectors, PV)
  - (4) instructions for any necessary system maintenance
  - (5) disposal instructions

b) Evaluation: Determine a rating for the user manual using the following guidelines:

- i) Adequate

(1) A user manual which includes all of the following information is included with the product
   (a) Information is presented using language and graphics that can be understood by the typical consumer and is accurate for the product being evaluated
   (2) PV array input parameters (if the array is sold separately)
      (a) Maximum power P_{mpp}
      (b) Open circuit voltage V_{oc}
      (c) Short-circuit current I_{sc}
      (d) Voltage at maximum power point V_{mpp}
   (3) Maximum power input for the pump
   (4) Maximum power input for the controller
   (5) Installation and Maintenance instructions
      (a) Instructions for making all required connections (PV module, controller, pump)
      (b) Any pre-use steps necessary for proper function
      (c) minimum water level above the pump
      (d) minimum distance between the bottom of borehole and intake of the pump (if applicable) (m)
      (e) Instructions for necessary system maintenance

ii) Not Adequate
   (1) No user manual is provided with the product (inside or printed on the product packaging)
   (2) Any of the information for an “adequate” rating (above) is not included in the user manual

7) Warranty Screening and Evaluation

a) Screening: Record the following information and note the source of the information. Sources of information can include: the user manual, warranty card, product packaging, details on the component itself, website (manufacturer, company, or other marketing entity) or manufacturer or company provided documentation.
   i) if a warranty is included
   ii) duration of warranty
   iii) how to access warranty service
   iv) if the warranty is consumer-facing
   v) warranty source (i.e in the user manual, on the website, etc)
   vi) special warranty stipulations
   vii) other features

b) Evaluation: Determine a rating for the warranty using the following guidelines
   i) Adequate
      (1) A warranty is provided in the user manual, warranty card, product packaging, details on the component itself or on a product website and includes all the following information:
         (a) What is covered by the warranty
         (b) Length of the warranty
         (c) How to access the warranty

(d) The warranty expiration date is based on the date of purchase (i.e. does not have a fixed end date)

ii) Not Adequate
   (1) no warranty information is provided
   (2) Any of the criteria for an “adequate” rating (above) are not met

4.2 Qualitative Assessment- Overall Functionality, Workmanship and Safety

1) **Functionality**:
   a) Test and document the functionality of all buttons, ports, and indicators on all components before performance testing begins. Record the number of observations of each deficiency listed below for each of 2 samples:
      i) major functionality deficiency:
         (1) the pump or controller will not turn on
         (2) water does not flow when the pump is turned on
         (3) limited, intermittent or uneven flow
         (4) permanent, non-superficial damage that could cause the pump to malfunction in the future
         (5) Any functional deficiency that results in the pump ceasing to provide water flow while operating
      ii) minor functionality deficiency:
         (1) indicator light or display failing to work
         (2) a non-essential accessory (such as extension cable) or extra port not functioning
         (3) Any functional deficiency that is not severe enough to result in the pump no longer providing steady water flow when turned on.
   b) Determine and note the functionality rating using the following guidelines:
      i) Good: All of the following criteria are met
         (1) no minor or major functionality deficiencies observed
         (2) all samples being tested continued to function throughout normal use during testing without any hazards or safety issues.
      ii) Fair: All of the following criteria are met
         (1) no major deficiencies observed
         (2) 3 or less minor functionality deficiencies
         (3) all of the initially functional samples being tested continued to function throughout normal use during testing, without any hazards or safety issues
      iii) Poor: Any of the following are observed
         (1) one or more major functionality deficiencies
         (2) more than 3 minor functionality deficiencies
         (3) one or more initially functional samples being tested stopped functioning or developed any safety hazard under normal use during testing

2) Workmanship-External Inspection

a) Document the workmanship with comments and photographs. Record the number of observations of each deficiency listed below for each of 2 samples:
   i) loose or missing screws
   ii) bent, dented, or damaged metal or housing material
   iii) cracks or gaps in the casing that could allow water to contact moving parts
   iv) soldering: note any poor solder joints, such as cold joints or joints with insufficient or excess solder
   v) wiring: note any poor wiring, such as a pinched wire, disconnected or exposed wires

3) Workmanship-Internal Inspection

a) After the performance, durability and protection testing is done, one pumping system sample shall be opened, inspected, and photographed. If the drop test was performed, perform the internal inspection on the same sample that was drop tested.
b) Take photos of the wiring, the pump mechanisms (the impeller(s), rotor, etc.), the inside of the casing, the motor (bearing assembly, seal, shaft, etc.). The following shall be documented when applicable:
   i) Type of impeller (*e.g.,* open, closed, semi-closed, etc.)
   ii) Impeller material (if applicable)
   iii) Bearing information:
      (1) brand/ model
      (2) type of bearing (*e.g*., ceramic plate, deep-groove, angular contact, etc.)
      (3) number of bearings
      (4) if the bearings are sealed
      (5) material of any seals
   iv) Any undesired water inside of the enclosure, specifically within the motor enclosure; note if any moving parts of the pump or sensitive electronics are exposed to water
      (1) Note that there are some pumps designed to allow water in, with water-cooled motor designs, for example. Water inside of a pump's enclosure does not always indicate an issue. The pump's design will determine whether water in the enclosure is a problem. If needed, the company may be consulted to determine whether water ingress is included in a pump's design.
   v) Rust or corrosion
   vi) Wiring: note any poor wiring, such as a pinched wire, disconnected or exposed wires
c) Document the workmanship with comments and photographs. Record the number of observations of each deficiency listed in section 4.2.2 (External inspection) for the sample. Additionally comment and photograph any rust or undesired water in the enclosure.

4) **Overall Workmanship Rating**

a) Determine and note the workmanship rating using the following guidelines:
   i) Good: All of the following criteria are met
      (1) no workmanship deficiencies observed
      (2) no moving parts or sensitive electronics of the pump are exposed to undesired water within the enclosure
      (3) no rust observed

ii) Fair: Any of the following are observed
   (1) 1-3 workmanship deficiencies
   (2) only pinpoint spots of rust on non-moving parts (See Annex B for examples of rust)
iii) Poor: Any of the following are observed
   (1) more than 3 workmanship deficiencies
   (2) moving parts or sensitive electronics have been exposed to undesired water
   (3) significant rust or corrosion defined as:
      (a) pinpoint rust observed on moving parts
      (b) any surfaces have condensed spots or generalized rust (See Annex B for examples of rust)
      (c) any rust observed is likely to cause damage to the pump in the future. The tester will use their discretion to determine if the amount of rust observed likely to cause damage to the pump in the future

5) **Safety**
a) Document any safety hazards with comments and photographs. Record the number of observations of each safety deficiencies listed below for each of 2 samples:
   i) sharp edges or deformed metal: all accessible surfaces shall be smooth and free from sharp edges, burrs, etc., which may damage the cables or pose a risk of injury during intended use, handling, or maintenance.
   ii) bare conductors near each other that could come into contact
      (1) include bare conductors observed during external and internal inspection
   iii) oil observed on the exterior of the pump, pumping system packaging/ shipping materials before testing begins and oil leaking into the source water during testing (Note that oil leakage could lead to health and safety hazards in agricultural applications along with environmental hazards. Any leaking oil will need to be collected and disposed of properly.)
   iv) electrical conditions that could lead to fire
   v) any other situation that arises during testing which the tester deems unsafe
b) Determine the safety rating using the following guidelines:
   i) Good: All of the following criteria are met
      (1) no safety deficiencies observed
      (2) no safety hazards developed under normal use during testing
   ii) Poor: Any of the following are observed
      (1) one or more safety deficiencies
      (2) one or more samples developed one or more safety hazards under normal use during testing
      (3) leaking oil is observed
         (a) Note: leaking oil will leave a visible layer of oil atop the source water and may be observed on the pump exterior or on the packing materials. (See photo in Annex B). Some pumps are designed with oil internal to the motor. A small amount of oily residue on the exterior of the pump before testing could be visible in small amounts in the source water. Residual oil from manufacturing/ assembly shall not be counted as a safety hazard. The tester will use their

discretion to determine if oil is leaking from the pump or is residual from manufacturing.

4.3 Full Tank Test

This procedure determines if the pump can stop pumping water once its storage tank is full. This test will be performed only for pumps that advertise this feature and have provided the test lab with any required, additional mechanisms needed, if applicable. The test is conducted on one sample.

1) **Procedure**
   a) Simulate 0 m of head or as close to 0 m of head as possible with the testing station.
   b) Using the steps outlined in *3.2 PV Array Simulation* to determine the correct PV array, simulate 700 W/m^2 with the solar array simulator power supplies.
   c) Once the pump has turned on, wait five minutes for the pump to stabilize.
   d) After the five-minute waiting period, simulate a full tank scenario. For example, many water pumps utilize a float switch which signals to the pump to stop once it starts floating on top of water. For pumps with this mechanism, simulating a full tank situation can be achieved by setting the float switch in a small tank of water or simply turning the float switch in a position that is representative of what the float switch would experience when exposed to water.
   e) As soon as the full-tank scenario has been initiated, start a timer. Stop the timer once the pump has come to a complete stop. Run this test for up to two minutes, and if the pump continues to run after this waiting period, it is determined that the pump does not have any full-tank protection.
2) **Report**
   a) Simulated irradiance (W/m^2)
   b) Time elapsed until the for pump turns off (s)
   c) Description of how the pump stops

4.4 Cold Start Test

This procedure determines the minimum irradiance needed to start the pump and references *IEC 62253: Start-up power measurements (5.3.4).*

1) **Procedure**
   a) Using the steps outlined in *3.2PV Array Simulation* to determine the correct PV array.
   b) Simulate 0 m of head or as close to 0 m of head as possible with the testing station.
   c) Starting at 50 W/m^2, increase the irradiance by 50 W/m^2 increments until the pump starts and runs for two minutes without turning off. If the pump turns off, there is not enough power for the pump to run for a sustained period of time, and the next irradiance step must be tested. When the two-minute mark is met and the flowrate is greater than approximately 1 litre per minute, this is the minimum irradiance required to start the pump.
2) **Report**

a) Simulated irradiance (W/m^2)
b) Measured flow at minimum PV power (litres per minute)
c) Simulated head (m)

4.5 Head Range Test

This procedure determines the head range at which the pump can provide flow at a simulated irradiance of 700 w/m^2. This procedure references IEC 62253:2011 H-Q characterization (5.3.3).

1) Procedure

a) Using the steps outlined in *3.2 PV Array Simulation* to determine the correct PV array, simulate 700 W/m^2 with the solar array simulator. All measurements for this test will be taken at 700 W/m^2.
b) Simulate 0 m of head or as close to 0 m of head as possible with the testing station.
c) Once the pump has stabilized, average and record the PV voltage, PV current, head, and flow over a two-minute period.
d) Slowly ramp up the pressure until the pump can no longer provide flow. This pressure is the highest head value for the pump's head range.
e) Repeat Step *c* at 25%, 50%, and 75% of the maximum head value for a minimum of 5 measurements over the head range. Additional measurements are recommended.

2) Calculate

a) Wire-to-water efficiency (hydraulic power output divided by the PV power input) for each head tested:

$$\eta = \frac{\rho g H Q}{I V}$$

where

η	is the efficiency (%)
ρ	is density (kg/m^3)
g	is gravitational acceleration (m/s^2)
Q	is flow rate (l/s)
H	is head (m)
I	PV current (A)
V	PV voltage (V).

b) Maximum efficiency
   i) With a spreadsheet or program, use a non-linear minimization technique to minimize the sum of the squared residuals (SSR) between measured efficiency and simulated efficiency by altering the input variables.
   ii) From the resulting equation, calculate the efficiency in 0.1 m increments, and determine the maximum efficiency and resulting head.
c) Useful Operating Head Range
   i) With a spreadsheet or program, use a non-linear minimization technique to minimize the sum of the squared residuals (SSR) between measured flow and simulated head by altering the input variables.

ii) From the resulting equation, calculate the head where the flow rate is the minimum measured value (greater than 0).

3) Report

a) Simulated irradiance at maximum head (W/m^2)
b) Available PV power (W)
c) Measured PV power (W)
d) Simulated heads (m)
e) Measured flows (litres per minute)
f) Calculated wire to water efficiency (%)
g) Maximum wire to water efficiency (%)
h) H-Q graph (Figure *2*)
i) Maximum Head (Useful operating head range) (m)

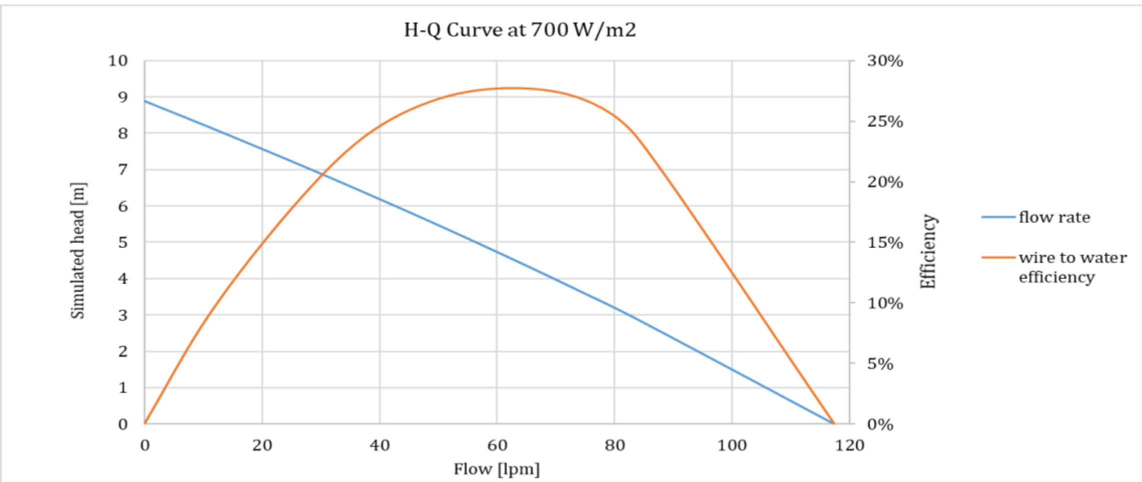

Figure 2. H-Q Curve

4.6 Volume Moved during Three Different Solar Days

This procedure determines the daily service rendered by the pump for a high irradiance, average irradiance, and low irradiance day. This procedure references *IEC 62253:2011 P-Q characterization (5.3.2)*.

1) Procedure

a) Use the steps outlined in *3.2 PV Array Simulation* to determine the correct PV array inputs.
b) Select the head value to use for this section based on the following:
   i) Use the head value specified by the manufacturer or the company submitting the pumping system for testing
   ii) If no head value is specified, the head at the maximum efficiency determined in the Head Range Test shall be used.

c) Ramp up the irradiance steps in 50 W/m^2 intervals until the pump is able to provide a stable flow at the requested head for two minutes without turning off.
d) As the irradiance is increased, the pressure sustaining device may need to be adjusted to maintain the requested head value.
e) Once the pump has stabilized, average and record PV voltage, PV current, head, and flow over a period of time that allows at least 10 data points to be collected.
f) Repeat the measurement procedure so that there are at least five measurements ranging from the lowest irradiance with flow to highest irradiance.
    i) At the 1000 W/m^2 step, increase the pressure of the test bench and note if the PV current increases as the test bench pressure increases. If it does not, then the Overcurrent Protection Test (4.8.4) does not need to be carried out. This will be specified in the test report.

2) Calculations

a) Irradiance versus flow curve
    i) With a spreadsheet or program, use a non-linear minimization technique to minimize the sum of the squared residuals (SSR) between measured flow and simulated flow by altering the input variables.
    ii) Graph this irradiance-flow curve based off of the equation determined in the previous step (Figure 3).

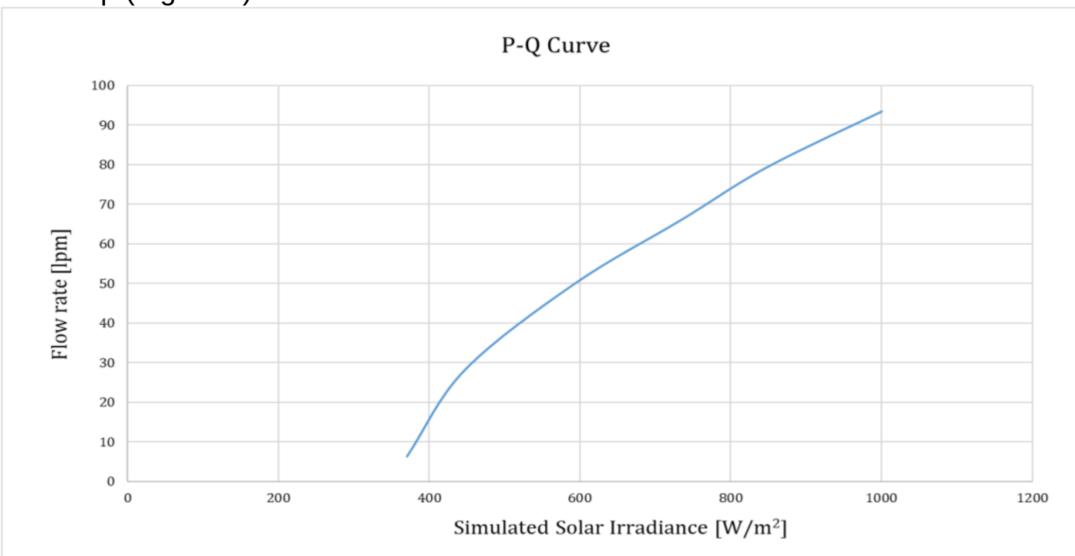

Figure 3. P-Q Curve

b) Different irradiance days
    i) In assessing the pump performance over a full day, three different solar days are used. The solar day equations and approximate day parameters are listed below:
        (1) *High* (max irradiance: 1000 W/m^2, 13.4 hours, 7.9 kWh)
            (a) $y = 0.2403x^4 - 6.7085x^3 + 37.457x^2 + 130.5x - 41.541$
        (2) *Average* (max irradiance: 700 W/m^2, 12 hours, 5 kWh)
            (a) $y = 0.2894x^4 – 6.9456x^3 + 32.65x^2 + 108.29x +0.06244$

(3) *Low* (max irradiance: 500 W/m^2, 9.5 hours, 2.6 kWh)
(a) $y = 0.3329x^4 - 7.9895x^3 + 42.12x^2 + 70.359x - 163.5$

ii) Calculations
(1) Using the equation for each solar day, create a spreadsheet that shows the irradiance for each minute over the solar day.
(2) Using the equation determined in irradiance-flow curve, calculate the flow for each minute over the solar day.
(3) Create a graph (Figure *4*) displaying both the irradiance over the day and flow rate over the day. Repeat this for each solar day.

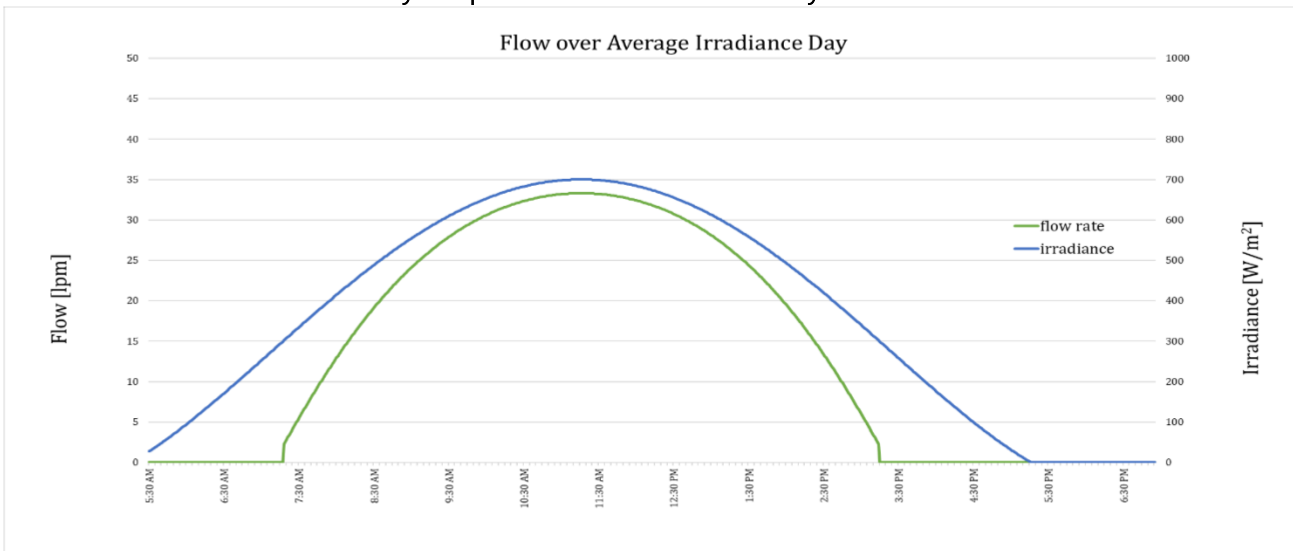

Figure 4. Flow over an average day

(4) Total volume moved (m^3/day)
(a) Add all of the water moved at each minute interval for each solar day and convert to m^3/day to calculate the total volume moved over each solar day.
(5) Hydraulic energy (Wh/day)
(a) Calculate the hydraulic energy at each minute interval and add this to determine the hydraulic energy for each solar day.

3) **Report**
a) For each simulated irradiance day
i) Flow (litres per minute) versus irradiance (W/m^2) graph
ii) Graphs irradiance (W/m^2), flow (litres per minute), time
iii) Total volume moved (m^3/day)
iv) Maximum flow (litres per minute)
v) Hours of operation (h)
vi) Hydraulic energy for each day (Wh/d)
vii) Average wire to water efficiency (%)

4.7 Durability Tests

These procedures reference IEC 62257-9-5:2018, Annex W. Note that there is equipment required to perform the durability tests that is not specified in this document. Please refer to IEC 62257-9-5:2018 for equipment specifications and accuracy requirements for this set of tests.

Also note that these procedures should be carried out after all performance tests have been completed and before the internal inspection has occurred. Additionally, these tests should be carried out on a different sample than the sample(s) used for performance testing and is only required to be conducted on one sample.

1) For all durability and protection tests use the description of safety hazards described in section 4.2.5 above.
2) For all durability and protection tests, functionality testing after each test can be conducted as follows:
   a) Turn the pumping system on in the same configuration used for performance testing (700 w/m^2 and 0 m head) and measure the flow. The power, voltage and current inputs for the functionality test should match the inputs determined in test procedure 3.2 (PV Array Simulation)
      i) The system is considered to function normally if the flow after the durability or protection test is within 10% of the flow measured during performance testing during the test procedure 4.5 (Head Range Test)
      ii) The system is considered non-functional if the pump does not provide flow within 10% of its previously measured performance or if any functional deficiency that results in the pump ceasing to provide water flow while operating is observed

4.7.1 Switches and connectors

1) **Procedure**
   a) Confirm each switch/button/port works prior to testing.
   b) Press each type of switch/button on the pump and/or charge controller (and/or inverter, if applicable) 1000 times, checking that the switch or button is functional after each round of 100 by confirming that the switch performs its intended function (powers on/ off; change modes, etc.). If the pump or controller has any ports, test the ports by inserting and removing the correct plug for each port 1000 times, checking for functionality of the port by confirming that it is able to power/ charge the intended load after each round of 100.
   c) Note, describe, and photograph and safety hazards or damages. See the description of safety hazards in section. As described in *IEC 62257-9-5:2018, Annex W*, superficial damage such as minor scrapes, “popped off” components that can easily be replaced and similar non-permanent, easily repairable damage will not be considered in the pass/ fail criteria. Permanent, non-superficial damages that cause the pump or controller to malfunction or could cause malfunctions in the future, such as exposed wires, grinding, overheating, cracks in the casing that could allow water to contact moving parts, loose or

missing screws that could results in future motor damage and similar should be reported and counted in the pass/fail criteria.

2) **Report**
   a) A description of what was tested (e.g., “The controller ON/OFF button”, “The PV input port on the controller”, etc.)
   b) Functionality of the switch/ button/ port after the test (yes/no)
   c) Permanent, non-superficial damage present after the test (yes/no, description)
   d) Safety hazard present after the test (yes/no, description)
   e) The number of cycles achieved for each switch or connector
   f) Overall results as follows:
      i) Pass: The system functions normally after the test with no safety hazards and no permanent, non-superficial damage observed
      ii) Fail: The system does not function normally after the test and/ or safety hazards or permanent, non-superficial damage is observed.

4.7.2 Cable Strain Relief

This procedure tests the durability of any permanently connected cable ends; this test shall be done for cables that are identified to meet this description. The cables to be tested include the input cables to the pump, any permanent cables for the controller and any applicable accessories or included appliances. This test does not apply to connectors; it applies only to those cables that are permanently attached on one or both ends. The procedure for this test is as follows:

1) **Procedure**
   a) Confirm the functionality of all cables prior to testing.
   b) Confirm that the clamp and weight have a combined mass equal to 2.000 kg, using either a calibrated scale or a reference calibrated weight
   c) Place the unit under test (pump, controller, etc.) on a strain relief angle apparatus (i.e., a setup that holds the cable in the correct angle relative to the direction from which the cable protrudes from the unit).
   d) Clamp the 2-kg weight on the cable under test so that there is cable on either side of the clamp. The clamp, attached to the cable, should be hanging freely at the specified angle. The following angles, relative to where the cable protrudes from the unit being tested, shall be tested: 0º, 45º, and 90º; each tested for 60 seconds with the hanging 2-kg weight/clamp configuration in place.
   e) Note, describe, and photograph any safety hazards or damages. See the description of safety hazards in section 4.2.5. As described in *IEC 62257-9-5:2018, Annex W*, superficial damage such as minor scrapes, “popped off” components that can easily be replaced and similar non-permanent, easily repairable damage will not be considered in the pass/ fail criteria. Permanent, non-superficial damages that cause the system to malfunction or could cause malfunctions in the future, such as exposed wires, cracks in the casing that could allow water to contact moving parts, loose or missing screws that

could results in future motor damage and similar should be reported and counted in the pass/fail criteria. See the internal inspection section for more information about evaluating water exposure.

f) After each angle is tested, check the unit for functionality following the guidance in section 4.7.2 Cable Strain Relief
g) Repeat this procedure for each unit/component that is required to undergo this test

2) Report

a) A description of each angle that was tested
b) Functionality after the test of each angle (yes/ no)
c) Permanent, non-superficial damage present after the test (yes/ no, description)
d) Safety hazard present after the test (yes/no, description)
e) Overall results as follows:
    i) Pass: The system functions normally after the test, with no safety hazards and no permanent, non-superficial damage observed
    ii) Fail: The system does not function normally after the test and/or safety hazards or permanent, non-superficial damage is observed

4.7.3 Drop Test

This procedure evaluates the pump's ability to withstand damage when dropped. This test is performed for all portable surface pumps and does not need to be performed on stationary and/or submersible pumps unless a pump is *advertised* to be portable. This test should be done after the other mechanical durability tests and on a sample with all packaging removed. Use a different sample than the sample that underwent performance testing. The sample that undergoes the drop test will undergo an internal inspection to specifically identify any damages and/or safety hazards caused by the drop test.

1) Procedure

a) Follow the procedure outlined in *IEC 62257-9-5:2018, Annex W* to perform this test on all portable surface pumps with the following additions/ changes:
    i) Test functionality after the pump is dropped on all sides, following the guidance in section 4.7.2 Cable Strain Relief. Note that functionality testing is only required if no safety hazards are identified or expected (tester's discretion).
    ii) Note, describe, and photograph any safety hazards or damages. See the description of safety hazards in section 4.2.5. As described in *IEC 62257-9-5:2018, Annex W*, superficial damage such as minor scrapes, "popped off" components that can easily be replaced and similar non-permanent, easily repairable damage will not be considered in the pass/ fail criteria. Permanent, non-superficial damages that cause the system to malfunction or could cause malfunctions in the future, such as exposed wires, cracks in the casing that could allow water to contact moving parts, loose or missing screws that could results in future motor damage and similar should be reported and counted in the pass/fail criteria. See the internal inspection section for more information about evaluating water exposure.

2) Report

a) If there are damages, description of the position of the pump when dropped (side facing the ground)
b) Functionality after the test (yes/ no)
c) Permanent, non-superficial damage present after the post test external and internal inspection (yes/no, description)
d) Safety hazard present after the post test internal and external inspection (yes/no, description)
e) Overall results as follows:
    iii) Pass: The system functions normally after the test, with no safety hazards and no permanent, non-superficial damage observed
    iv) Fail: The system does not function normally after the test and/or safety hazards or permanent, non-superficial damage is observed

4.8 Protection Tests

The following tests are done to determine whether or not the pumping system has protection if used or installed incorrectly. Do not start these tests until all performance testing has been completed, as damage may result in some of these tests. It is good practice to do these tests prior to starting the mechanical durability tests if the same sample will be used. These tests are required for one sample only.

4.8.1 Reverse Polarity

This procedure is to determine whether or not a pumping system will be damaged if any non-permanent electrical connections, such as the PV module or array leads, or output leads of an included controller/inverter are wired in reverse polarity. This test will only be done if miswiring is possible (i.e., if a connector can be plugged into the wrong port or attached to the wrong connector). Some examples of non-permanent connections include WAGO connectors, screw terminals, similar ports, terminal blocks, or other clips and connectors that can easily be connected/disconnected by the user.

1) **Procedure** (dependent on existing potential miswiring scenarios)
    a) The first possible scenario is a SWP that does not include a charge controller or inverter.
        i) With the power OFF, feed the positive power lead for the simulated PV power to the negative pump lead and the negative input power lead to the positive pump lead so as to mismatch the power leads when wiring up the pump.
        ii) This scenario is only to be tested if there are non-permanent connections that are made by the user or installer.
    b) A second possible scenario is a SWP that includes either a separate charge controller or inverter that is connected between the PV module and the pump.
        i) Feed the positive lead for the simulated PV power to the negative controller/ inverter lead and the negative input PV power lead to the positive controller/ inverter lead so as to mismatch the power leads when wiring up the inverter/ controller.
        ii) This scenario is to be tested if there are non-permanent connections that are made by the user or installer.

   c) A third scenario may be possible if the output leads of an included inverter/ controller can be wired directly to the pump in reverse polarity. This may be most commonly seen when the user must connect the pump to the inverter/ controller via screw terminals or terminals with clips.
      i) If this is the case, mismatch the pump leads going into the controller/ inverter. If there are more than two pump leads, then arbitrarily choose which two leads to mismatch for the test and specify this in the test report.
   d) Test any other scenarios, when relevant, where reverse polarity connections are possible.
   e) Once the system is wired, simulate an input power equivalent to 1000 W/m^2 for twenty minutes. Discontinue the test if any safety hazards are observed.
   f) Note, describe, and photograph the reverse polarity configuration.
   g) If the system functions (provides flow) when wired with reverse polarity, note the flow rate during the test.
   h) Note, describe, and photograph any safety hazards or damages. See the description of safety hazards in section 4.2.5 As described in *IEC 62257-9-5:2018, Annex W*, superficial damage such as minor scrapes, “popped off” components that can easily be replaced and similar non-permanent, easily repairable damage will not be considered in the pass/ fail criteria. Permanent, non-superficial damages that cause the system to malfunction or could cause malfunctions in the future, such as exposed wires, cracks in the casing that could allow water to contact moving parts, loose or missing screws that could results in future motor damage and similar should be reported and counted in the pass/fail criteria. See the internal inspection section for more information about evaluating water exposure.
   i) Note and describe any indication of a fault condition (warning light, error code, alarm)
   j) After testing all possible reverse polarity wiring scenarios, rewire the pump with normal polarity and test the functionality following the guidance in section 4.7.2 Cable Strain Relief.
2) **Report**
   a) Description of the reverse polarity scenario.
   b) Fault indication (yes/no, description)
   c) Safety hazard observed (yes/no, description)
   d) Permanent, non-superficial damages observed (yes/no, description)
   e) Functionality when the system is wired in reverse polarity (yes/no)
   f) Functionality when the system is wired with normal polarity after the test (yes/no)
   g) Overall result for sufficient protection against reverse polarity as follows:
      i) Pass: The system functions normally after the test, with no safety hazards and no permanent, non-superficial damage observed
      ii) Fail: The system does not function normally after the test and/or safety hazards or permanent, non-superficial damage is observed.

4.8.2 Dry Run Test

This procedure determines if the pumping system has protection against a low water level or dry well situation. If no guidance is provided by the submitting entity or if the system comes with a dry run sensor, perform the test below. However, some systems may have innovative dry run protection that will need to be assessed on a case-by-case basis.

1) Procedure

a) Simulate a 0 m of head or as close to 0 m of head as possible with the testing station.
b) Using the steps outlined in 3.2 PV Array Simulation to determine the correct PV array, simulate 700 W/m^2 with the solar array simulator power supplies.
c) Once the pump has turned on, wait for the pump to stabilize. The pump is considered to be stabilized if over a five-minute period, the flow rate is not fluctuating by more than 5%.
d) After the five-minute waiting period, simulate a dry well situation by either pulling the water level sensor out of the water, removing the intake hose from the water, or another method to achieve a dry well situation.
e) As soon as the dry well situation has been initiated, start a timer. Stop the timer once the pump has come to a complete stop.
    i) If a dry run protection period is advertised, run the test for the advertised time period. If the pump is still running at the end of the advertised time period or if any safety hazards are observed, turn the pump off manually.
    ii) If no dry run protection period is advertised, run this test for two minutes. If the pump is still running at the end of the two-minute time period or if any safety hazards are observed during the test, turn the pump off manually.
f) Note and describe how the pump stops and any indication of a fault condition (warning light, error code or audible alarm)
g) Note, describe, and photograph any safety hazards or damages. See the description of safety hazards in section 4.2.5. As described in *IEC 62257-9-5:2018, Annex W*, superficial damage such as minor scrapes, "popped off" components that can easily be replaced and similar non-permanent, easily repairable damage will not be considered in the pass/ fail criteria. Permanent, non-superficial damages that cause the system to malfunction or could cause malfunctions in the future, such as exposed wires, cracks in the casing that could allow water to contact moving parts, loose or missing screws that could results in future motor damage and similar should be reported and counted in the pass/fail criteria. See the internal inspection section for more information about evaluating water exposure.
h) Return the system to normal operating conditions (water sensor or intake hose returned to the water) and test the functionality of the system following the guidance in section 4.7.2 Cable Strain Relief

2) Report

a) Simulated irradiance (W/m^2)
b) Rated dry run protection time (s)
c) Time elapsed at dry run condition before pump turns off (s) or is manually turned off due to safety hazard
d) Fault indication (yes/ no, description)
e) Safety hazard observed (yes/no, description
f) Permanent, non-superficial damages observed (yes/ no, description)

g) Overall Results for sufficient protection from dry running as follows:
   i) Pass: All of the following criteria are met
      (1) the pump turns off within 2 minutes (or within the advertised dry run protection time if longer than 2 minutes)
      (2) no safety hazards observed during the test
      (3) no permanent, non-superficial damage observed during the test
      the system functions normally during post-test functionality testing

   ii) Fail: Any of the following are observed
      (1) the pump continues to run for longer than 2 minutes (or longer than the advertised dry run protection time if longer than 2 minutes)
      (2) safety hazards are observed during or after the test
      (3) permanent, non-superficial damage is observed during the test
      (4) the system does not function normally during post-test functionality testing

4.8.3 Overvoltage Protection Test

The voltage of a PV module or array can be significantly higher than the normal operating voltage range of a solar water pumping system. For example, if a user connects a PV module or array that has power parameters outside of the advertised range to a solar pumping system, this may create an overvoltage condition for the system. If not properly regulated, high voltage has the potential to cause damage to the pumping system. The overvoltage protection test assesses whether the pumping system has protection from an overvoltage condition and provides a mechanism for alerting the user to the fault condition.

1) Procedure

a) Determine the maximum rated input voltage for the solar pumping system. Use the highest voltage from the following possible sources:
   i) The max input voltage rating provided by the company submitting the pump for testing.
      (1) Note- if the company provided rating is lower than the rating from the other sources below, contact the company before testing to confirm that testing at a higher voltage will not be hazardous. If the company has a safety concern with testing at 110% of the voltage from the max rating below, conduct the test at 110% of the company provided voltage. See notes in section 4.8.3.2giii below for reporting the results from tests conducted at a voltage lower than 110% of the max rating due to company safety concerns.
   ii) The max input voltage rated on the controller (if included).
   iii) The max input voltage rating on the pump (if the system includes an internal controller or no controller).
   iv) The PV module V_{mp} rating provided by the company submitting the pump for testing.
   v) The PV module V_{mp} rating provided in the user manual or other consumer-facing materials provided with the pump.

b) Multiply the voltage determined in step 4.8.3.1a above by 1.05. This calculated value will be the voltage input programmed on the solar array simulator during this test.
c) Program the I-V curve in the solar array simulator to provide the same power determined in test procedure 3.2 (PV Array Simulation) for the 700 W/m^2 step for the pumping system. Use the voltage calculated in the step (b) above when setting the voltage input. Note that changing the voltage will also result in a change in the current limit for this I-V curve.
d) Turn on the solar array simulator and pumping system.
    i) If the pump does not provide flow at the first step (105% of the voltage determined in step 4.8.3.1a record details of any error codes, warning lights or alarms on the controller, whether any observable damage occurred, and whether any user safety hazard is present.
    ii) If the pump provides flow at 105% of the voltage determined in step 4.8.3.1a increase the voltage input in the solar array simulator by 5% (keep the total input power input the same) and repeat the test. Continue to increase the voltage in steps of 5% up to 110% of the value determined in in step 4.8.3.1a if the pump continues to function at each step.
    iii) If the pump stops providing flow before reaching 110% of the rated voltage, record the highest voltage input at which the pump continued to provide flow and the voltage of the step at which the pump stopped providing flow. If possible, report the measured voltage where the pump continued to provide flow and the measured voltage where the pump stopped providing flow.
    iv) If the pump continues to operate at 110% of the voltage rating, allow the pump to run for 10 minutes unless there is a safety hazard observed. Note in the report if the pump stops working within the 10-minute time frame.
e) Note and describe any indication of a fault condition (warning light, error code, alarm)
f) Note, describe, and photograph any safety hazards or damages. See the description of safety hazards in section 4.2.5 As described in *IEC 62257-9-5:2018, Annex W*, superficial damage such as minor scrapes, “popped off” components that can easily be replaced and similar non-permanent, easily repairable damage will not be considered in the pass/ fail criteria. Permanent, non-superficial damages that cause the system to malfunction or could cause malfunctions in the future, such as exposed wires, cracks in the casing that could allow water to contact moving parts, loose or missing screws that could results in future motor damage and similar should be reported and counted in the pass/fail criteria. See the internal inspection section for more information about evaluating water exposure.

g) If the system no longer functions, review the steps below, and then return to step 4.8.3.1d and resume testing, as applicable:
    i) If the problem can be identified and repaired by following instructions in the user documentation (e.g., replacing a blown fuse or resetting a tripped circuit breaker),

using no tools except a screwdriver used to remove and insert screws, without creating a safety hazard, repair the fault.

(1) Only spare parts included with the pumping system (or their equivalent, in case the supply of included spare parts is exhausted through repeated testing) may be used. (For example, if a fuse is blown, and the manufacturer did not supply replacement fuses, the pumping system does not have adequate protection from overvoltage.)

ii) If the pumping system is functional after the repair, and the repair can be conducted without exposing the person conducting the repair to a safety hazard, return to step 4.8.3.1d and continue testing.

iii) If the problem can be easily identified and repaired by the test laboratory, but requires steps not documented in the user documentation, tools other than a screwdriver used to remove and insert screws, or spare parts not included with the pumping system, the pumping system is considered to not have adequate protection from overvoltage. However, the test laboratory may, at its discretion, repair the fault and continue the test. (For example, if a replacement fuse is required, the test laboratory may replace the fuse, continue the test, and state in the report that the system does not have adequate overvoltage protection, but would be considered to have adequate overvoltage protection had spare fuses been included).

iv) Test the functionality of the system following the guidance in 4.7.2 Cable Strain Relief.

2) Report

a) Highest voltage input at which the pump continued to provide flow and the voltage of the step at which the pump stopped providing flow [V]

b) Functionality after the test (yes/ no)

c) Fault indication (yes/ no, description)

d) Permanent, non-superficial damage present after the test (yes/no, description)

e) Safety hazard present after the test (yes/no, description)

f) Repairs needed after the test (yes/ no, description)

g) Overall results for presence of sufficient overvoltage protection

i) Pass: All of the following criteria are met

(1) the system does not function or stops functioning during the test

(2) no safety hazards observed during the test

(3) no permanent, non-superficial damage observed during the test

(4) The system functions normally during post-test functionality testing

ii) Fail: Any of the following are observed

(1) the system develops safety hazards during the test

(2) the system develops permanent, non-superficial damage during the test

(3) The system does not function normally during post-test functionality testing

iii) Undetermined: Note that the system did not have protection at the overvoltage levels in this test procedure if either (1) or (2) were met
  (1) the system continues to function at the maximum (110% step) overvoltage condition for 10 minutes and
    (a) no safety hazards observed during the test
    (b) no permanent, non-superficial damage observed during the test
    (c) the system functions normally during post-test functionality testing
  (2) the pump was not tested using the highest rated value from in step 4.8.3.1a because of safety concerns from the company

4.8.4 Overcurrent Protection Test

The current of a PV module or array can be significantly higher than the maximum current a solar water pumping system is designed for. For example, if a user connects a PV module or array that has power parameters outside of the advertised range to a solar pumping system, this may create an overcurrent condition for the system. If not properly regulated, high current has the potential to cause damage to the system. The overcurrent protection test assesses whether the pumping system has protection from an overcurrent condition and provides a mechanism for alerting the user to the fault condition.

1) Procedure

a) Check the results from test procedure 4.6 (Volume Moved over Three Different Solar Days) to determine if the overcurrent test is required. If the current being drawn by the pumping system does not increase above the max rated current during the step of test procedure 4.6.1fi (increase the pressure to the system at the 1000 w/m^2/day irradiance step) the overcurrent protection test is not required. If the test is not required to be conducted, note in the overcurrent section of the test report that the system is considered to have overcurrent protection, because the system was not observed to have drawn the max current available while powered at the 1000 W/m^2 step during the solar day test *while* increasing pressure.

b) If the overcurrent test is required, determine the maximum rated input current for the solar pumping system. Use the highest value from the following sources:
  i) The max current provided by the company submitting the pump for testing.
    (1) Note- if the company provided rating is lower than the rating from the other sources below, contact the company before testing to confirm that testing at a higher current will not be hazardous. If the company has a safety concern with testing at 125% of the current from the max rating below, conduct the test at 125% of the company provided voltage. See notes in section 4.8.4.2vii3b below for reporting the results from this test.
  ii) The max input current rated on the controller (if included).

   iii) The max input current rating on the pump (if the system includes an internal controller or no controller)
   iv) The PV module I_{mp} rating provided by the company submitting the pump for testing
   v) The PV module I_{mp} rating provided in the user manual or other consumer-facing materials provided with the pumping system (note if this is the highest rating, before testing contact the manufacturer to clarify that the rating provided for the PV module is correct)

c) Program the I-V curve in the solar array simulator by calculating the PV power set point for the solar array simulator as follows:
   i) PV set point = (Current value determined in step 4.8.4.1b x 125%) x Voltage used in the 1000 W/m^2 step from test procedure 3.2(PV Array Simulation)
   ii) Ensure that the maximum current setpoint shown by the solar array simulator is equivalent to the identified maximum current from step 4.8.4.1b multiplied by 125%.

d) Turn on the solar array simulator and pumping system and set pressure to simulate 0 m of head (i.e. valves on test bench are 100% open)
   i) If the pump functions at that pressure, gradually increase the pressure (by closing the valves) to encourage the pumping system to draw more current. Monitor the current draw to make sure it doesn't exceed 125% of the max current determined in step 4.8.4.1b. Do not exceed this calculated current.
   ii) If the current does not increase as pressure is increased, it is not necessary to continue testing. If the current is oscillating between a higher and lower value, continue to test if the highest current measured continues to increase as the pressure is increased
   iii) If the flow decreases to zero or the pump turns off during the test, continue to provide power to the system for 30 seconds longer without adjusting the pressure before discontinuing the test. Discontinue the test immediately if any safety hazards are present
   iv) If the pump continues to provide flow and the pump is drawing 125% of the max current, allow the pump to run for 10 minutes. Discontinue the test immediately if any safety hazards are present

e) Record the highest current input at which the pump continues to provide flow and the current at which the pump stopped providing flow.

f) Record the current draw at which the pump stopped providing flow

g) Note and describe any indication of a fault condition (warning light, error code, alarm)

h) Note, describe, and photograph any safety hazards or damages. See the description of safety hazards in section 4.2.5. As described in *IEC 62257-9-5:2018, Annex W*, superficial damage such as minor scrapes, "popped off" components that can easily be replaced and similar non-permanent, easily repairable damage will not be considered in the pass/ fail criteria. Permanent, non-superficial damages that cause the system to malfunction or could cause malfunctions in the future, such as exposed wires, cracks in the casing that could allow water to contact moving parts, loose or missing screws that could results in future motor damage and similar should be reported and counted in the pass/fail criteria. See the internal inspection section for more information about evaluating water exposure.

i) If an overcurrent protection device operates, record the type of protection device, the tools required to reset it, and whether the user documentation (including the user's manual and any labels on the pump or controller) contains sufficient instructions to carry out the procedure. If the overcurrent protection device is a non-resettable fuse, record whether the system includes spare fuses. Include photos of the damages and repairs.

j) If the system no longer functions review the steps below and then, as applicable, return to step 4.8.4.1d and resume testing

- i) If the problem can be identified and repaired by following instructions in the user documentation (e.g., replacing a blown fuse or resetting a tripped circuit breaker), using no tools except a screwdriver used to remove and insert screws, without creating a safety hazard, repair the fault.
  - (1) Only spare parts included with the pumping system (or their equivalent in case the supply of included spare parts is exhausted through repeated testing) may be used. (For example, if a fuse is blown, and the manufacturer did not supply replacement fuses, the pumping system does not have adequate protection from overvoltage.)
- ii) If the pumping system is functional after the repair, and the repair can be conducted without exposing the person conducting the repair to a safety hazard, return to step 4.8.4.1d and continue testing.
- iii) If the problem can be easily identified and repaired by the test laboratory, but requires steps not documented in the user documentation, tools other than a screwdriver used to remove and insert screws, or spare parts not included with the pumping system, the pumping system is considered to not have adequate protection from overvoltage. However, the test laboratory may, at its discretion, repair the fault and continue the test. (For example, if a replacement fuse is required, the test laboratory may replace the fuse, continue the test, and state in the report that the system does not have adequate overvoltage protection, but would be considered to have adequate overvoltage protection had spare fuses been included).
- iv) Test the functionality of the system following the guidance in section 4.7.2

2) Report

a) Highest current input at which the pump continues to provide flow and the current of at which the pump stops providing flow [A]

b) Functionality after the test (yes/ no).

c) Fault indication (yes/ no, description)

d) Permanent, non-superficial damage present after the test (yes/no, description)

e) Safety hazard present after the test (yes/no, description)

f) Repairs needed after the test (yes/ no, description)

g) Overall results for presence of sufficient overcurrent protection
- i) Pass: All of the following criteria are met
  - (1) the system does not function or stops functioning during the test
  - (2) the system does not draw the max current available (125% rating from step 4.8.4.1b)
  - (3) no safety hazards observed during the test
  - (4) no permanent, non-superficial damage observed during the test
  - (5) The system functions normally during post-test functionality testing
- ii) Fail: Any of the following are observed
  - (1) the system develops safety hazards during the test
  - (2) the system develops permanent, non-superficial damage during the test
  - (3) the system does not function normally during post-test functionality testing
- iii) Undetermined: Note that the system did not have protection at the overvoltage levels in this test procedure if either (1) or (2) below were met
  - (1) the system continues to function at the maximum (125% rating from step 4.8.4.1b) overcurrent condition for 10 minutes and
    - (a) no safety hazards observed during the test
    - (b) no permanent, non-superficial damage observed during the test
    - (c) the system functions normally during post-test functionality testing
  - (2) the system was not tested using the highest rated value from step 4.8.4.1b because of safety concerns from the company.

4.9 Alternative Method for Testing Solar Water Pump Performance

This section provides two options for carrying out the Alternative Method for evaluating the performance of SWPs. The Alternative Method involves testing the SWP performance using an actual solar array as the power source instead of a solar array simulator. This approach may be used if there are interaction issues between the solar water pump controller/inverter and the solar array simulator. Interaction issues often arise when the response time of the solar array simulator is not fast enough to effectively communicate with the SWP controller/ inverter, which results in the SWP functioning in irregular and unexpected ways. SWP malfunctioning may be observed when the expected head cannot be achieved at specified power inputs, if the pump's flow rate is irregular or lower than expected, or if the pump cannot start normally or maintain operation. If the supplied I-V Curve can be seen in real time, one indication that there may be interaction issues occurring is if the power input algorithm is operating on the right-hand side of the I-V Curve maximum power point, which typically results in significant oscillations in input voltage. Generally, the pump's input power points should be shown in real time either to the left-hand side of the maximum power point on the I-V Curve or close to the maximum power point. If system malfunction is suspected during testing, the company that submitted the SWP for testing should be contacted, and use of the Alternative Method should be discussed. Option 1 or Option 2 of the Alternative Method may be used depending on the lab's resources and abilities. [3]

4.9.1 Alternative PV Array Simulation Method- Option 1

The following equipment/ conditions are required:

1) PV array stand / mounting rack that is adjustable, moveable, and can follow the sun throughout the day
2) Calibrated pyranometer
3) PV array that meets recommended specifications for the SWP (i.e. an array that operates within the recommended voltage and current limits for the system under test given the local solar resource conditions). Note that it may be difficult to achieve the exact recommended power inputs in every case, depending on the availability of PV modules and solar resource conditions at the site. In such cases, the array configuration that comes closest to generating the target voltage and current should be used.
4) Clear skies where the irradiance will reach 1000 W/m^2

The test set up is identical to normal testing except, instead of using the solar array simulator to power the system under test, an actual PV array (or module) will be the source of power (Figure *5*). Figure *5* depicts a submersible pumping system. The layout for a surface pumping system

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[3] Option 1 was validated using the Chroma solar array simulator for comparison of test results. It was found that, among the SWPs used for validation, this alternative method can be used in cases where the SWP controller/inverter and solar array simulator have poor interaction. Option 2 has not been validated yet, but this technique is expected to generate test results that do not differ significantly from those generated using Option 1. Option 2 should be chosen above Option 1 if the required resources for Option 1 are not available. Some observations and notes regarding the Alternative Method include the following:

- The two options within this Alternative Method do not always allow for the same data acquisition over time as a solar array simulator (such as the Chroma 62150H-600S-220V PV solar array simulator). A solar array simulator may consistently output a specified power until there are sufficient measured data points to analyze. The Alternative Method options are used in an environment that is much more difficult to regulate, and therefore yields single-measurement test data, as opposed to tens of data points. There is insufficient data to determine whether the Alternative Method options tend to show superior or inferior pump performance when compared to Chroma data. Validation tests indicate that the Alternative Method generally produces results that are less precise because it provides fewer data points.
    - Alternative Method Option 1 was validated using fewer than ten SWPs, and these pumps were not fully representative of the overall population of SWPs that may be tested using these methods. Once more SWPs have been tested and more validation work has been completed, a more complete assessment of the Alternative Method can be made.
    - The Alternative Method may not be feasible throughout the year in some testing locations due to weather conditions and sun-earth geometry. If the Alternative Method must be used to assess a SWP, there may be a delay in testing and providing test results.

would be the same with the exception that the pump would be placed outside of the water tank. Please note that the reporting and calculations for the standard test and the Alternative Method are the same. Alterations to the procedures are outlined below.

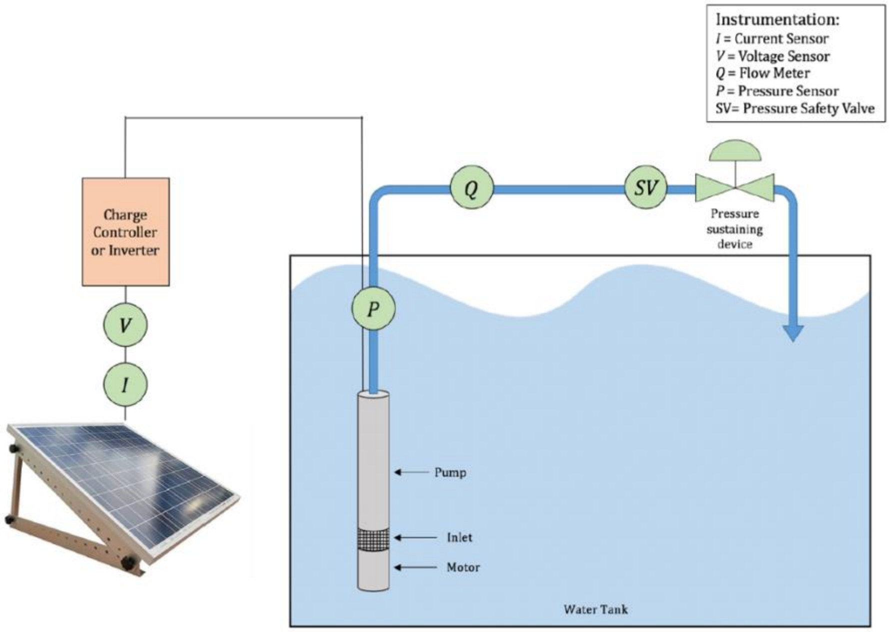

Figure 5. Alternative Test Set-Up

1) **Procedure:** Alternative PV Array Simulation: Option 1
   i) Instead of following steps *i to v* in section 3.2 *PV Array Simulation*, connect the actual PV modules sold with the system, or an array with equivalent wattage and the same configuration, to the system. Place the PV array on a PV stand / mounting rack so that each panel is on the same plane.
   ii) When performing the tests using this method, a pyranometer must be placed in the same plane as the PV array on the stand to determine the irradiance that the PV array is exposed to.
   iii) By slowly rotating the entire PV array and pyranometer on the stand, you can change the irradiance that the PV array is exposed to for each PV power input step.
   iv) Using this method requires at least two people. One person is operating the test station while the other person is monitoring the irradiance and adjusting the PV array stand accordingly.
   v) While following the stabilization and averaging in the normal test methods is recommended, because of quickly changing environmental conditions, point measurements without averaging are also acceptable for this method.
   vi) Note in the test report that Alternative PV Array Simulation- Option 1 was used for testing

a) Full tank test
   i) Follow the test procedure for 4.3 *Full Tank Test* except instead of using the solar simulator in step a and *b* to simulate the PV array, follow the *Alternative PV Array Simulation- Option 1* procedure to simulate 700 W/m^2.
b) Cold start
   i) Follow the test procedure for 4.4 *Cold Start Test*, except instead of using the solar simulator in step a and *b* to increase the irradiance in 50 W/m^2 increments, follow the *Alternative PV Array Simulation- Option 1* procedure to increase the irradiance in 50 W/m^2 increments.
c) Head Range
   i) Follow the test procedure for 4.5 *Head Range Test* except instead of using the solar simulator in step *a* and *b* to simulate the PV array, follow the *Alternative PV Array Simulation- Option 1* to simulate 700 W/m^2.
d) Volume Moved Per Solar Day
   i) Follow the test procedure 4.6 *Volume Moved over Three Different Solar Days* except instead of using the solar simulator in step *a* and *c* increase the irradiance in 50 W/m^2 increments, follow the *Alternative PV Array Simulation- Option 1* procedure to increase the irradiance in 50 W/m^2 increments.
e) Reverse Polarity
   i) Follow the test procedure for 4.8.1 *Reverse Polarity Test* procedure; however, ensure that the PV modules are covered and/ or out of the sun when wiring the pump and/ or controller/ inverter to not create a safety hazard.
f) Dry run Test
   i) Follow the test procedure for 4.8.2 *Dry Run Test* except instead of using Step *a* and *b* to simulate the PV array, follow the *Alternative PV Array Simulation- Option 1* to simulate 700 W/m$^{2.}$
g) All other tests use the same procedures as described in the normal test methods, except that they use the PV array.

4.9.2 Alternative PV Array Simulation: Option 2

The following equipment/ conditions are required:

1) PV array that meets recommended specifications for the SWP (i.e. an array that operates within the recommended voltage and current limits for the pumping system under test given the local solar resource conditions). Note that it may be difficult to achieve the exact recommended power inputs in every case, depending on the availability of PV modules and solar resource conditions at the site. In such cases, the array configuration that is able to come closest to generating the target voltage and current should be used
2) Slightly opaque plastic sheets, such as greenhouse plastic. These can be smaller than the PV modules themselves, as demonstrated in Figure 6, below.
3) A data acquisition system that measures and displays input power in real-time (this can be added to the data acquisition system that is already in-place for the standard test method).
4) A flat surface that is exposed to sun for a reasonable portion of the day (e.g. for at least 2 hours of sunlight per day)

5) Clear skies where the irradiance will reach 1000 W/m^2

Figure 6. Opaque plastic sheets covering sections of the PV module to control PV Power input during testing

1) Procedure: Alternative PV Array Simulation: Option 2[4]
   a) Instead of following steps *i to v* in test procedure 3.2 *PV Array Simulation*, connect the actual PV modules sold with the system, or an array with equivalent wattage and the same configuration, to the system.
   b) Wire the PV array and lay it flat on the ground facing the sun next to the test bench.
   c) Monitor the data acquisition screen as the PV module cells are evenly covered with the opaque material, until the target power is reached.
      i) The entire PV module isn't always covered. The plastic pieces are used to cover only enough of the module so that the power input is at the correct step for each test/step.

4.10 Photo Appendix

Include all photos of the pumping system (interior and exterior) and all components listed in the photos section of the Visual Screening. Any relevant photos taken during testing can be added to this section of the report.

[4] Note that *Alternative Method: Option 2* has not yet been validated. However, test results using this method on select SWPs produced data that were representative of expected, normal pump behavior. As more pumping systems are tested, more data can be collected, and this method can be validated using additional samples.

5 Annex A: Equipment

5.1 LAB Bench equipment list

A complete list of equipment used for testing can be found in the SWP-Test-Bench-Instruction-Manual-Feb-2023 published on the VeraSol website here: https://verasol.org/wp-content/uploads/import/SWP-Test-Bench-Instruction-Manual-Feb-2023.pdf

5.2 Instrument Accuracy Recommendations

Table 2. Instrument Accuracy Recommendations

Parameter	Unit	Accuracy
PV Voltage	V	≤ 2%
PV Current	A	≤ 2%
Pressure	psi	≤2%
Flow	litres per minute	≤ 2%

6 Annex B: Rust and Oil examples

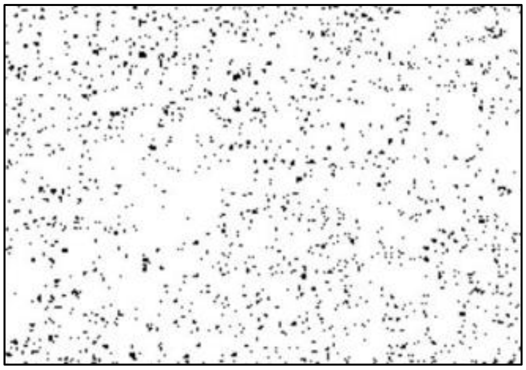

Figure 7. Pinpoint Rust

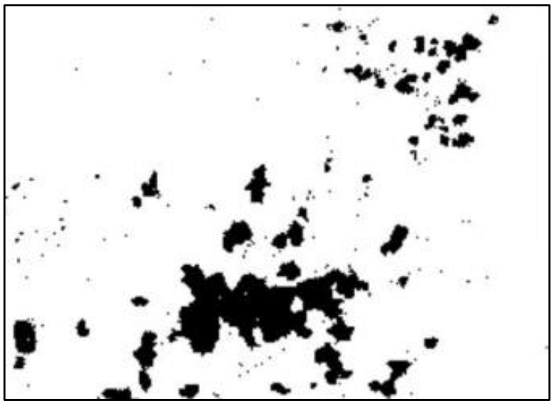

Figure 8. Condensed Rust

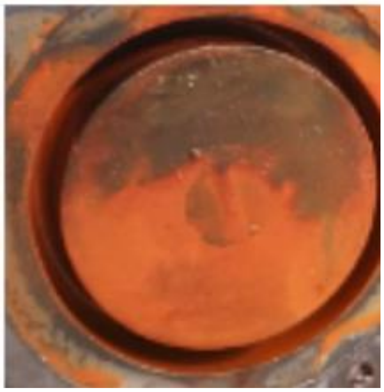

Figure 9. Generalized Rust

Figure 10. Leaking oil in source water

Figure 11. Leaking oil on product packaging