Global LEAP Solar Water Pump Test Method

Version 2

April 5, 2021

Context

This document includes test methods for evaluating small 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 11 additional SWPs, and several procedures were added after the competition had concluded. The additional methods draw from the outcomes of SWP durability research that were published in 2020 in 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.*

When developing this test method, the Schatz Center worked in close collaboration with CLASP as part of the Low Energy Inclusive Appliances (LEIA) program, which is a flagship program of the Efficiency for Access Coalition. Efficiency for Access is a global coalition that promotes energy efficiency as a potent catalyst in clean energy access efforts. Currently, Efficiency for Access Coalition members lead 12 programs and initiatives spanning three continents, 44 countries, and for 22 key technologies.

The Efficiency for Access Coalition is jointly coordinated by both CLASP, which is an international appliance energy efficiency and market development specialist, non-profit organization, and the UK's Energy Saving Trust, which specializes in energy efficient product verification, data and insight, advice, and research.

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1 Scope

This document defines methods to evaluate the quality, performance, and general durability of small-scale (less than 2 kilo-watts of power input required) off-grid solar water pumps (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 manufacturer 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

A pump whose motor powers its impellers to rotate, which forms a suction to move fluid.

2.2 Positive Displacement Pump

A pump that traps water in cavities and uses decreasing pressure on the discharge side and increasing pressure on the intake side to move fluid.

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.

2.4 Submersible Pump

A pump that is designed to be installed under the water source, such as in wells and boreholes. Since these pumps are submerged, they do not need to be primed before operating. Additionally, maximum suction lift limits do not apply to submersible pumps.

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 Power-width Modulation (PWM)

A charge controller algorithm that uses an electronic switch to control the input PV voltage to the controller through the use of quick on-off phase cycling to consistently accept the best voltage input available.

2.7 Inverter

A mechanism that transforms DC (direct current) into AC (alternating current).

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 PV Array

Multiple PV modules that are connected in parallel or series.

2.10 Standard Testing Conditions (STC)

Testing conditions for PV modules and is defined as a cell temperature of 25 °C at 1000 W/m^2 and an airmass of 1.5. This is a standard in the solar industry to compare PV modules to one another.

2.11 Solar Array Simulator

Power supply that simulates an I-V curve, which allows a SWP charge controller to operate anywhere along that curve based off of the charge controlling algorithm.

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

Quantifies the inverse relationship between temperature and voltage of a PV module, often given in %/°C.

2.13 Float Switch

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

2.14 Head (m)

The vertical distance water 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 Solar Irradiance (W/m^2)

Amount of solar power in watts available per m^2 of area at a given time.

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 Solar Day (hr)

Time over a day where there is solar irradiance above 0 W/m^2. Details on each simulated solar day and their assumptions can be found in the *Volume Moved over Three Different Solar Days Test Method*.

2.20 Testing Solar Irradiance

For the three defined solar days, the highest input power points used for the pump are based off of maximum irradiance points of 450 W/m^2 for a low irradiance day, 700W/m^2 for an average irradiance day, and 1000 W/m^2 for a high irradiance day. For most of the tests defined in this test method, a solar irradiance of 700 W/m^2 is used as the set point to determine input power.

2.21 Inrush Current (mA)

Directly after supplying a pump with input power, there may be a sudden electrical inflow current to the pump that is significantly greater than the rated pump current. This greater current is defined as inrush current and only occurs within the few first moments after power is supplied to the pump.

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

Defined as the rate of change in the voltage or current output over time. This term is used in the context of the solar array simulator function and parameters.

2.23 Program response time (ms)

This is similar to slew rate and may be understood as the time it takes for a solar array simulator to respond to a change in either output voltage or current.

2.24 Battery-integrated SWPs

Some SWP systems include integrated batteries. SWPs may include batteries to achieve one or more objectives. 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 procedures

3.1 Visual Screening

The purpose of this section is to guide the Visual Screening process. Each of the following sub-sections (§3.1.1 through 3.1.8) 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, and all included items, such as the user manual, that have been received by the test lab. This photograph should be representative of what a customer 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, manufacturer's 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 along with any included accessories, the PV module, the product packaging, and the user manual/ warranty card (if applicable). These photographs should capture each side of the pump and its accessories as well as any ratings or product information. Photos should be 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
      i. This is the branded entity on the product that will service any warranty-related issues. It could be the original manufacturer or an entity that rebrands a product manufactured by a different company.
   b) Manufacturer
      i. This is the entity that actually manufactures the SWP apparatus/system.

c) Submitting entity

    i. This is the entity that submitted the product to be tested and can be the company, manufacturer, or another entity like a distributor.

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

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 or other marketing entity website, markings or labels on the pump itself, responses entered in the Global LEAP nomination sheet, the pump specification sheet from the manufacturer, 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.

a) Pump category: submersible or surface
b) Pump type (*e.g.*, centrifugal, helical rotor, positive displacement)
c) Impeller material (if applicable)
d) Motor type (*e.g.*, brushed DC, brushless DC, AC)
e) Materials used for the pump housing
f) Ingress protection (IP) rating
g) IP certifications (if provided for the pump body)
h) Dimensions [length x width x height]
i) Minimum voltage input
j) Maximum voltage input
k) Minimum current input
l) Maximum current input
m) Inrush current
n) Minimum power input
o) Maximum power input
p) Power rating
q) Wire gauge of the pump cable
r) Maximum flow rate
s) Head range
t) Hours of operation
u) Volume of water moved per day
v) Type of pipe included
w) Length of pipe included
x) Diameter of included pipe
y) Indicators (indicators are listed in the functionality section of the visual screening section of the test report)

z) 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?

4) Controller or Inverter

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; the pump, controller, or inverter manufacturer or other marketing entity website; markings or labels on the pump, controller, or inverter itself; responses entered in the Global LEAP nomination sheet; the pump, controller or inverter specification sheet from the manufacturer; 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.

a) Inverter or controller (an AC pump would include an inverter; a DC pump would be equipped with 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 attached to the pump during use)
d) Dimensions for separate controllers/inverters [length x width x height]
e) Minimum input voltage
f) Maximum input voltage
g) Maximum input current
h) Minimum input power
i) Maximum input power
j) Minimum wire gauge input
k) Maximum wire gauge input
l) Type of conductor connection
m) IP rating
n) IP certifications (if provided)
o) Remote monitoring present?
p) Indicators (this is listed in the functionality section of the visual screening section of the test report)
q) Battery (if applicable)
   i. Chemistry
   ii. Pack type
   iii. Nominal voltage
   iv. Capacity [Ah]
   v. Overvoltage protection [V]
   vi. Low voltage disconnect [V]
   vii. Manufacturer
   viii. Safety or balancing circuit present?
   ix. Battery safety certifications
   x. Encasing material

r) 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?

Note that if the SWP system includes a Lithium battery, then battery safety certifications (specified in Table 1 below) must be submitted before any testing begins on the battery itself. As listed above, there is a section in the Visual Screening portion of the test report where battery safety certifications are recorded.

Table 1 summarizes the battery safety certifications required for all included Lithium batteries. These safety certifications shall be submitted with the other product information prior to testing. These requirements are consistent with *IEC TS 62257-9-8:2020.*

Table 1. Lithium battery required information and certifications. These requirements are consistent with *IEC TS 62257-9-8:2020.*

Lithium Battery Documentation	Provide documentation that the battery meets **ONE** of the following: IEC 62281; or IEC 62133-2; or UL 1642; or UN 38.3	IEC 62281, IEC 62133-2, UL 1642 and UN 38.3 are safety standards related to transport / shipping of lithium batteries. The submitted documentation must cover the battery pack that is included in the product. Documentation is required for all lithium batteries included with the product, including batteries in components and included appliances if applicable.
Lithium Battery Usage Safety Certification Documentation - Full Battery pack AND Individual Cell (Required for IEC TS 62257-9-8:2020)	For lithium batteries used in **stationary application**s, provide documentation that the battery meets **ONE** of the following documents or combinations: • IEC 62133-2; or • UL 62133; or • BOTH UL 1642 AND UL2054; or • BOTH UN 38.3 AND IEC 62619; or • BOTH IEC 62281 AND IEC 62619; or • BOTH UN 38.3 AND UL 1973; or • BOTH IEC 62281 AND UL 1973 For lithium batteries used in a **component with a mass > 18 kg**, provide documentation that the battery meets **ONE** of the following documents: • IEC 61629; or • UL 1973	Documentation must be submitted for all batteries in the product, including all components and included appliances with batteries if applicable. The battery test reports must be issued from an ISO 17025 accredited laboratory and must cover both the individual cell and the fully assembled battery pack.

Lithium Battery Individual Cell Protection Documentation	Provide **ONE** of the following: • A written description of individual cell protection measures; or • A battery test report or specification sheet that clearly describes individual cell protection. Indicate where in the document that the description is located.	Any product that includes lithium batteries must have battery protection that ensures individual cells (or sets of parallel-connected cells) are maintained within safe voltage limits.

5) PV Module

For each PV module included 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; the pump or PV module manufacturer or other marketing entity website; markings or labels on the PV module itself; responses entered in the Global LEAP nomination sheet; the pump system or PV module specification sheet from the manufacturer; 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.

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}
e) Current at maximum power point I_{mpp}
f) Temperature coefficient
g) Active cell area (in cm^2)
h) Dimensions [length x width x height]
i) Cable length
j) Outdoor cable rating/certifications
k) Active solar material
l) Encasing material
m) Other listed certifications (*e.g.,* UL, CE, etc.)

6) Documentation

Record the following as it is provided on the included documentation:

a) Company information
   i. Address
   ii. Phone number
   iii. Website
b) Manufacturer information
   i. Address
   ii. Phone number
   iii. Website
c) Submitting Entity Information

i. Address
ii. Phone number
iii. Website

d) Operation manual provided?
e) Operation manual languages
f) Any warning labels?
g) Any certifications listed?

7) User or Operation Manual

Review the user or operation manual for the following information, and record whether or not the information included:

a) PV operation

i. do not damage the back of the PV module
ii. how to connect PV module to unit
iii. maximum distance between PV array and controller or pump
iv. face PV module surface toward the sun

b) Installation

i. any required pre-use steps described (*e.g.*, fully charge battery, insert supplied fuse, if applicable)
ii. instructions on how to prime the pump before use (if applicable)
iii. instructions for wire termination or connection during installation
iv. how to make all required permanent connections
v. keep away from fire
vi. install securely
vii. controller location requirements
viii. is professional installation by company that sells the DUT and/or trained technicians required (and if so, if technician training documentation or other detailed installation instructions are provided to professional installers)
ix. temperature restrictions
x. 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
xi. dry run warnings
xii. other warnings
xiii. minimum water level above the pump
xiv. minimum water level above the bottom of the borehole
xv. liquid requirements
xvi. pump placement or orientation
xvii. instructions on how to set up remote monitoring

c) Product operation

i. how to connect all advertised appliances
ii. battery state-of-charge instructions
iii. display instructions, if display is included

iv. warning not to cut or heat cable

d) Maintenance
   i. warning to keep PV module surface clean
   ii. specifications for components that may require replacement (*e.g.,* fuses, lights, PV, batteries)
   iii. instructions for replacing components that may require replacement (*e.g.,* fuses, lights, PV, batteries)
   iv. instructions for any necessary system maintenance
   v. battery state-of-charge directions for long-term storage
   vi. disposal instructions

8) Warranty

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, or manufacturer provided documentation.

1. if a warranty is included
2. duration of warranty
3. how to access warranty service
4. if the warranty is consumer-facing
5. warranty source
6. special warranty stipulations
7. other features

3.2 Qualitative Assessment

Provide a rating (good, satisfactory, needs improvement, poor) for the following categories:

a) Overall Visual Screening
   i. Test the functionality of all buttons, ports, and indicators on all components
   ii. Note any safety, functionality, or workmanship deficiencies
   iii. Rating scale:
      1. Good – No workmanship or functionality deficiencies were observed.
      2. Satisfactory – Small or insignificant workmanship deficiencies were observed such as slight scratches, very few missing screws/ adhesives, or small deformities, but these issues did not affect functionality of the product.
      3. Needs improvement – Many workmanship issues were observed such as deep or substantial scratches or numerous missing screws that either did not affect the overall functionality of the product or resulted in minor functionality issues, or minor functionality issues were observed such as broken indicator lights.
      4. Poor – Many or significant workmanship issues were observed that affected the overall functionality of the product or may contribute to significant safety hazards.

b) Overall Safety

  i. Note any external safety deficiencies.

  ii. Rating scale:
     1. Good – No safety deficiencies were observed.
     2. Satisfactory – One or two deficiencies such as sharp edges or deformed metal that could injure a user were observed.
     3. Needs improvement – Many small safety deficiencies such as sharp edges or deformed metal that could injure a user were observed.
     4. Poor – Serious safety issues, such as exposed wires, that could severely injure a user were observed.

c) Internal Inspection

  i. After the testing is done, the pump shall be opened up and inspected, and photographs shall be taken of the interior parts. Parts to be photographed include any wiring, the impeller(s), the inside of the casing, the motor (bearing assembly, seal, shaft, etc.). The following shall be documented when applicable:
     1. Type of impeller (*e.g.,* open, closed, semi-closed, etc.)
     2. 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
     3. Materials of any seals noted
     4. If there is any undesired water inside of the enclosure; if so, are any moving parts of the pump exposed?
        1. Note that there are some pumps are 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 manufacturer may be consulted with to determine whether or not water ingress is included in a pump's design.
     5. Rust or corrosion
     6. Wire connection: are there any exposed and/or disconnected wires after testing.

  ii. Note any safety, functionality, or workmanship deficiencies

  iii. Rating scale:
     1. Good – No deficiencies were observed, and none of the moving parts or sensitive electronics of the pump are exposed to undesired water within the enclosure.
     2. Satisfactory – One or two small/ insignificant workmanship deficiencies were observed such as missing screws or small deformities that do not affect

functionality of the product, and none of the moving parts or sensitive electronics of the pump are exposed to undesired water within the enclosure.

3. Needs improvement – Many small workmanship deficiencies were observed such as multiple missing screws or deformities that do not affect functionality of the product. Or small amounts of rust were observed that may affect the long-term functionality of the product. Some of the moving parts in the pump are exposed to undesired water that affects the performance of the pump but does not make the pump fail to function.

4. Poor – Many or significant issues such as large amounts of rust or loose wires were observed that affected the overall functionality of the product or pose safety concerns. One or more of the moving parts in the pump and/ or sensitive electronics have been exposed to undesired water and have significant rust and/ or effect on the pump's function.

d) User Manual

i. Note any deficiencies
ii. Rating scale:
1. Good – All the necessary information is clearly provided so that the consumer can set up and use the product based on the provided information.
2. Satisfactory – Some information may reference older products or other information may be missing or confusing, but the consumer can set up the product based on the provided information.
3. Needs improvement – Additional information is required in order for a consumer to set up and use the product.
4. Poor – There is no user manual, or the user manual provided references a completely different product.

e) Warranty

i. Note any deficiencies
ii. Rating scale:
1. Good – The warranty includes what is covered by the warranty, the length of the warranty, and how to access the warranty. The warranty does not specify a hard expiration date.
2. Satisfactory – The warranty includes what is covered by the warranty and the length of the warranty, but does not explain how to access the warranty.
3. Needs improvement – A warranty is provided, but there is conflicting information on what is covered by the warranty, the length of the warranty, or how to access the warranty. The warranty might specify a length of time from a static date or have a hard expiration date instead of the date of purchase. Or the warranty is not consumer-facing.
4. Poor – There is no warranty information provided.

3.3 Test Station Description and Layout

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

a) A general layout of the test station can be seen in Figure 1, and accuracy recommendations can be found in Instrument Accuracy Recommendations

b) **Table 3**.

c) 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 recommended or included PV module have not yet been established. In some cases, a cost-effective solution may not yet be available. At the time of publication, we are recommending testing with a solar array simulator that has a programming response time of no more than 30 milliseconds. However, some pumps require shorter response times and must be tested using the *Alternative Test Method*, which is described later in this document. We recommend using nothing slower than the programming response times and slew rates listed in Table 2. 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 2. Chroma 62150H-600S-220V Specifications

Accuracy	0.1% + 0.1%F.S.*
Programming Response Time	
Rise Time 50%F.S. CC Load [ms]**	30
Fall Time: 50%F.S. CC Load [ms]	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 [V/ms]	0.001-0.1
Minimum Transition Time [ms]	0.5

*F.S. is full-scale
**CC is constant current

d) 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.

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

f) 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

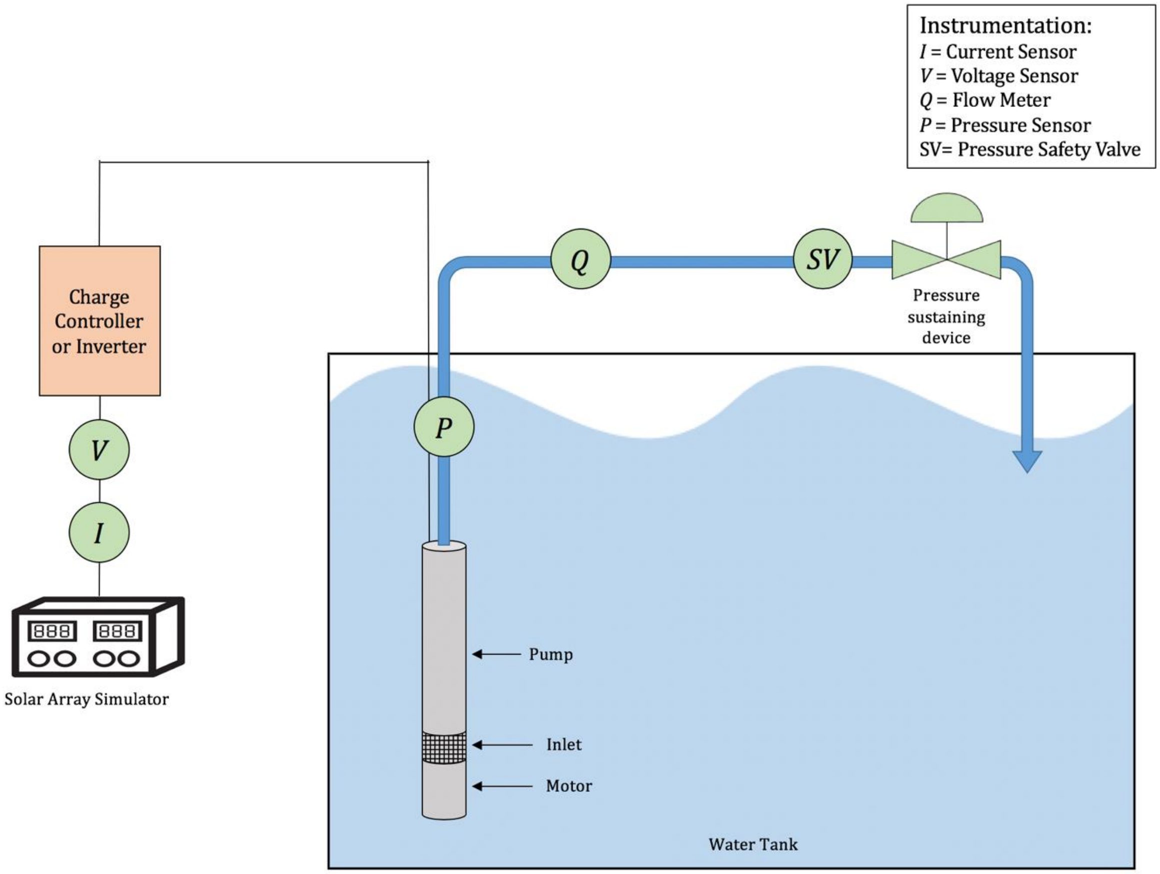

Figure 1: Test station diagram

3.4 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 by the solar array simulator during testing.

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 manufacturer guidance, determine the STC V_{mp} and I_{mp} values of the array. For many the 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 specifies a temperature coefficient, -0.43 %/°C is used for monocrystalline PV modules, and -0.35 %/°C is used for polycrystalline PV modules.
   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.

The $V_{mp,50°C}$ and PV power at 50° C are then entered into the solar array simulator software to generate an IV curve for the recommended PV array. 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 pump.

3.5 Full Tank Test

This procedure determines if the pump has the ability to stop pumping water once its storage tank is full. This test will be performed for pumps that advertise this ability and have provided the test lab with any required, additional mechanisms needed, if applicable.

a) Procedure

i. Simulate 0 m of head or as close to 0 m of head as possible with the testing station.
ii. Using the steps outlined in *3.4 PV Array Simulation* to determine the correct PV array, simulate 700 W/m2 with the solar array simulator power supplies.
iii. Once the pump has turned on, wait five minutes for the pump to stabilize.
iv. 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.
v. As soon as the full-tank situation has been initiated, start a timer and 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 determined that the pump does not have any full-tank protection.

b) Report

i. Simulated irradiance (W/m^2)
ii. Time taken for pump to turn off (s)
iii. Description of how the pump stops

3.6 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).*

a) Procedure

i. Using the steps outlined in *3.4 PV Array Simulation* to determine the correct PV array.
ii. Simulate 0 m of head or as close to 0 m of head as possible with the testing station.
iii. 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 step must be tested. When the two-minute mark is met and the flowrate is greater than approximately 1 lpm, this is the minimum irradiance required to start the pump.
iv. Simulate the cold start irradiance determined in step iii. Connect a clamp meter capable of measuring inrush current to one of the input leads from the charge controller/ inverter to the pump to measure this value.

b) Report

i. Simulated irradiance (W/m^2)
ii. Measured flow at minimum PV power (lpm)
iii. Simulated head (m)
iv. Inrush current to the pump (mA)

3.7 Head Range Test

This procedure references *IEC 62253: H-Q characterization (5.3.3)*.

a) Procedure

i. Using the steps outlined in *3.4 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.
ii. Simulate 0 m of head or as close to 0 m of head as possible with the testing station.
iii. Once the pump has stabilized, average and record the PV voltage, PV current, head, and flow over a two-minute period.
iv. Slowly ramp up the pressure until the pump can no longer provide flow. This is pressure is the highest head value for the pump's head range.
v. Repeat Step *iii* at 25%, 50%, and 75% of the maximum head value for a minimum of 5 number of measurements over the head range. Additional measurements are recommended.

b) Calculate

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

$$\eta = \frac{\rho g H Q}{IV}$$

where

η is the efficiency (%);
ρ is density (kg/m^3);
G is gravity (m/s^2)
Q is flow (l/s);
H is head (m);
I PV current (I);
V PV voltage (V).

ii. Maximum efficiency
   1. 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.
   2. From the resulting equation, calculate the efficiency in 0.1 m increments, and determine the maximum efficiency and resulting head.

iii. Useful Operating Head Range

This calculation is only performed for surface pumps.

   1. 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.
   2. From the resulting equation, calculate the head where the flow rate is 50% of the maximum flow rate.

c) Report

i. Simulated irradiance (W/m^2)
ii. Measured PV power (W)
iii. Simulated heads (m)
iv. Measured flows (lpm)
v. Calculated efficiency (%)
vi. Maximum efficiency (%)
vii. H-Q graph (Figure 2)
viii. Useful operating head range (surface pumps only)

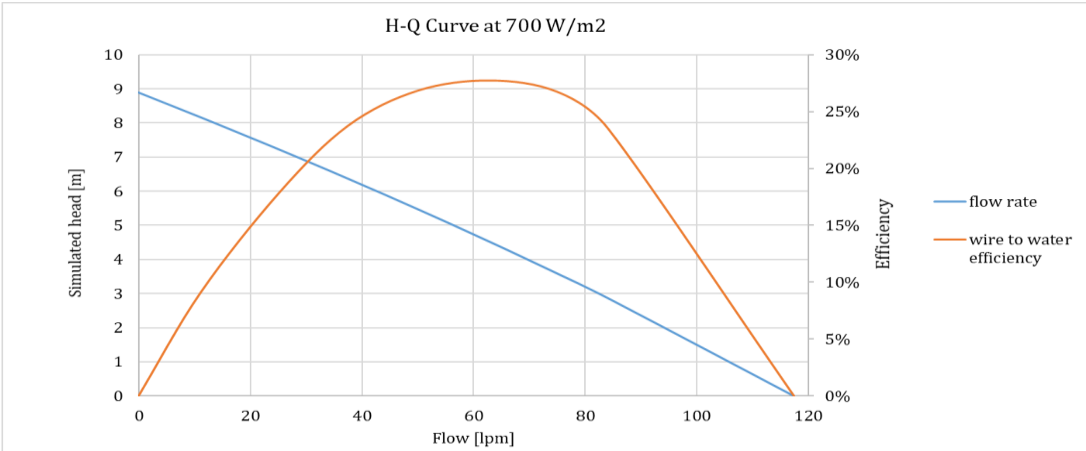

Figure 2: H-Q Curve

3.8 Volume Moved over Three Different Solar Days

This procedure references *IEC 62253: P-Q characterization (5.3.2)*.

a) Procedure

i. Use the steps outlined in *3.4 PV Array Simulation* to determine the correct PV array inputs.

ii. Which head value to use for this section is dependent on how these test methods are being used evaluate a product:

1. If this evaluation is for a competition, the head value should be determined by the administrators running the program in conjunction with the entity submitting the product for testing.
2. If this is a private evaluation, the head value should be determined by the manufacturer or the entity submitting the product for testing.
3. If this is a randomly selected product from the market, this head value should be determined by how it's advertised use in that market.

iii. Ramp up the irradiance steps in 50 W/m2 intervals until the pump is able to provide a stable flow at the requested head for two minutes without tripping.

iv. As the irradiance is increased, the pressure sustaining device may need to be adjusted to maintain the requested head value.

v. Once the pump has stabilized, average and record PV voltage, PV current, head, and flow over a two-minute period.

vi. Repeat the measurement procedure so that there are least five measurements ranging from the lowest irradiance with flow to highest irradiance.

b) Calculations

i. Irradiance versus flow curve

1. 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.

2. Graph this irradiance-flow curve based off of the equation determined in the previous step (Figure 3).

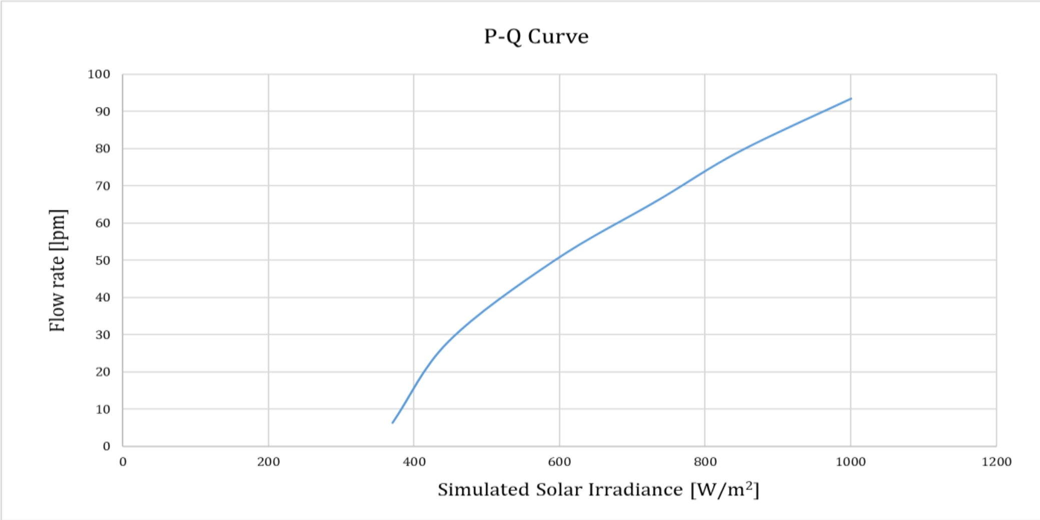

Figure 3: P-Q Curve

ii. Different irradiance days

1. 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:
   a. High (max irradiance: 1000 W/m^2, 13.4 hours, 7.9 kWh)
      i. $y = 0.2403x^4 - 6.7085x^3 + 37.457x^2 + 130.5x - 41.541$
   b. Average (max irradiance: 700 W/m^2, 12 hours, 5 kWh)
      i. $y = 0.2894x^4 – 6.9456x^3 + 32.65x^2 + 108.29x +0.06244$
   c. Low (max irradiance: 500 W/m^2, 9.5 hours, 2.6 kWh)
      i. $y = 0.3329x^4 - 7.9895x^3 + 42.12x^2 + 70.359x - 163.5$

iii. 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.

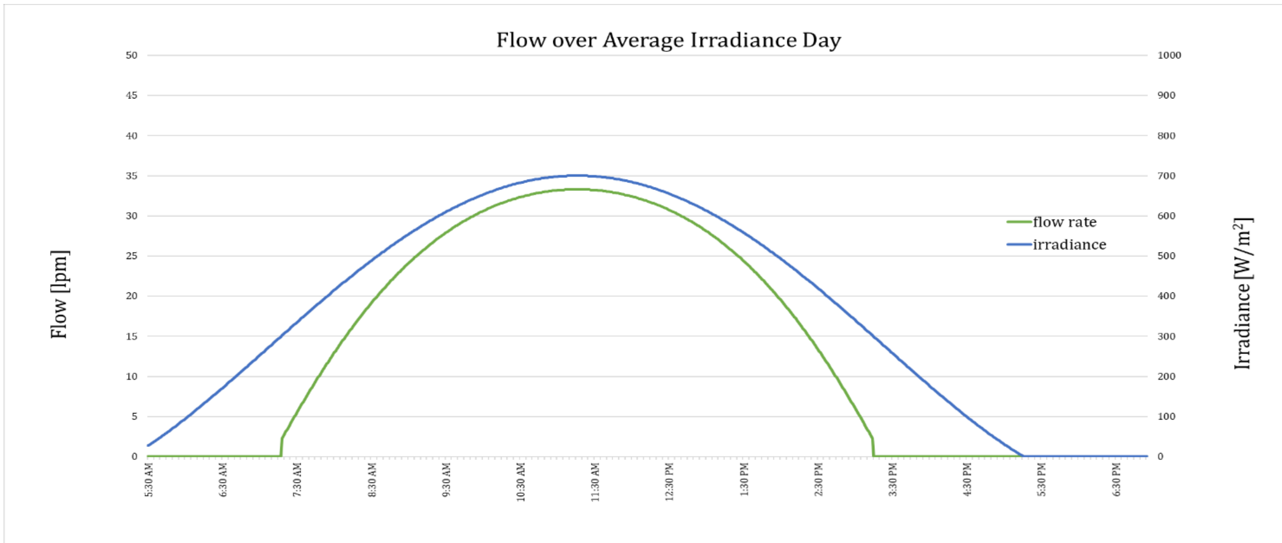

Figure 4. Flow over an average day

4. Total volume moved (m^3/day)
    i. 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)
    i. Calculate the hydraulic energy at each minute interval and add this to determine the hydraulic energy for each solar day.

iv. Report
1. For each simulated irradiance day
    a. Flow (lpm) versus irradiance (W/m^2) graph
    b. Graphs irradiance (W/m^2), flow (lpm), time
    c. Total volume moved (m^3/day)
    d. Maximum flow (lpm)
    e. Hours of operation (h)
    f. Hydraulic energy for each day (Wh/d)
    g. Average wire to water efficiency (%)

3.9 Mechanical Durability Tests

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

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 the internal inspection.

3.9.1 Switches, connectors, and/ or goosenecks

The procedure for this test is as follows:

i. Confirm each switch/button/port works prior to testing.
ii. Press each type of switch/button on the pump and/or charge controller (and/or inverter, if applicable) 1000 times, checking for functionality after each round of 100.
iii. If the product has any ports, test the ports by inserting and removing the correct plug for each port 1000 times, checking for functionality after each round of 100.

a) Report
    i. A description of what was tested (*e.g.,* "The controller ON/OFF button", "The PV input port on the controller", etc.)
    ii. Any damage, functionality failures, or safety concerns
        1. If any are reported, also take photos and include them in the test report
    iii. The number of cycles achieved

3.9.2 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, any applicable accessories or included appliances, and PV module cables. 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:

i. Confirm the functionality of all cables prior to testing. For a pump, turn the pump ON in the same configuration used during performance testing. For a PV module, cut the plug and measure the open-circuit voltage and short-circuit current with the module facing the sun using a digital multimeter.

ii. 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 to make the confirmation.

iii. Place the unit under test (PV module, pump, 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).

iv. 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.

v. After each angle tested, check the unit for functionality, any noticeable physical damage, and safety hazards.

    1. Specify if there is functionality after testing for each specified angle.

    2. If there is permanent damage, enter "FAIL" in the "damages" column in the test report for the specified angle. Include photos and a description of any damages observed.

3. If there are any safety hazards, enter "FAIL" in the safety hazards column in the test report for the specified angle. Include photos and a description of any safety hazards.

vi. Repeat this procedure for each unit/component that is required to undergo this test.

3.9.3 Drop Test

Follow the procedure outlined in *IEC 62257-9-5:2018, Annex W* to perform this test on all portable surface pumps. This test does not need to be performed on stationary and/or submersible pumps, unless a pump is *advertised* to be portable. Some additions to this referenced IEC test method that are related to testing SWPs are as follows:

1. This test should occur after the other mechanical durability tests required for a SWP.
2. Only test portable, surface pumps or portable appliances/accessories *if advertised as portable* (which may include submersible pumps in some cases).
3. Use a different sample than the sample that underwent performance testing.
4. There may be a post functionality test after dropping if no safety hazards are identified or expected. The internal inspection for the drop-tested sample can be conducted in parallel with 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.

3.10 Protection Tests

The following tests are done to determine whether or not the pump 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.

3.10.1 Reverse Polarity

This procedure is to determine whether or not a pumping system will be damaged if the 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.

a) Procedure (dependent on existing potential miswiring scenarios)

   i. 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.

ii. 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.

iii. 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.

iv. Test any other scenarios, when relevant, where reverse polarity connections are possible.

v. Once the system is wired, simulate an input power equivalent to 700 W/m^2 for twenty minutes (as long as no safety hazards are noticed).

vi. Note whether or not the pump is functional when the power leads are reversed, whether there is any damage, and whether there are any safety hazards.

vii. After testing each scenario, re-wire the pump with normal polarity and note whether or not the pump is functional. Take photos and insert them and all observations in the test report along with a description of each reverse polarity scenario tested.

3.10.2 Dry Run Test

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

a) Procedure

i. Simulate a 0 m of head or as close to 0 m of head as possible with the testing station.

ii. Using the steps outlined in 3.4 PV Array Simulation to determine the correct PV array, simulate 700 W/m^2 with the solar array simulator power supplies.

iii. Once the pump has turned on and wait for the pump to stabilize. The pump is considered to be stabilized if over a five-minute period, the flow rate in not fluctuating by more than 5%.

iv. 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 house from the water, or another method to achieve a dry well situation.

v. As soon as the dry well situation has been initiated, start a timer and stop the timer once the pump has come to a complete stop. Run this test for two minutes, and if the pump continues to run after this waiting period, it determined that the pump does not have any dry run protection.

b) Report
   i. Simulated irradiance (W/m^2)
   ii. Time taken for pump to turn off (s)
   iii. Description of how the pump stops

3.11 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 quick 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 flowrate 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 left-hand side of the maximum power point on the I-V Curve or close to the maximum power point. If pump malfunction is suspected during testing, then the company that submitted the SWP for testing should be contacted, and it should be further discussed whether or not the Alternative Method should be used instead. Option 1 or Option 2 of the Alternative Method may be used depending on the lab's resources and abilities.

Option 1 was validated using the Chroma solar array simulator for comparison of test results, and 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 consistent data acquisition over time in the way the test method using a solar array simulator (such as the Chroma 62150H-600S-220V PV solar array simulator) allows. For instance, the Chroma may consistently output a specified power until there are sufficient measured data points to analyze; however, 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 to average.
- There are not yet enough supporting data to confidently compare the Alternative Method options to the Chroma. There are insufficient data to determine whether

the Alternative Method options tend to show superior or inferior pump performance when compared to Chroma data. Experience with validation tests indicates that the Alternative Method generally produces results that are less precise because it involves collection of 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 usable 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.

It shall be noted in the test report if a SWP is tested using one of the Alternative Method options.

3.11.1 Alternative Method- Option 1

The following equipment is required for Option 1.

- PV array stand / mounting rack that is adjustable, moveable, and can follow the sun throughout the day

- Calibrated pyranometer

- PV array that meets recommended specifications for the SWP (i.e. an array that operates within the recommended voltage and current limits for the pump 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 generated the target voltage and current should be used.

- 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 product under test, an actual PV array (or module) will be the source of power (Figure 5). 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.

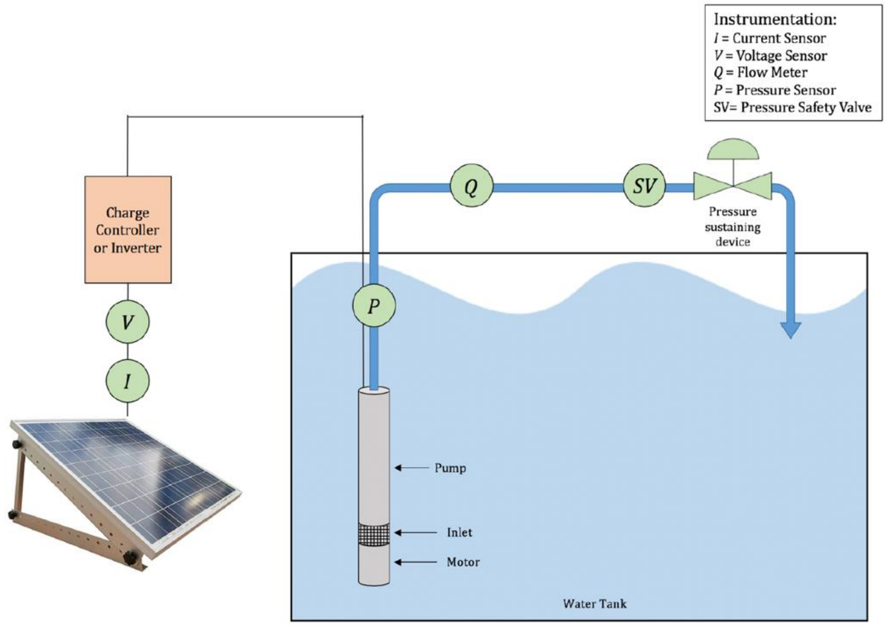

Figure 5: Alternative Test Set-Up

a) Alternative PV Array Simulation: Option 1
    a. Instead of following steps *i to v* in *PV Array Simulation*, connect the actual PV modules sold with the product, or an array with equivalent wattage and the same configuration, to the product. Place the PV array on a PV stand / mounting rack so that each panel is on the same plane.
    b. 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.
    c. 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.
    d. Using this method requires at least two people to successfully complete the test. One person is operating the test station while the other person is monitoring the irradiance and adjusting the PV array stand accordingly.
    e. 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.

b) Dry run Test
    a. Procedure
        i. Follow Steps *i-v* of the *Dry Run Test* ***Error! Reference source not found.*** except instead of using Step *ii* to simulate the PV array, follow the *Alternative PV Array Simulation- Option 1* to simulate 700 W/m^2 .

c) Full tank test
    a. Procedure
        i. Follow Steps *i-v* of the *Full Tank Test* except instead of using Step *ii* to simulate the PV array, follow the Alternative PV Array Simulation to simulate 700 W/m^2.

d) Cold start
  a. Procedure
    i. Follow Steps *i-v* of the *Cold Start Test***Error! Reference source not found.**, and instead of using Step *iii* increase the irradiance in 50 W/m^2 increments using the Alternative PV Array Simulation.

e) Head Range
  a. Procedure
    i. Follow Steps *i-v* of the *Cold Start Test* Full Tank Test except instead of using Step *ii* to simulate the PV array, follow the *Alternative PV Array Simulation- Option 1* to simulate 700 W/m^2.

f) Volume Moved Per Day
    i. Follow Steps *i-vi* of the *Volume Moved over Three Different Solar Days*Full Tank Test except instead of using Step *iii* increase the irradiance in 50 W/m^2 increments using the *Alternative PV Array Simulation- Option 1*.

g) Reverse Polarity
  a. Follow steps *i-viii* in the *Reverse Polarity Test* procedure; however, ensure that the PV modules are covered and/ or out of the sun when wiring up the pump and/ or controller/ inverter to not create a safety hazard.

h) All other tests use the same procedures as described in the normal test methods, except that they use the PV array.

3.11.2 Alternative Method: Option 2

The following information, equipment, and conditions are required for Alternative Method: Option 2.

- PV array that meets recommended specifications for the SWP (i.e. an array that operates within the recommended voltage and current limits for the pump 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 generated the target voltage and current should be used

- Slightly opaque plastic sheets, such as greenhouse plastic. These can be smaller than the PV modules themselves, as demonstrated in Figure 6, below:

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

- 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).

-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)

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

In this method, everything is set up and carried out similarly to the *Alternative Method: Option 1*, except the way the PV power is controlled is different. In this method, instead of using an adjustable PV array stand and pyranometer, the PV array will be wired up and laid flat facing the sky under the sun next to the test bench. The PV input power will then be controlled by shading the cells with thin, opaque material such as greenhouse plastic to reduce the power input without risking creating potentially dangerous or damaging hot spots in the PV modules.

Each test will be carried out like the *Alternative Method: Option 1*. However, to achieve the correct input power for each test/ step, the data acquisition screen will be monitored as the PV modules are evenly covered, layer by layer, with the plastic sheets until the target power input has been reached. 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.

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

3.12 Photo Appendix

This section will include all photos of the pump (interior and exterior) and all components listed in the photos section of the Visual Screening. Some photos that may also be added to this section could include relevant photos taken during testing.

4 Annex A: Equipment

4.1 Instrument Accuracy Recommendations

Table 3: Instrument Accuracy Recommendations

Parameter	Unit	Accuracy
PV Voltage	V	$\leq$ 2%
PV Current	A	$\leq$ 2%
Pressure	psi	$\leq$2%
Flow	lpm	$\leq$ 2%