BS EN 62253:2011

BSI Standards Publication

# Photovoltaic pumping systems — Design qualification and performance measurements

## National foreword

This British Standard is the UK implementation of EN 62253:2011. It is identical to IEC 62253:2011.

The UK participation in its preparation was entrusted to Technical Committee GEL/82, Photovoltaic Energy Systems.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.



ISBN 978 0 580 66937 8

ICS 27.160

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 September 2011.

**Amendments issued since publication**

| Date | Text affected |
|---|---|

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

# EN 62253

September 2011

ICS 27.160

English version

**Photovoltaic pumping systems -**
**Design qualification and performance measurements**
(IEC 62253:2011)

Systèmes de pompage photovoltaïques -
Qualification de la conception et mesures de performance
(CEI 62253:2011)

Photovoltaische Pumpensysteme -
Bauarteignug und Prüfung des Leistungsverhaltens
(IEC 62253:2011)

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European Committee for Electrotechnical Standardization
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Europäisches Komitee für Elektrotechnische Normung

**Management Centre: Avenue Marnix 17, B - 1000 Brussels**

## Foreword

The text of document 82/647/FDIS, future edition 1 of IEC 62253, prepared by IEC TC 82, "Solar photovoltaic energy systems" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62253:2011.

The following dates are fixed:

| | | |
|---|---|---|
| • latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement | (dop) | 2012-05-19 |
| • latest date by which the national standards conflicting with the document have to be withdrawn | (dow) | 2014-08-19 |

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## Endorsement notice

The text of the International Standard IEC 62253:2011 was approved by CENELEC as a European Standard without any modification.

# Annex ZA
(normative)

## Normative references to international publications with their corresponding European publications

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

| Publication | Year | Title | EN/HD | Year |
|---|---|---|---|---|
| IEC 60068-2-6 | - | Environmental testing - Part 2-6: Tests - Test Fc: Vibration (sinusoidal) | EN 60068-2-6 | - |
| IEC 60068-2-30 | - | Environmental testing - Part 2-30: Tests - Test Db: Damp heat, cyclic (12 h + 12 h cycle) | EN 60068-2-30 | - |
| IEC 60146 | Series | Semiconductor converters - General requirements and line commutated converters | EN 60146 | Series |
| IEC 60364-4-41 | - | Low-voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock | HD 60364-4-41 | - |
| IEC 60364-7-712 | - | Electrical installations of buildings - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems | HD 60364-7-712 | - |
| IEC 60529 | - | Degrees of protection provided by enclosures (IP Code) | - | - |
| IEC 60947-1 | - | Low-voltage switchgear and controlgear - Part 1: General rules | EN 60947-1 | - |
| IEC 61000-6-2 | - | Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments | EN 61000-6-2 | - |
| IEC 61000-6-3 | - | Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments | EN 61000-6-3 | - |
| IEC 61215 | - | Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval | EN 61215 | - |
| IEC 61646 | - | Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval | EN 61646 | - |
| IEC 61683 | 1999 | Photovoltaic systems - Power conditioners - Procedure for measuring efficiency | EN 61683 | 2000 |
| IEC 61725 | - | Analytical expression for daily solar profiles | EN 61725 | - |
| IEC 61730-1 (mod) | - | Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction | EN 61730-1 | - |
| IEC 61730-2 (mod) | - | Photovoltaic (PV) module safety qualification - Part 2: Requirements for construction | EN 61730-2 | - |

| Publication | Year | Title | EN/HD | Year |
|---|---|---|---|---|
| IEC 61800-3 | - | Adjustable speed electrical power drive systems - Part 3: EMC requirements and specific test methods | EN 61800-3 | - |
| IEC 62103 | - | Electronic equipment for use in power installations | - | - |
| IEC 62109-1 | - | Safety of power converters for use in photovoltaic power systems - Part 1: General requirements | EN 62109-1 | - |
| IEC 62124 | 2004 | Photovoltaic (PV) stand-alone systems - Design verification | EN 62124 | 2005 |
| IEC 62305-3 | - | Protection against lightning - Part 3: Physical damage to structures and life hazard | EN 62305-3 | - |
| IEC 62458 | - | Sound system equipment - Electroacoustic transducers - Measurement of large signal parameters | EN 62458 | - |
| IEC 62548 | 201X[1)] | Design requirements for photovoltaic (PV) arrays | EN 62548 | 201X[1)] |
| ISO 9905 | 1994 | Technical specifications for centrifugal pumps - Class I | EN ISO 9905 | 1997 |

[1)] To be published.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

# PHOTOVOLTAIC PUMPING SYSTEMS – DESIGN QUALIFICATION AND PERFORMANCE MEASUREMENTS

## FOREWORD

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International Standard IEC 62253 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this standard is based on the following documents:

| FDIS | Report on voting |
|---|---|
| 82/647/FDIS | 82/656/RVD |

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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# PHOTOVOLTAIC PUMPING SYSTEMS – DESIGN QUALIFICATION AND PERFORMANCE MEASUREMENTS

## 1 Scope and object

This International Standard defines the requirements for design, qualification and performance measurements of photovoltaic pumping systems in stand-alone operation. The outlined measurements are applicable for either indoor tests with PV generator simulator or outdoor tests using a real PV generator. This standard applies to systems with motor pump sets connected to the PV generator directly or via a converter (DC to DC or DC to AC). It does not apply to systems with electrical storage unless this storage is only used for the pump start up (< 100 Wh).

The goal is to establish a PV pumping system design verification procedure according to the specific environmental conditions. This Standard addresses the following pumping system design features:

- Power vs. flow rate characteristics at constant pumping head
- Pumping head vs. flow rate characteristics at constant speed
- System design parameters and requirements
- System specification
- Documentation requirements
- System design verification procedure

The object of this standard is to establish requirements in order to be able to verify the system performance characteristics of the PV pumping system. For this purpose the test set-up is outlined, the measurements and deviations to be taken are defined and a checklist for the data mining is established.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068-2-6, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-30, *Environmental testing – Part 2:30: Tests – Test Db: Damp heat, cyclic (12 + 12 h cycle)*

IEC 60146 (all parts), *Semiconductor converters – General requirements and line commutated converters*

IEC 60364-4-41, *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock*

IEC 60364-7-712, *Electrical installations of buildings – Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems*

IEC 60529, *Degree of protection provided by enclosures (IP Code)*

IEC 60947-1, *Low voltage switchgear and controlgear – Part 1: General rules*

IEC 61000-6-2, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity for industrial environments*

IEC 61000-6-3, *Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments*

IEC 61215, *Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval*

IEC 61646, *Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval*

IEC 61683:1999, *Photovoltaic systems – Power conditioners – Procedure for measuring efficiency*

IEC 61725, *Analytical expression for daily solar profiles*

IEC 61730-1, *Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction*

IEC 61730-2, *Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing*

IEC 61800-3, *Adjustable speed electrical power drive systems – Part 3: EMC requirements and specific test methods*

IEC 62103, *Electronic equipment for use in power installations*

IEC 62109-1, *Safety of power converters for use in photovoltaic power systems – Part 1: General requirements*

IEC 62124:2004, *Photovoltaic (PV) stand-alone systems design verification*

IEC 62305-3, *Protection against lightning – Part 3: Physical damage to structures and life hazard*

IEC 62458, *Sound system equipment – Electroacoustical transducers – Measurement of large signal parameters*

IEC 62548[1], *Design requirements for photovoltaic (PV) arrays*

ISO/DIS 9905, *Technical specifications for centrifugal pumps – Class I (ISO 9905:1994)*

# 3 Terms, definitions, system-types and -parameters

## 3.1 Terms and definitions

### 3.1.1 PV converter

The PV converter converts the DC voltage of the PV generator into a high or low DC voltage or converts this DC voltage and/or DC current into one-phase or multi-phase alternating-current voltage or alternating current

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[1] To be published.

NOTE the PV converter may also include equipment for MPPT, monitoring, metering and for protection purposes.

### 3.1.2 PV pump aggregate

The PV pump aggregate consists of the pump (centrifugal pump, displacement volume pump) the driving motor and control

### 3.1.3 PV pump terminal cable

A PV pump terminal cable connects the PV converter and the pump aggregate

### 3.1.4 PV pump systems

A PV installation is comprised mainly of the following components and equipment:

PV generator, cabling, control unit (e.g. inverter, DC/DC converter, etc.), motor, pump and hydraulic piping

### 3.1.5 Photovoltaic pumping systems in stand-alone operation

Photovoltaic pumping systems in stand-alone operation are photovoltaic pumping systems with no connection to the grid

### 3.1.6 Impedance matching

DC/DC Converter, which may include MPPT or V/I tracking maybe with temperature correction

## 3.2 System-types and -parameters

For the purposes of testing, PV pumping systems can be divided into four categories as shown in Table 1. The measurement access points within the system define these categories.

Figure 1 illustrates the four basic arrangements, and defines the parameters that can be measured at each accessible point in the system. The parameters are defined in Table 2.

**Table 1 – Categories of PV pumping systems for the purposes of testing**

| Pumping system types |
|---|
| A. DC systems either directly connected or with a control (impedance matching) electronics integral with motor-pump |
| B. DC system with separate impedance matching unit, connected to either brushed or electronics commutated motor-pump unit where the corresponding controls are integral with motor-pump |
| C. DC system (brushless) with separate commutation control (and impedance matching) |
| D. System with DC/AC inverter for operation of a standard AC pump-motor |

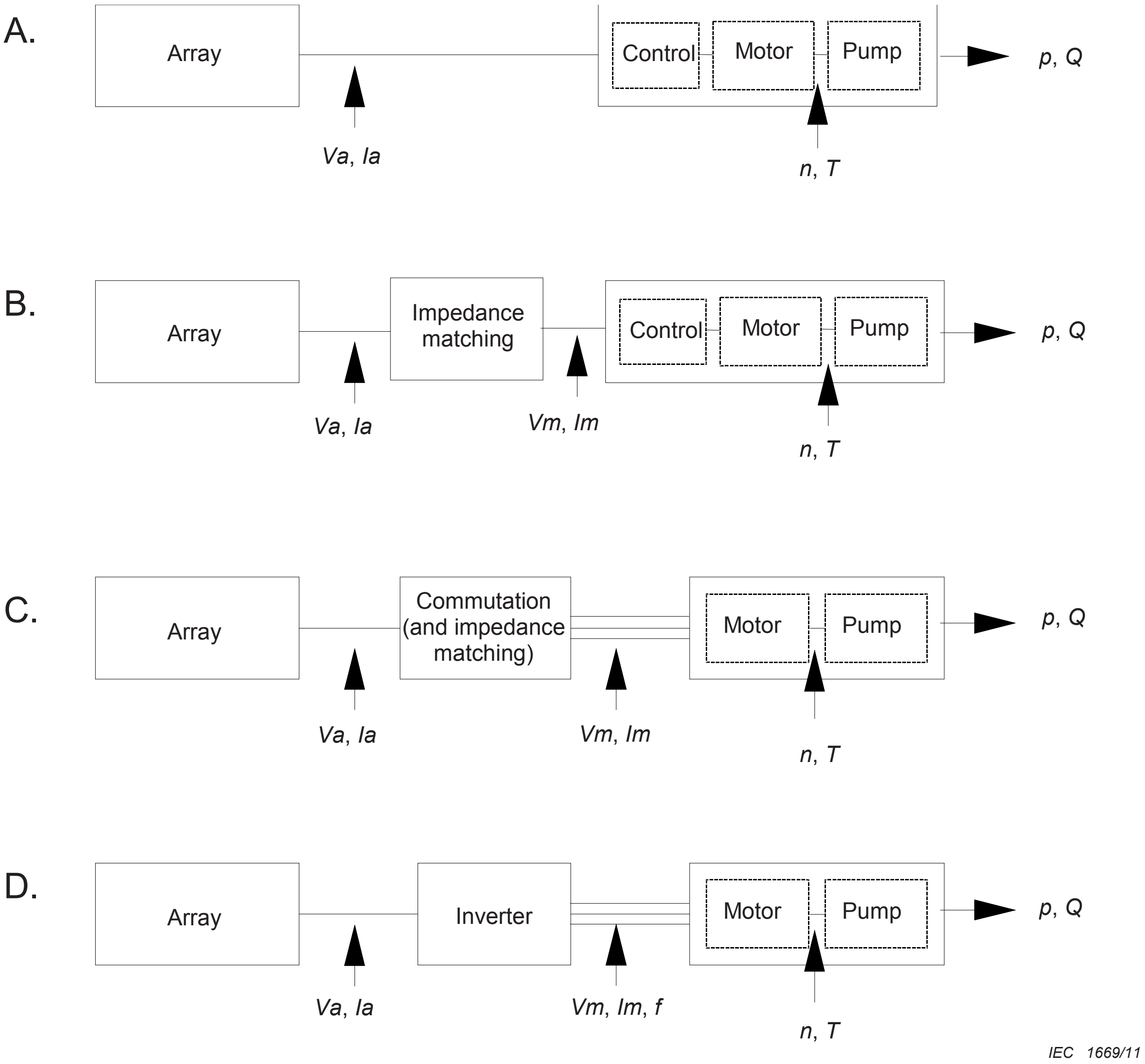


**Figure 1 – Schematic of system types for the purposes of testing**
(In case C, Vm and Im may be electronically commutated voltage and current)

**Table 2 – Definition of the parameters**

| No. | Parameter | Sym | Unit |
|---|---|---|---|
| 1 | Generator voltage DC | *Va* | V |
| 2 | Generator current DC | *Ia* | A |
| 3 | Generator open circuit voltage DC | *Voc* | V |
| 4 | Generator short cut current DC | *Isc* | A |
| 5 | Generator maximum power point voltage DC | *Vmpp* | V |
| 6 | Generator maximum power point current DC | *Impp* | A |
| 7 | Pressure as measured | *p* | Pa |
| 8 | Flow rate | *Q* | $m^3/h$ |
| 9 | Motor voltage DC or AC | *Vm* | V |
| 10 | Motor current DC or AC | *Im* | A |
| 11 | Motor voltage (multi-phase AC) | $V_{rms}$ | V |
| 12 | Motor current (multi-phase AC) | $I_{rms}$ | A |
| 13 | Power factor | $\lambda$ | - |
| 14 | AC frequency (or DC switching frequency) | *f* | Hz |
| 15 | Motor speed | *n* | $min^{-1}$ |
| 16 | Torque at motor-pump coupling | *T* | Nm |
| 17 | Water temperature (at inlet) | *t* | °C |

## 4 Requirements for system components

### 4.1 General

Typically a PV pumping system consists of the following main components:

- PV generator
- Electronic converters which are separate (impedance matching device or inverter)
- Combined motor pump unit

### 4.2 Relations to other standards

PV pumping systems are one of the applications for photovoltaics. Therefore existing standards for the components shall be applied.

PV modules should comply with the requirements of relevant standards. For crystalline PV modules IEC 61215, for thin-film PV modules IEC 61646 and for safety requirements for PV modules IEC 61730-1 and IEC 61730-2 are applicable. PV generators should be installed according to IEC 62548. The PV generator combiner box should bear a warning label indicating that active parts of the PV generator combiner box may still be live even after disconnection from the converter.

As PV pumping systems are stand-alone systems IEC 60364-7-712 applies as well.

The PV generator combiner boxes and the switchgear assembly for the installation of the PV converter should be in compliance with the requirements of IEC 60947-1. A warning label is required to the extent that fuses or disconnect devices should not be withdrawn or switched under load if such devices are installed on the DC side.

Power Conditioning Units (DC-DC converter, DC-AC converter) have to fulfil the requirements given in IEC 62109-1.

Upon selection of the electrical equipment of the DC side one should ensure that the equipment is suited for direct voltage and direct current. PV generators are to be connected in series up to the maximum open-circuit voltage of the PV generator. The respective specifications are to be given by the module manufacturer. If blocking diodes are necessary, their reverse voltage is to be rated at twice the value of the open-circuit voltage of the PV generator under STC. IEC 62458 for PV installation shall be referred.

The protection concept should meet the requirements against electric shocks (IEC 60364-4-41) and the operation safety of the system. Testing of electrical components and electronic apparatus shall comply with IEC 60146, IEC 62103 and all relevant standards.

Lightning protection shall be compliant to the relevant standards and the requirements of IEC 62305-3.

The damp-heat suitability of electronic apparatus shall be compliant at local ambient conditions to IEC 60068-2-30 (ref. to damp-heat cyclic). 5 cycles shall be made for the electronic apparatus.

Severity: With plants for tropical application the temperature amounts to 55 °C max.
With plants in temperate climates the temperature amounts to 45 °C max.

Protection against contact, foreign bodies and water shall be compliant to IEC 60529.

Type testing of the transportability of electronic apparatus with packaging shall be compliant to IEC 60068-2-6.

Assessment of immunity against conducted and radiated disturbing quantities shall be compliant to IEC 61000-6-2, IEC 61000-6-3 and IEC 61800-3.

Pumps can be classified into 4 main categories, although supplementary types might exist.

Centrifugal pumps shall fulfil the requirements given in ISO/DIS 9905 Class I.

## 5 Performance measurement

### 5.1 General

The performance of the system can be determined by evaluation the complete system under varying conditions. The performance shall be evaluated either under laboratory (replicable and reproducible) conditions or under field conditions for acceptance test. One of them is enough.

### 5.2 Test set-up

The minimum requirement for a test set-up for performance measurement is defined as follows (Maximum measurement uncertainties are given in Table 4):

Electric:

- Real PV generator with irradiance and wind measurement (for field acceptance) or
  Programmable PV solar generator simulator capable to simulate a given PV solar generator configuration (i.e. the number of modules, the type and the series/parallel combination) for laboratory test.
- Real cable type, length and diameter (for field acceptance or laboratory test) or
  Cable impedance simulator (for laboratory test).

- Measurement equipment with acceptable accuracy and precision for detection and registration of the parameters listed in Table 2.

Hydraulic:

- Water tank
- Motor-pump set
- Pressure transducer
- Pre-pressurised air chamber (where the pressure level can be adjusted)
- Flow transducer
- Pressure sustaining device
- Discharge pipe

An example test circuit schematic is shown in Figure 2.

NOTE Any equivalent test circuit (e.g. for different pumping types) verifying correct hydraulic characteristics and system performance can be used, provided that it ensures the required initial counter pressure.

The pipe set up between the pump outlet and the pressure sensor should be the same diameter as the manufacturer's outlet fitting. 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 and the kinetic energy component of the water at the pump outlet will be small compared to the increase in potential energy due to the increased pressure across the pump. These assumptions should be verified and if necessary the effect on the calculation of hydraulic power should be corrected. This should be noted in the test report.

The general layout of the system pipe work should be designed to avoid airlocks.

For instantaneous performance testing, pressure can be sustained by means of a simple gate valve in which a backpressure is sustained by restricting the flow. There are also special valves available which sustain a constant upstream pressure (pressure sustaining valves) although care should be taken, as their performance can be unpredictable. Some better equipped test laboratories may sustain pressure by means of a pre-pressurised air chamber operating with a pressure maintaining valve at the outlet or a real water column (see Table 3).

If a flow meter is used for laboratory measurements, then the end of the discharge pipe should be beneath the water surface to prevent splashing. This could cause a mixed water / air bubbles fluid entering the pump inlet and affecting its proper operation. If the bucket and stop-watch method (field method) is used, it is not possible to discharge the water beneath the surface, and so a vertical baffle shall be inserted in the tank between the pump intake and the return pipe such that water has to pass under the baffle near the bottom of the tank to reach the pump. In this way any small bubbles will be excluded, as they will remain near the surface. Alternatively a large pipe can be placed around the pump with its top breaking the surface and an arch cut in its base to allow water entry.

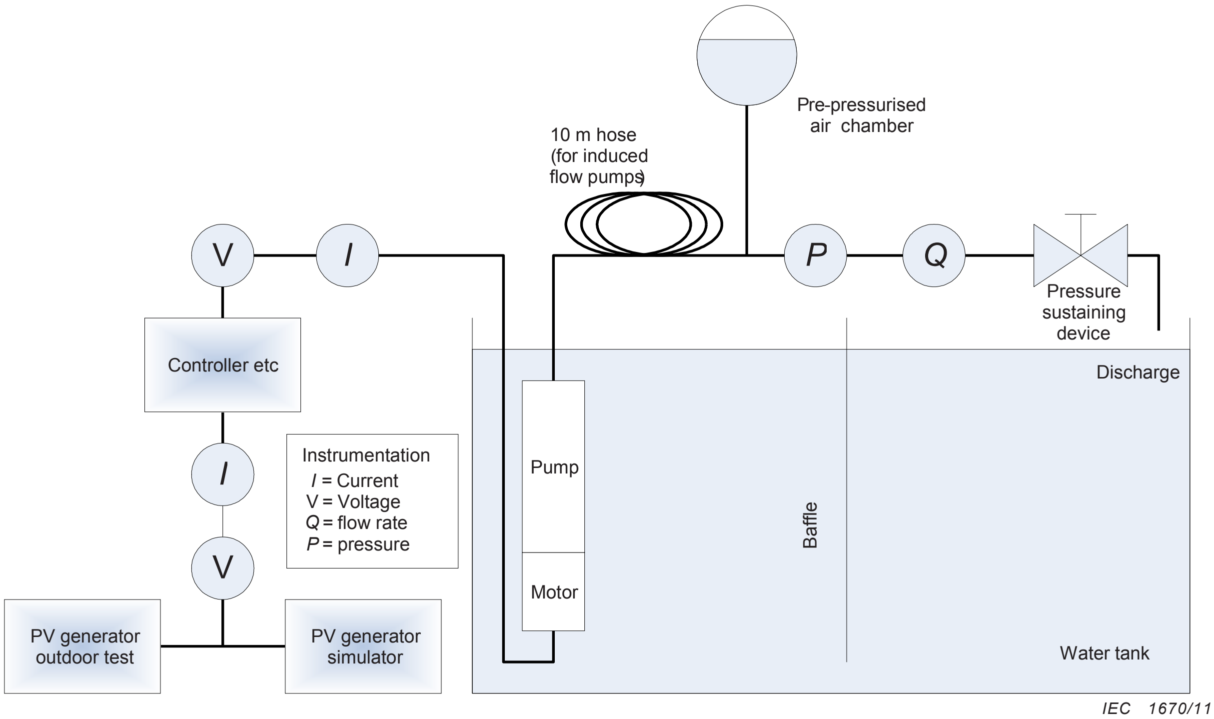


**Figure 2 – Example of PV pump test circuit in the lab**

### 5.3 Pumping system performance tests

#### 5.3.1 General

The characteristics agreed to in the component and implementation specification shall be verified in the performance tests. During the performance test, components or subsystems are submitted to various test procedures and are tested for adherence to the stipulated characteristics. A first design check will be carried out after the performance curves have been determined to compare them with the required design data of the plant. Data for the system as a whole is verified on site by performing the field performance test. The test provides all necessary information and performance curves to be taken as a basic for the field performance test.

Laboratory performance test: A schematic of the required laboratory system test circuit is shown in Figure 2.

The converter efficiency test is performed according to IEC 61683:1999 and therefore not detailed in this standard.

#### 5.3.2 P-Q characterisation

It is important to test the performance of the pumping systems at constant head (*H*) and varying input power (*P*) to determine the resultant flow rate (*Q*). In the laboratory these characteristic constant head (*H*) curves for *P* over *Q* shall be determined.

The following constant head (*H*) curves should be determined (unless the manufacturer defines the lowest allowed head different. Then $H_1$ should be taken as $H_{min}$):

$H_1 =$ 0,3 $H_{max}$

$H_2 =$ 0,4 $H_{max}$

$H_3 =$ 0,5 $H_{max}$

$H_4 =$ 0,6 $H_{max}$

$H_5 =$ 0,7 $H_{max}$

$H_6 =$ 0,8 $H_{max}$

$H_7 =$ 0,9 $H_{max}$

See also Figure 3 (example for a centrifugal pumping system) as an example of a graphical representation. $H_{max}$ ($Q$ = 0 for centrifugal pumps. For other pump types, e.g. helical rotor pumps $H_{max}$ is defined by the manufacturer as the maximum allowed operational head) is the maximum pumping head of the pump at the maximum safe motor speed or the maximum frequency supplied by the converter (in case this is lower than the safe motor speed). Safety requirements from the pump manufacturer should be considered.

The pumping system shall be run at nominal speed for 5 min at low pressure respectively open valves in order to get air bubbles out of the test loop.

The pressure is set to a fixed value. Measurements are started at the highest pressure. The system input power is varied from high to low in steps and the flow rate is measured, for this purpose, the PV generator simulator or real PV generator I-V characteristics shall be as specified in the system design. Between high input power and low input power at least 5 measurement points with equal delta flows (the difference in the flow rates should be equal from measurement point to measurement point) shall be taken. This results in one P-Q curve for constant pressure (water head in m).

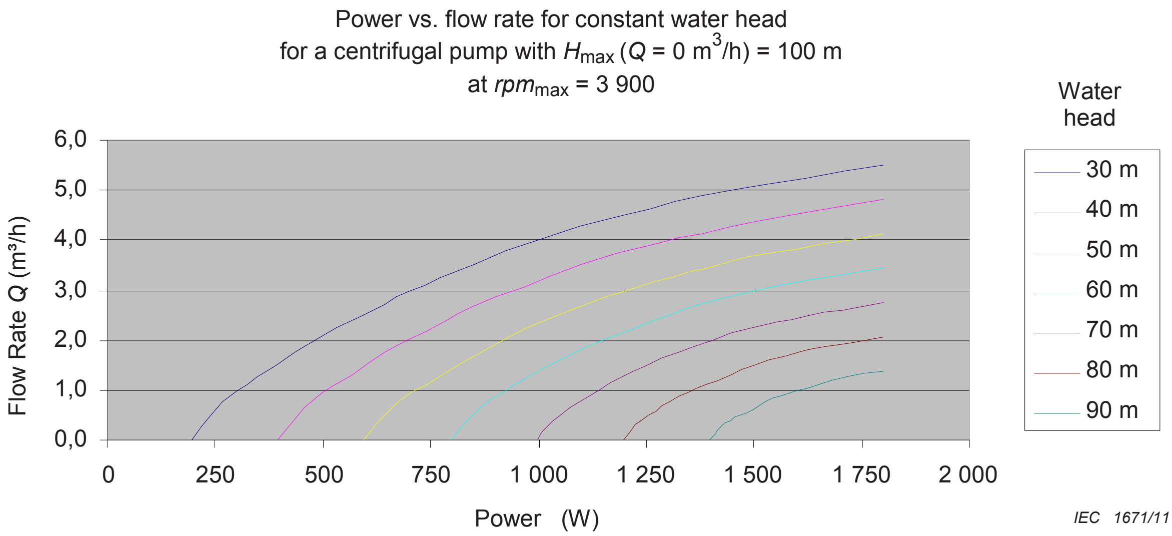


**Figure 3 – Example of a P-Q diagram**

For field application a simplified procedure is applied:

The PV pumping system is installed at the desired location. A pressure sensor is brought into the well to determine the real water pumping head $H$ [m] (static + dynamic water head). The flow rate of pumped water $Q$ [l/s] is measured either with a calibrated flow meter or with the bucket method mentioned in 5.2. At the input of the converter DC voltage $V$ [V] and current $I$ [A] are measured. With these measurement the efficiency of the converter-motor-pump subsystem can be calculated (g = earth gravity = 9,81 m/s²):

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

### 5.3.3 H-Q characterisation

In this characterisation the systems power is varied so that the pump runs at a set speed (parameter *n*). One of the speeds included in the characterisation should include the speed equivalent to the measured manufacturer data which for a.c. pumps would be related to the inverter output frequency (US data (60 Hz) – EU data (50 Hz)).

The procedure is:

- Initially the pumping system shall be run at nominal speed for 5 min at low pressure with open valves in order to get air bubbles out of the test loop.
- The valve is then set in a way that the pump is running against its full head. (For centrifugal pumps the valve can be fully closed, for displacement pump the valve is closed so that the rated maximum head of the pump is reached.)
- From this point the valve is opened in steps so that the maximum flow is reached.
- Every time a new point is reached, the input power has to be adjusted so that the set speed is reached again (parameter *n*). For this purpose, the PV generator simulator or real PV generator I-V characteristics shall be as specified in the system design.
- Between closed valve and opened valve at least 5 measurement points for equal delta flows shall be taken. This results in one H-Q curve for constant speed, whereas voltage and current might differ.
- This procedure is repeated for other speeds. A set of 5 curves should be taken where the speed difference corresponds to 5 Hz.

Figure 4 shows an example graphic presentation.

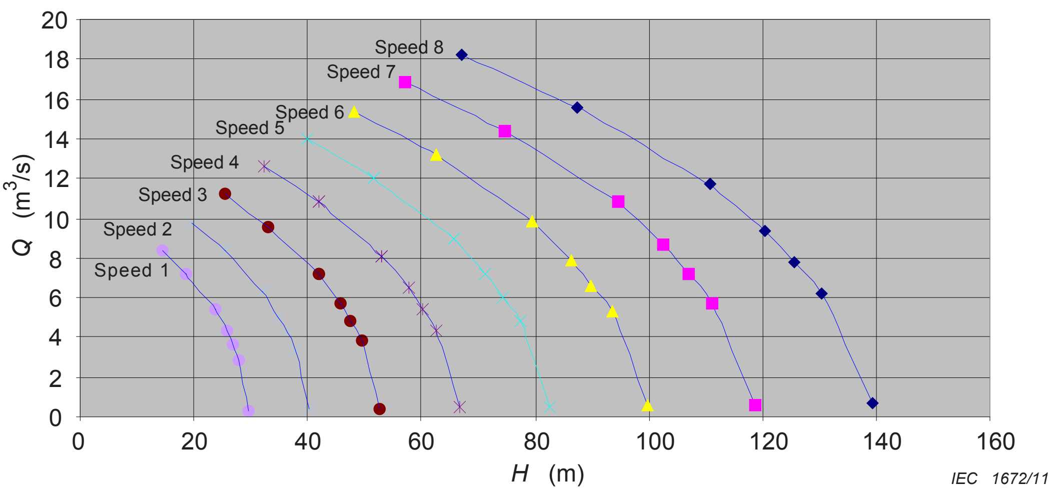


**Figure 4 – Example of an H-Q diagram for the same pump at different rotational speeds**

### 5.3.4 Start-up power measurements

This test is for the determination of the minimum power needed to start a photovoltaic pumping system. This test is obsolete for centrifugal pumps if no non-return valve is installed in the pump.

The pump is switched off. The pre-pressurised air chamber is filled 50 % with water and air pressure is applied until the nominal head of the pump is reached in the system. The pressure-sustaining device (e.g. a pressure controlled valve) is as well set to this head value (see Figure 2). The PV generator simulator is set to a maximum current value (irradiance) and the system is started. This procedure is repeated from low value to high value until the system starts, runs stable for 2 min and does not trip. This is the needed start up power for the specified head.

For displacement pumps the procedure applies in the same way. The difference to centrifugal pumps is that with each start up test a water film is sucked between rotor and stator and serves as lubricant. This reduces the friction and therefore the start-up power. As in practice between shut down in the evening and start up in the morning there are several hours during which the water film is pressed out, a waiting time between 2 start-up tests of 2 h is appropriate for helical rotor pumps.

## 6 Design qualification for a pumping system

### 6.1 General

A fundamental requirement for planning solar energy pumping systems is that adequate data is available for use as a basis. On the one hand sufficient data from the customer shall be made available to the planner and on the other hand the planner shall take reliable data from the component manufacturer as a basis.

This clause gives a guideline on how to properly design a solar pumping system for optimized operation.

### 6.2 Customer data

**a) Geographical**

– Longitude, latitude, topography

  Longitude and latitude define the site where the system is located. The topography defines the local situation, e.g. orientation of the generator in azimuth and elevation, shading conditions and air quality (humidity and dust level).

**b) Climatic data**

– Irradiation: Design basis: IEC 61725. NASA data.

  If there is no data given by the customer, use the default irradiation data of IEC 62124:2004, Table A.1.

– Temperature data: average, min, max.

  If there is no data given by the customer, use the default average ambient temperature of 30 °C.

– Precipitation.

– Maximum and average wind speed.

**c) Specific local conditions**

– Well data or data of the water source:

  - well depth (static head), well diameter;
  - well productivity ($Q_{max}$ in $m^3/h$ and total pumping head at this level) and evidence of well suitability;
  - dynamic water level (the well output is determined according to international or national regulations);
  - TDH (total dynamic head, including the friction losses of the piping system);
  - required daily water supply under defined worst condition (irradiance, date, water head).

For adjusting the pressure in the pre-pressurised air chamber, also see Table 3.

Water quality shall be according to international or national regulations, indication of dirt or sand particles.

**d) Water demand**

– Required daily water supply under defined worst condition (irradiance, date, water head) as $Q_d$ in $m^3$/day

– Consumption profile

**e) Project description**

– Site description (including photographs where available)

– Type of site with height data for the determination of the total pump head, TDH, piping systems, (length, diameter)

– Existing or planned buildings

– Vegetation with regard to shading

– Storage and distribution facilities

– Water tank, other distribution or storage facilities including technical specifications

The required data supplied by the customer leads to diagrams 1 and 2 and to the value v (average daily pumped water) of Figure A.1 (example for a direct coupled PV centrifugal pumping system). This is the basis of the design performed by the systems supplier.

**Table 3 – Pressure in bars for equivalent heads of water**

| Head<br>m | Pressure<br>hPa | | Head<br>m | Pressure<br>hPa | | Head<br>m | Pressure<br>hPa |
|---|---|---|---|---|---|---|---|
| 5 | 0,49 | | 40 | 3,92 | | 75 | 7,36 |
| 10 | 0,98 | | 45 | 4,41 | | 80 | 7,85 |
| 15 | 1,47 | | 50 | 4,91 | | 85 | 8,34 |
| 20 | 1,96 | | 55 | 5,40 | | 90 | 8,83 |
| 25 | 2,45 | | 60 | 5,89 | | 95 | 9,32 |
| 30 | 2,94 | | 65 | 6,37 | | 100 | 9,81 |
| 35 | 3,43 | | 70 | 6,87 | | | |

For templates for the capture of data, see Clause A.2.

## 6.3 System characteristics

(See the example of a centrifugal pumping system in Figure A.1 for further details.)

From the available data the system supplier defines the following plant characteristics:

- Dynamic pump head *H* including pressure losses due to pipe friction, measuring appliances and well draw-down over volume flow *Q* (see curve 1 in Figure A.1).
- Solar irradiance profiles (see curve 2 in Figure A.1).
- Power characteristic of the photovoltaic generator (see curve 3 in Figure A.1) dependent on the irradiation under the operational (ambient temperature) important is the temperature of the PV module cells conditions and with regard to the generator setting angle. This figure shall be given by at least four points ($G_{max}$, 0,8 × $G_{max}$, 0,6 × $G_{max}$, 0,4 × $G_{max}$).
- The PV-generator should be defined by the following characteristic: electrical output P over irradiation G. This characteristic is formed from the maximum power points (MPPs) for various irradiations at the module temperatures occurring for set limiting conditions. The limiting conditions (air temperature, wind speed) taken as a basis by the manufacturer when establishing the characteristic should be quoted. Possible deviations of the converter from the MPPs should be taken into account when quoting the PV-generator characteristic. With direct-coupled DC motors the adaptation of the generator characteristic to the motor operation is to be observed. Voc of the PV generator has to the considered as well, *Uoc* must be < *Umax* of the converter electronics at any ambient conditions.

- The volume flow rate should be stated for the course of irradiation and for these plant characteristics. It shall be defined by at least four points ($G_{max}$, 0,8 × $G_{max}$, 0,6 × $G_{max}$, 0,4 × $G_{max}$).
- The integral of the flow rate graph represents the quantity of water pumped daily. This value should meet the value of the required volume within a tolerance of –5 % to +20 %.

It may become apparent during the dimensioning of the system that an optimal design that achieves within –5 % / 20 % of the daily requirement is not possible due to the discrete design parameters (e.g. number of strings). If this is the case, an agreement shall be reached with the operator, and if necessary, the operator's criteria should be modified.

### 6.4 Dimensioning of hydraulic equipment

Pressure loss calculations need not be made if the following dimensioning criteria are fulfilled: Piping should be dimensioned to achieve feasible friction losses. Recommended maximum friction loss is 5 % (at STC) of total dynamic head. The nominal flow rate of water meters should be at least 1,5 times the maximum volume flow rate.

### 6.5 Documentation

#### 6.5.1 General

The documentation shall serve as reference for the way the design was performed. It shall outline the data and assumptions on which the design was based as well as the process used in the design. Measures for a safe, sustainable and environmental friendly operation shall be stated. By this, in case the installed system does not comply with the requirements, the documentation will help in the discussion.

#### 6.5.2 Operating and maintenance handbook for the pump maintenance staff at the PV pumping site

This document shall contain easily comprehensible descriptions with simple figures covering the following topics:

- Standard operational procedures such as start-up and shut-down
- Functional description, description of functional supervision and interpretation of status and error indicators
- Rules for action on faulty operation
- Instructions on safety techniques
- Personal safety behaviour, protection against electric shocks
- Maintenance work such as cleaning

A logbook should be established in order to gain continuous operation information. The document shall be written in the language common to the country and in English.

#### 6.5.3 Maintenance handbook covering operation, repair and servicing

This document shall contain easily comprehensible descriptions with simple figures covering the following topics:

- Installation instructions
- Functional description
- Operation and servicing instructions with details of service schedules, with start-up instructions and with troubleshooting checklists for the plant as a whole
- Schematic description in the form of an overview plan with references to the relevant detail plans

- Electrical circuit and regulation diagrams, implementation plans, wiring and terminal diagrams
- Parts list in agreement with the graphical documents quoting all the data necessary for an order
- Exploded drawings of the pump unit with particular attention paid to the labelling of working parts

The document shall be written in the language common to the country and in English.

### 6.6 Design check of the PV pumping system in respect to the daily water volume

For the given hydraulic characteristics of the system performance curve in the characteristics, $P$ over $Q$ can be marked. Using this performance characteristic curve it is possible to determine the volume flow rates from the daily course of irradiation over the PV-generator output and from the performance plant characteristic.

The dimensioning as part of the total design is accepted if the volume flow rates, determined in the way described above, have a maximum deviation of –5 % to +20 % (plus allowance for the measurement tolerance) for the $G_{max}$, $0,8 \times G_{max}$, $0,6 \times G_{max}$, $0,4 \times G_{max}$ points for the volume flow rate corresponding to the daily water volumes to be pumped.

Measurement is calculated using the individual tolerances of the sensors allowing for measuring transducer error. The measurement should be defined to a maximum uncertainty of 3 % of the measured value.

For a field application the calculated subsystem efficiency in 5.3.2 can be used to check against the calculated value. It has to be taken in consideration that the power degradation of the PV generator can be up to 30 % depending on high cell temperatures (>70 °C), aging and dirt on the surface.

### 6.7 Recording of the measured parameters

In all cases a laboratory logbook should be kept, in which all original measured quantities are recorded.

As shown in Figure 1 (point D), different measured parameters are appropriate to different system configurations. In addition, different laboratories will have different measurement capabilities. It is therefore proposed that for each system configuration (A to D) there shall be defined a set of core-measured parameters and a set of optional measured parameters. The core parameters are straightforward to measure, requiring only basic equipment, and are the minimum data set needed to characterise the system. It is expected that all participating laboratories will measure all the core parameters. The optional parameters may require more sophisticated measurement equipment.

Table 4 summarises the core and optional parameters for each system configuration defined in Clause 3.

**Table 4 – Core and optional parameters to be measured and recorded**

| No | Parameter | Symbol | Unit | A | B | C | D | Uncertainty |
|---|---|---|---|---|---|---|---|---|
| 1 | Generator voltage | *Va* | V | Core | Core | Core | Core | ≤1 % |
| 2 | Generator current | *Ia* | A | Core | Core | Core | Core | ≤1 % |
| 3 | Pressure as measured | *p* | bar | Core | Core | Core | Core | ≤2 % |
| 4 | Flow rate | *Q* | $m^3/h$ | Core | Core | Core | Core | ≤2 % |
| 5 | Motor voltage | *Vm* | V | | Core | | | ≤1 % |
| 6 | Motor current | *Im* | A | | Core | | | ≤1 % |
| 7 | Motor voltage (multi-phase AC) | $V_{rms}$ | V | | | | Option | ≤1 % |
| 8 | Motor current (multi-phase AC) | $I_{rms}$ | A | | | | Option | ≤1 % |
| 9 | Power factor | $\alpha$ | frac | | | | Option | ≤1 % |
| 10 | AC frequency (or DC switching frequency) | *f* | Hz | | | Option | Option | ≤2 % |
| 11 | Motor speed | *n* | $min^{-1}$ | Option | Option | Option | Option | ≤2 % |
| 12 | Torque at motor-pump coupling | *T* | Nm | Option | Option | Option | Option | ≤2 % |
| 13 | Water temperature (at inlet) | *t* | °C | Core | Core | Core | Core | ≤2 % |

| Key | Meaning |
|---|---|
| Core | Basic parameter that should be measured by all laboratories |
| Option | Optional parameter that may be measured by those with the appropriate facilities |
| | Not applicable |
| Uncertainty | Maximum uncertainty of the measured value |
| Symbol | Symbol of the SI units |

# Annex A
(informative)

# Performance diagram, component characteristics and definitions

## A.1 Diagrams to show system performance for centrifugal pumping system

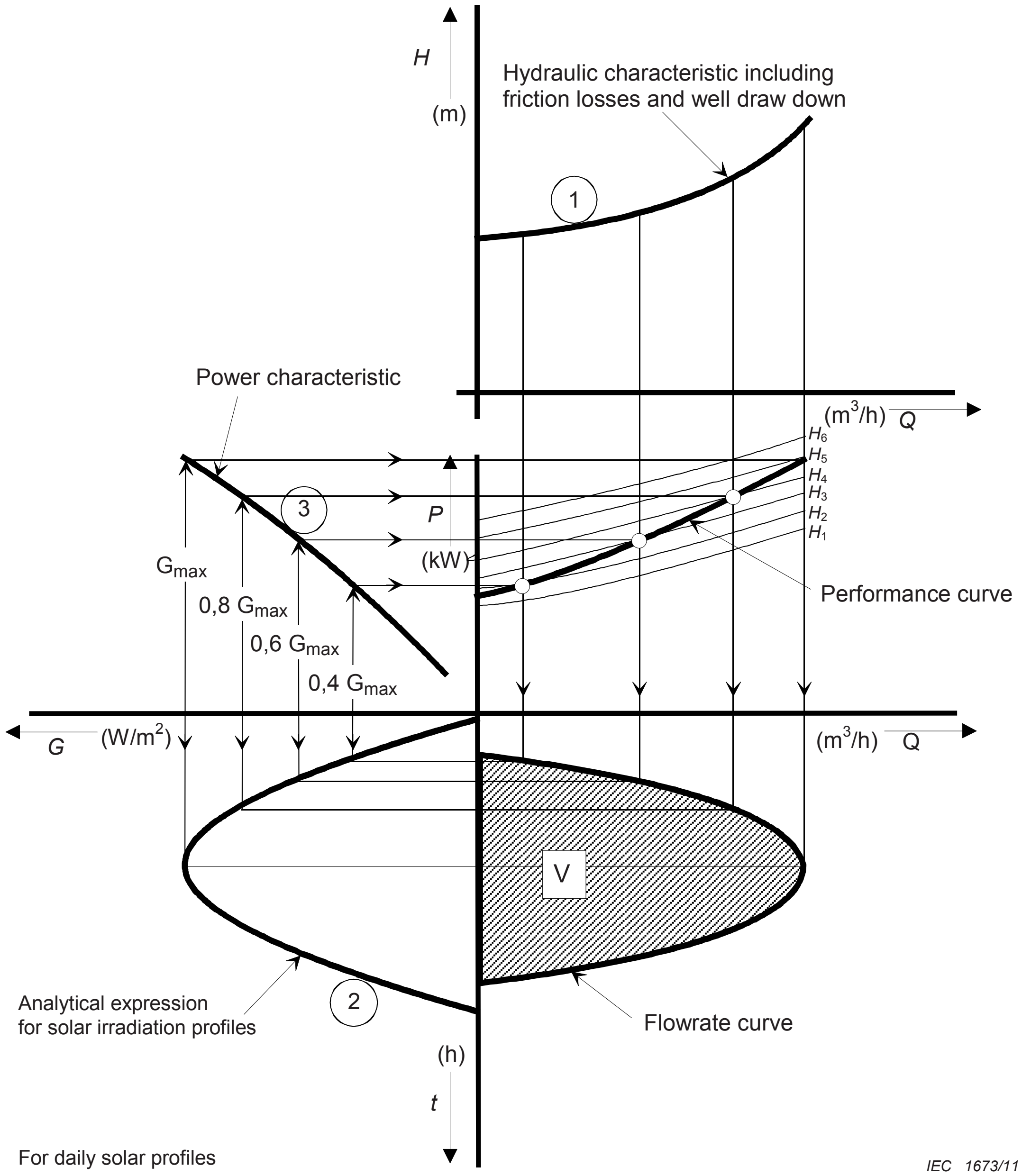


**Figure A.1 – System performance for a centrifugal pumping system**

## A.2 Technical data, component characteristics (to be supplied by component manufacturers)

### PV-Generator

Module manufacturer: ____________________

Module type: ____________________

Number of modules (serial x parallel): ____________________

Module size: ____________________

Modules certified according to

IEC 61215, IEC 61646 and IEC 61730, ☐ Yes ☐ No

I-V characteristics of PV-generator at corresponding ambient temperatures (PV-module cell temperature) and irradiance levels.

300 W/m$^2$ to 1000 W/m$^2$ in 100 W/m$^2$ steps

The output data should contain the mismatch losses. The PV-generator data should be given for the expected ambient temperature (PV-module cell temperature) range and at a wind speed of 1 m/s.

### PV-Converter (as applicable)

Manufacturer: ____________________

Type: ____________________

Output:
DC, EC ☐
AC mono-phase ☐
AC, three-phase ☐

Input voltage: $U_N$ = ________________ V
$U_{min}$ = ________________ V
$U_{max}$ = ________________ V

MPPT Yes ☐ No ☐

Input current $I_{max}$ ________________ A
Input voltage $U_{max}$ ________________ V
Output: ________________ VA/W
Output voltage range: ________________ V
Output frequency range: ________________ Hz if applicable
Output current: $I_{max.}$ ________________ A

Converter efficiency progression from 0,05 $P_N$ to $P_N$ (see IEC 61683:1999 Table 1)

### Motor

Manufacturer: __________________________ ☐ AC ☐ DC

Type: __________________________

Nominal output: __________________________ W

Nominal voltage/frequency: ____________ V ____________ Hz (if applicable)

Voltage operation range: ____________________

Nominal current: ____________________ A

Maximum current: ____________________

Power factor cos φ: __________ at __________ Hz (if applicable)

Max. diameter and length of motor: ________________ mm

Temperature range min.: _______ max.: _______ °C

**Pump**

Manufacturer: ____________________

Type: ____________________

Pump head: range of operation: __________ m nominal = _______ m

Volume flow: range of operation: __________ $m^3/h$ nominal = _______ $m^3/h$

Max. diameter and length of pump: __________ mm

Temperature range min.: _______ max.: _______ °C

**Other specifications**

| | yes | no |
|---|---|---|
| Dry running protection: | ☐ | ☐ |
| Overload protection | ☐ | ☐ |

Other information: ________________________

________________________

___________

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