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Government of India
Ministry of New and Renewable Energy
(Standards & Quality Control Division)
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Atal Akshay Urja Bhawan
Opp. C.G.O. Complex, Lodhi Road
New Delhi-110003
Dated: 12.8.2026

OFFICE MEMORANDUM

Subject: Invitation of comments on Draft Specification of Solar Pump Controllers- reg.

The National Institute of Solar Energy (NISE) has prepared draft revised specifications for the Solar Pump Controller, which are now placed in the public domain through the official website of the Ministry of New and Renewable Energy (MNRE) for invitation of comments from all the stakeholders. The comments, if any, may be furnished to **rajkumarb.mnre@gov.in** and **kamlesh.yadav@nise.res.in** latest by 28th August 2026.

2. A copy to the draft specification is enclosed herewith.

(Rajkumar Bhawariya)
Scientist "C"

To

All Concerned

Copy to:

1. PS to JS (S&QC)
2. Hiren Chandra Borah, Scientist 'E'
3. Director (NIC) – for uploading draft specification on the website of MNRE

The PM-KUSUM Scheme has emerged as a transformative initiative for promoting energy security, enhancing agricultural productivity, and improving the livelihoods of farmers through the deployment of decentralized solar energy systems. Under Component-B of the Scheme, standalone solar photovoltaic water pumping systems have been deployed across diverse climatic and geographical regions of the country, enabling reliable irrigation while reducing dependence on conventional energy sources.

With the successful implementation of a large number of solar pumping systems, valuable field experience has been gained regarding system performance, technological evolution, long-term maintainability, and opportunities for enhanced utilization of the installed solar assets. The rapid advancement of photovoltaic module technologies, changes in module ratings and operating voltages, and the growing need for greater flexibility in rural energy applications necessitate a forward-looking approach in the design and specification of solar pump controllers to improve system flexibility, long-term sustainability, and overall utilization of installed solar assets.

Presently, solar pumping systems are primarily designed for irrigation applications and remain underutilized for a substantial part of the year. At the same time, advancements in photovoltaic module technologies, changes in module ratings and operating voltages, and the need for long-term serviceability require controller designs that are adaptable, interoperable, and future-ready. The proposed specification, therefore, emphasizes wider PV input voltage operating ranges, robust MPPT functionality, compatibility with evolving PV module technologies, and reliable operation under varying climatic conditions across India.

The specification also introduces provisions for multifunctional controller operation, including off-grid, off-grid with storage, and hybrid modes. These capabilities can facilitate productive utilization of available solar energy beyond water pumping applications, improve asset utilization, enhance energy access in rural areas, and create opportunities for additional income generation wherever feasible.

The objective of this specification is to establish a standardized, reliable, and future-compatible framework for solar pump controllers that supports technological innovation, protects farmer interests, improves system longevity, and strengthens the long-term effectiveness of the PM-KUSUM programme in achieving India's clean energy and sustainable agriculture goals.

Solar Photovoltaic Water Pumping Controllers —Performance, Safety and Test Requirements

1 Scope

This standard specifies the minimum technical, safety, performance, power quality, environmental, and test requirements for solar photovoltaic (PV) water pumping controllers intended for use in off-grid: with or without Storage, Multi-function controller, grid-feeding, and grid-interactive pumping systems. It applies to agricultural, potable water supply, community water systems, and industrial Solar pumping applications. The standard covers controllers with PV input voltages up to 1000 V d.c., single- or/and three-phase outputs, and compatibility with induction motors, permanent magnet synchronous motors (PMSM), and brushless direct current (BLDC) motors.

2 Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this standard. The latest editions shall apply.

• IS 17018-1 — Solar photovoltaic water pumping systems — Centrifugal pumps

• IS 16221 (Part 1) — Safety of power converters for use in photovoltaic power systems

• IS 16221 (Part 2) — Safety of power converters for grid-connected photovoltaic systems

• IS 16169 — Procedure for islanding prevention measures

• IEC 60990:1999 — Touch Current Measurement

• IEC 60529 — Degrees of protection provided by enclosures (IP Code)

• IS/IEC 61683 — Procedure for measuring efficiency of PV power conditioners

• IEC 62116 — Test procedure of islanding prevention measures

• IEC 60068-1,2,14 & 30 (series) — Environmental testing

• IS 3043 — Code of practice for earthing

2.2 Informative References

The following documents are provided for information and guidance only and do not constitute normative requirements of this standard:

- Ministry of New and Renewable Energy (MNRE), *Technical Specifications for Solar Water Pumping Systems*

- IEC 61000-4-7, *Electromagnetic Compatibility (EMC) — Part 4-7: Testing and Measurement Techniques — General Guide on Harmonics and Interharmonics Measurements and Instrumentation for Power Supply Systems and Equipment Connected Thereto*
- IEC 61000-3-2, *Electromagnetic Compatibility (EMC) — Part 3-2: Limits — Limits for Harmonic Current Emissions*

3 Terms and Definitions

For the purpose of this standard, the definitions given in IS 16221 and the following shall apply.

3.1 **Solar PV Water Pumping Controller** — A power electronic unit that converts DC power from a PV array into suitable electrical output for driving a water pump motor, incorporating control, protection, and monitoring functions.

3.2 Maximum Power Point Tracking (MPPT)
An algorithm or control mechanism employed to continuously adjust the operating point of a PV array in order to extract the maximum available power under varying irradiance and temperature conditions.

3.3 Static MPPT Efficiency
The ratio of the actual power extracted from the PV array to the theoretical maximum available power under steady-state operating conditions, expressed as a percentage.

3.4 Dynamic MPPT Efficiency
The ratio of the actual energy extracted from the PV array to the theoretical maximum energy available during transient operating conditions involving rapidly varying irradiance, typically evaluated using hot and cold irradiance profiles as per IS 17018-1.

3.5 Total Harmonic Distortion (THD)
A measure of the harmonic content of a voltage or current waveform, expressed as a percentage of the fundamental frequency component.

3.6 Single-Fault Condition
Any reasonably foreseeable failure of a single component or element that may occur during normal operation or reasonably foreseeable misuse of the equipment.

3.7 Grid-Feeding Controller
A solar PV water pumping controller designed to supply electrical power to the utility grid, either simultaneously with or independently of pump operation, in accordance with applicable grid codes and safety requirements.

3.8 Anti-Islanding
A protection function that prevents the controller from energizing the utility grid during a grid outage or loss of mains supply.

3.9 Voltage Spike
A short-duration transient increase in voltage beyond the normal operating range, typically caused by switching operations, motor cable impedance, or inductive load effects.

3.10 V/f Control
A motor control strategy in which the ratio of output voltage to frequency is maintained at a constant value to ensure constant magnetic flux in the motor.

3.11 Induction Motor
An alternating current motor in which the rotor current is induced by the magnetic field produced by the stator, resulting in rotor motion by electromagnetic induction.

3.12 Permanent Magnet Synchronous Motor (PMSM)
A synchronous alternating current motor in which the rotor magnetic field is produced by permanent magnets.

3.13 Brushless Direct Current Motor (BLDC)
An electric motor in which commutation is achieved electronically using power electronic switches, eliminating the need for mechanical brushes.

3.14 Dry Run (No-Load Operation)
Operation of a water pump without adequate water flow or discharge, which may lead to overheating, mechanical damage, or premature failure if not detected and controlled.

3.15 Decisive Voltage Classification (DVC)

DVC-A (Safe to Touch): - No protection against direct contact required

- AC: ≤25V RMS (16V in wet locations)

- DC: ≤60V (35V in wet locations)

DVC-B (Hazardous): - Protection against direct contact required

- AC: ≤50V RMS (33V in wet locations)

- DC: ≤120V (70V in wet locations)

DVC-C (Hazardous): - Full protection measures required

- Above DVC-B limits

3.16 Insulation Types

Basic Insulation: Minimum protection against electric shock

Supplementary Insulation: Additional protection in case of basic insulation failure

Double Insulation: Basic + supplementary insulation

Reinforced Insulation: Single system equivalent to double insulation

Functional Insulation: For proper operation only, not shock protection

3.17 Environmental Classifications

Pollution Degrees: - PD1: No pollution or dry non-conductive pollution

- PD2: Non-conductive pollution, occasional temporary conductivity

- PD3: Conductive pollution or non-conductive pollution becoming conductive

Overvoltage Categories (OVC):

- OVC-I: Equipment with measures to limit transient over voltage

- OVC-II: Energy-consuming equipment supplied from fixed installation

- OVC-III: Fixed installation equipment

- OVC-IV: Origin of electrical installation equipment

4 General Requirements

4.1 Rating, Capacity and Marking

Rated Power Requirement:

The rated power of the controller shall be declared by the manufacturer and verified through independent testing. The controller shall be capable of continuously delivering its marked output power or rated current, as applicable, for a minimum duration of two hours while operating the pump at its peak rated voltage and frequency. During this period, the controller shall operate without tripping any overcurrent protection devices and without shutdown due to activation of over-temperature protection.

The controller rated power shall be equal to or greater than the peak power of the connected PV array, as specified for each water pumping system model in the MNRE specifications and IS 17018-1. This requirement ensures full utilization of the available PV array power, particularly for motors and pumps designed to operate over a wide frequency range.

Marking:

The controller shall be provided with a permanent rating plate and safety markings that are etched or embossed, with a minimum character height of 3 mm for text and minimum symbol size of 10 mm, and shall be weatherproof, in accordance with IS 16221 (Part 1):2016, Clause 5.1 and Annex C. The rating plate and markings shall be securely fixed and shall remain legible throughout the service life of the equipment.
The rating plate shall include, at a minimum, the following information:

a) Manufacturer and Identification Details

Manufacturer’s name and/or trademark

Model number
Serial number
Month and year of manufacture

b) PV (DC Input) Ratings and Markings

Maximum PV input voltage: ___ V DC
Maximum PV short-circuit current: ___ A
Maximum permissible PV array power: ___ kWp
MPPT voltage range: ___ to ___ V DC
Maximum PV input current per MPPT (if applicable): ___ A
Number of MPPT inputs (if applicable): ___
Overvoltage Category: OVC III
Pollution Degree: PD 3
Degree of protection (enclosure): IP65 or higher
Equipment class: Class I
Ambient temperature range: 0 °C to 50 °C

c) Motor Output Ratings

Motor output voltage range: ___ to ___ V AC/DC
Rated motor power: ___ kW
Rated output current: ___ A
Supported motor type(s): Induction / PMSM / BLDC (as applicable)

d) In addition to the above, the following mandatory safety symbols and warning markings shall be provided, as applicable as per as per Annex C IS 16221-1:

a). Warning – Disconnect PV Supply Before Servicing
Text: "DISCONNECT PV SUPPLY BEFORE MOTOR OR CONTROLLER SERVICE" (Symbol No. 21)
b). Protective Earth (PE) Terminal Green-yellow identification with M6 earthing stud (Symbol No. 11)
c). Hot Surface Warning - Required where accessible surface temperature exceeds 70 °C (Symbol No. 14)
d). Warning – Hazardous DC Voltage- Required for PV input terminals exceeding 120 V DC, as per Annex C

4.2 Input Voltage Range

The solar pumping controller shall incorporate Maximum Power Point Tracking (MPPT), either as an integral or externally connected unit, to effectively manage PV array voltage variations resulting from changes in temperature, solar irradiance, module ageing, and environmental degradation. The DC input voltage operating range shall be sufficiently wide to accommodate variations in the number and rating of PV modules arising from technological advancements such as improvements in module efficiency and changes in module size.

The system shall also permit operation with one PV module more or less, which may occur due to bypass diode activation under certain operating conditions. The minimum, nominal, and maximum PV input voltage values shall be declared by the manufacturer. In addition, testing shall be carried out at minimum, nominal, and at least 90% of the maximum declared input voltage.

For all motor–pump sets, the controller shall be capable of at least operating at PV input voltages of **nominal −15%, nominal, and nominal +15%**, delivering the rated power at all three voltage levels. This requirement ensures reliable year-round operation across all regions of India, including under both low- and high-temperature conditions throughout the available sunshine hours.

Water pumping systems with a rated capacity of **10 kVA or higher** shall be equipped with **multi-channel MPPT** to minimize PV array mismatch losses and to maximize overall energy harvest.

5. Overall System Efficiency and MPPT Performance Requirements

5.1 Power Conversion Efficiency

For operation at or above **80% of rated STC PV power**, the **static power conversion efficiency** of the system shall meet the requirements specified below, irrespective of the controller topology, i.e., single-stage (inverter only) or two-stage (DC–DC buck/boost followed by inverter):

- For systems with **rated capacity ≥ 5 kVA / 5 HP**, the static power conversion efficiency shall be **not less than 94%**.
- For systems with **rated capacity < 5 kVA / 5 HP**, the static power conversion efficiency shall be **not less than 93%**.

5.2 MPPT Efficiency Requirements

5.2.1 Static MPPT Efficiency

Static MPPT efficiency is defined as the ratio of the actual power extracted from the PV source to the theoretical maximum power available from the PV array under steady-state operating conditions.

$$\eta_{MPPT,static} = \left(\frac{P_{in,actual}}{P_{in,theoretical}}\right) \times 100$$

where:

- $P_{in,actual} = V_{dc} \times I_{dc}$ is the measured DC input power, and
- $P_{in,theoretical}$ is derived from the PV module datasheet at the applied operating voltage.

Static MPPT efficiency shall be **not less than 98%** over the operating range of **10% to 100% of rated PV input power**.

5.2.2 Dynamic MPPT Efficiency

Dynamic MPPT efficiency is defined as the average maximum power point tracking efficiency of the controller under transient operating conditions with continuously varying irradiance, including both **hot-day** and **cold-day** profiles, as specified in **IS 17018-1**.

$$\eta_{MPPT,dynamic} = \left(\frac{\text{Energy Extracted}}{\text{Energy Available}}\right) \times 100$$

Dynamic MPPT efficiency shall be **not less than 97%** under dynamic operating conditions.

5.3 Overall System Efficiency

Overall system efficiency represents the combined efficiency of power conversion by the controller and its MPPT tracking performance.

$$\text{Overall System Efficiency} = \frac{\text{Static Power Conversion Efficiency} \times \text{Dynamic MPPT Efficiency}}{100}$$

Overall system efficiency shall be evaluated at **minimum, nominal, and 90% of maximum DC input voltage**, and at the following DC input power levels:

DC Input Power (%)	Static Power Conversion Efficiency (%)	Static MPPT Efficiency (%)	Overall System Efficiency (%)
10 (Partial load)			
25			
50			
75			
100 (Rated load)			

The minimum overall system efficiency requirements, evaluated at **≥ 80% of rated PV input power**, shall be as specified in Table below:

Controller Rating	Operating Point	Conversion Efficiency	MPPT Efficiency	Minimum Overall Efficiency
< 5 HP	≥ 80% of rated PV power	≥ 93%	≥ 97%	≥ 90.2%
≥ 5 HP	≥ 80% of rated PV power	≥ 94%	≥ 97%	≥ 91.2%

6. Control and Operating Modes

The controller shall support suitable motor control strategies, such as constant V/f control, flux control, or equivalent manufacturer-developed algorithms, to ensure stable and reliable operation from zero speed up to rated speed.

In the case of a Universal Solar Pump Controller (USPC) capable of operating other agricultural loads such as chaff cutters, atta chakki (flour mills), and similar equipment, the controller shall additionally be capable of withstanding a minimum torque overload of 150% for a duration of 30 seconds, at any operating power level.
Compliance with the above requirement shall be verified using a torque testing arrangement, either by:

- increasing the applied mechanical torque up to 150% of rated torque, or
- increasing the motor load current up to 150% of rated current, while the motor is connected to alternator and operated by the universal solar controller.

Further, the USPC shall provide multiple selectable load outputs; however, only one load shall be operable at any given time. Load selection shall be carried out through the controller interface, ensuring electrical and operational interlocking between outputs.

7. Power Quality Requirements

Output Waveform (accordance with IS 16221 (Part 2):2015, Clause 4.7.5)

For solar pump controllers supplying to induction motors and PMSM motors with sinusoidal output, the stand-alone inverter shall deliver an AC output voltage waveform with total harmonic distortion (THD) not exceeding 10 %, and no individual harmonic component exceeding 6 % of the fundamental. Compliance shall be verified at 25 % (or minimum continuous), 50 %, and 100 % of rated output power to the load, with the controller supplied at nominal DC input voltage. THD shall be calculated considering harmonic orders from n = 2 to n = 40. This requirement ensures stable motor operation, acceptable heating, reduced torque ripple, and reliable long-term performance for induction, PMSM, motors operated with sinusoidal voltage excitation.

For motor operation with intentionally non-sinusoidal output voltage, the controller shall comply with relaxed waveform limits suitable for dedicated motor loads. In such cases, the voltage THD shall not exceed 40 %, the rise and fall slope of voltage transitions shall be limited to 10 V/µs (measured between 10 % and 90 % of peak voltage), and the peak output voltage shall not exceed 1.414 × 110 % of the rated RMS output voltage. Compliance shall be verified at 10 %, 50 %, and 100 % of rated output power, at the DC input voltage producing the worst-case condition. The inverter–motor combination shall be demonstrated, through testing or analysis, to operate safely without excessive heating, insulation stress, or malfunction of protective and control circuits, and appropriate information shall be provided in the installation instructions.

Voltage Spike Limitation

The peak voltage at motor terminals (after adding more than 60-meter cable) shall not exceed 620 V for 415 V systems. Spike duration shall be less than 1 µs.

8 Protection Against Electric Shock

8.1 Insulation Requirements
The controller shall be designed and constructed to provide adequate protection against electric shock under normal operating conditions and single-fault conditions. The insulation

withstands and insulation resistance tests shall be carried out in accordance with IS 16221 (Part 1):2016, Clause 7.5.

Test Procedure

1. Subject the equipment to humidity preconditioning of 92%RH/40°C for 48h in accordance with IS 16221 (Part 1):2016, Clause 4.5.
2. Electrically connect the following terminals together as applicable for the test configuration:
   - PV positive (PV+)
   - PV negative (PV−)
   - Motor output terminals (U, V, W)
   - Protective earth (PE), where required
3. Apply an AC test voltage of **V_H: ___ V (r.m.s.)** at 50 Hz for a duration of 1 minute, calculated as *($V_H = 2 \times$ maximum PV input voltage + 1000 V)*.
4. Measure the leakage current during the test.

Acceptance Criteria

- Leakage current shall not exceed 5 mA (r.m.s.)
- No insulation breakdown, flashover, or arcing shall occur during the test
- After completion of the dielectric withstand test, the insulation resistance shall be greater than 100 MΩ when measured at 500 V DC, in accordance with IS 16221 (Part 1):2016, Clause 7.5.3

8.2 Touch Current Test

Test Procedure

(Detailed circuits: IEC 60990:1999 Clause 9)

Connect PE terminal to meter (Network 1 for AC, Network 2 for DC)

1. Operate at rated PV input → rated motor load
2. Measure steady-state leakage

Acceptance Criteria: ≤3.5 mA AC / ≤10 mA DC *(IS 16221 Part 1:2016 Table 16)*, Meter reading within limits, no unintended shutdown.

8.3 Stored Energy Discharge

Test Procedure *(IS 16221 Part 1:2016 Clause 7.3.9)*

1. Charge to Vmax PV = Based on the controllers rating VDC (steady-state)
2. Disconnect PV input (simulate switch open)
3. Measure PV terminal voltage at t=2, 5, 10 seconds

Acceptance Criteria: Voltage <60 V at t=10s *(all capacitors/points)*.

9 Environmental Protections

Solar pump controllers operate in harsh Indian farm conditions: high dust (Pollution Degree-3), monsoon humidity (92% RH), being a Fixed installation equipment (OVC III). This clause specifies tests ensuring enclosure integrity and insulation withstand.

9.1 IP65 Ingress Protection Test

Equipment shall provide complete protection against dust ingress (IP6X) and water jets IPX5) typical of farm environments - dusty fields + monsoon rains.

Test Procedure: *IS/IEC 60529:2013 Clause 14)*
Mount controller per installation instructions. Verify all covers/doors closed. Inspect for gaps/cracks.

1. **Dust Test (IP6X)**:
   The equipment shall be placed inside the dust test chamber containing talcum powder at a concentration of 2 kg/m³. Continuous air circulation shall be maintained for a duration of 8 hours (±15 minutes) to ensure uniform suspension of the dust. During the test, a pressure differential shall be applied such that the pressure inside the enclosure is maintained at 2 kPa below ambient pressure. After completion of the dust exposure, the equipment shall be removed from the chamber and allowed to rest under ambient environmental conditions for a minimum period of 1 hour before further evaluation.
2. **Water Test (IPX5)**:
   For the water ingress test (IPX5), water at a temperature of ambient ±10 °C shall be used. Water jets shall be applied to the equipment from a distance of 2.5 m to 3.0 m with nozzle mounted 30° tilt from horizontal. The water jet shall be directed successively at 0°, 90°, 180°, and 270° around the enclosure, and exposure shall be maintained for a duration of 3 minutes in each direction, ensuring uniform coverage of all accessible surfaces.
   Upon completion of the water test, the equipment shall be allowed to drain for a minimum period of 1 hour under ambient conditions, with no external electrical power applied, before inspection or further evaluation.

   Acceptance Criteria
   Dust: No visible talcum powder ingress (internal inspection)
   Water: No water accumulation affecting components/function
   Functional: Normal operation shall be observed post-test

9.2 Humidity Preconditioning
Simulates monsoon conditions causing Pollution Degree3 (dry dust becomes conductive when wet). Mandatory before dielectric tests as per clause 6.1
Test Procedure: (*IS 16221 Part 1:2016 Clause 4.5; detailed: IEC 60068-2-78)*

1. Place controller in chamber (powered OFF, covers closed)
2. Stabilize: 92% RH ±3%, 40°C ±2°C
3. Continuous exposure: 48 hours ±2 hours
4. Remove and dry externally (no internal drying)
5. Proceed to dielectric test as per clause 6.1 and (Seq 3) - no more than 2 hours delay

9.3 Impulse Voltage Test (OVC III)
Verifies insulation withstand against rural lightning-induced transients. Test voltage derived from V_{Max} PV × OVC III multiplier *(IEC 60664-1 Table F.1)*.
Note: For detailed OVC III voltage selection, refer **IEC 60664-1:2007 Clause 6.2.3** (1000 V PV × 4.0 multiplier = 6 kV).

Test Procedure: *(IS 16221 Part 1:2016 Clause 7.5.1; waveform: IEC 60060-1)*
Test Circuits *(Apply between indicated points, all other terminals shorted to ground)*:

Circuit Pair	Test Points
PV ↔ Motor	PV+ ↔ Motor U/V/W

PV ↔ Earth	PV+/- ↔ PE terminal
Motor ↔ Earth	Motor U/V/W ↔ PE terminal

1. Verify waveform: 1.2 µs rise, 50 µs decay (open-circuit voltage)
2. Apply: 6 kV peak ×3 positive, ×3 negative pulses
3. Pulse interval: Minimum 1 minute
4. Monitor: Leakage current, flashover, component damage

Acceptance Criteria

- No flashover, puncture, or excessive leakage (>5 mA peak)
- No component disruption (visual + functional check)
- Repeat dielectric test (Seq 3): PASS required
- Insulation resistance >100 MΩ @500 VDC post-test

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10. THERMAL REQUIREMENTS

Normal Operation Thermal Test *(IS 16221 Part 1:2016 Clause 4.3)*
Test Procedure:

Materials and components shall be selected so that under the most severe rated operating conditions, the temperatures do not exceed the temperature limits below. Tests of equipment rated for use in ambient temperatures up to 50 °C may be conducted at any ambient temperature, in which case the difference between the maximum rated ambient temperature and the actual test ambient is to be subtracted from or added to (as appropriate) the measured temperatures for comparison to the limits specified below table. Record temperatures after 4 hours steady-state (±2°C variation)

Acceptance Criteria: All readings within limits, no deformation/melting.

Table 7.1 - Temperature Limits *(IS 16221 Part 1:2016 Tables 1-3)*

Component	**Max Temp (°C)**	**Measurement Method**
Metal surfaces (touchable)	65	Surface TC
Plastic enclosure	75	Surface TC
Operator controls	55	Surface TC
Transformer/motor windings	155 (Class F)	Resistance method *(Eq. 1)*
Semiconductors	Per datasheet	Case TC

10. Fault Condition Tests

10.1 Fan Block Test *(IS 16221 Part 1:2016 Clause 4.4.4.8)*
Test Procedure: Cover vents/heatsink with 2 cm surgical cotton, run 7 hours full load.
Acceptance criteria: External surfaces ≤90°C, cotton indicator clean (no ignition).

10.2 Output Short Circuit Test

Test Procedure: *(IS 16221 Part 1:2016 Clause 4.4.4.5)*
Short motor terminals: U-V, V-W, W-U, all 3 together

1. Full PV input (1.25×Isc capacity)
2. Record: peak current, 3-cycle RMS, clearing time

Acceptance criteria: No fire/enclosure deformation, stable OR protection operates *(record max current for manual)*.

10.3. **Dry-run (no-load) operation**

Controller should detect the Dry run operation of the motor and provide error for dry run protection.

10.4. **Open circuit and Reverse polarity of PV input**

Controller should detect Open circuit and Reverse polarity of PV input and provide corresponding error at the display.

11. Requirement in case of controller is with electrical storage:

If the controller having battery charging option, then battery charging circuit meet additional requirement as per -IS 16797: 2019/ IEC 62509: 2010 Battery Charge Controllers for Photovoltaic Systems — Performance and Functioning.

12. Grid-Feeding and Grid-Interactive Requirements

For grid-connected operation, the Hybrid Multi-Function Controller shall additionally comply with the anti-islanding requirements specified in **IEC 62116** and the applicable safety requirements specified in **IS 16221 (Part 2)**.

In the event of a utility grid failure or loss of grid supply, the controller shall automatically detect the abnormal condition and disconnect from the grid within **2 seconds**, thereby preventing unintentional islanding and ensuring the safety of utility personnel and connected equipment.

Prior to connecting or reconnecting to the utility grid, the controller shall synchronize with the grid by ensuring that the voltage, frequency, and phase angle are within the permissible synchronization limits specified by the IEC 61727 and Indian grid code.

13. Type Test Sequence

Seq	**Test**	**PRE**	**METHOD *(Reference)***	**REQUIREMENT**	**PASS**	**POST**	**Remarks**

1	Visual	As received	Markings *(IS 16221-1:5.1)*	All present	Rating plate OK	Verified	Authenticity
2	Humidity	New unit	92%RH/40°C, 48h *(IS 16221-1:4.5)*	PD3 sim	No corrosion	Dry	Conform operation in Monsoon dust
3	Dielectric AC	Post-humidity	V/1min *(IS 16221-1:7.5.2)*	≤5mA	No breakdown	IR>100M Ω	Insulation
4	Impulse	Post-3	6kV×6 *(IS 16221-1:7.5.1)*	OVC III	No flashover	Repeat 3 PASS	Lightning
5	Touch Current	Normal op	PE leakage *(IEC 60990)*	≤3.5mA AC	Meter OK	Running	Conform safety from Wet hands touch
6	Stored Energy	PV=V Max	Disconnect *(IS 16221-1:7.3.9)*	<60V/10s	Oscilloscope	Safe voltage	During Maintenance
7	Thermal Normal	50°C amb	Full load 4h *(IS 16221-1:4.3)*	Table 7.1	TCs OK	No deform	High ambient temperature operation
8	IP65	Post-7	Dust+jet *(IS/IEC 60529)*	No ingress	Visual	Dry/func	Protection form Dust+monsoon
9	Waveform	Rated PV	*(IS 16221-2:4.7.5)*	Table 9.1	THD OK	Motor stable	Efficiency
10	Short Circuit	Full PV	Motor short *(IS 16221-1:4.4.4.5)*	No fire	Stable/trip	IR>100M Ω	Wiring fault
11	Backfeed	PV off	Motor short *(IS 16221-1:4.4.4.6)*	≤Isc rating	Current OK	Thermal OK	Reverse flow
12	Fan Block	Full load	Vents blocked *(IS 16221-1:4.4.4.8)*	≤90°C ext	Cotton clean	Repeat 7	Dust block
13	Overload	150% load	Continuous *(IS 16221-1:4.4.4.7)*	≤90°C ext	Trip/stable	Func OK	Pump stall
15	Efficiency test	PV sweep	Operation complete range of MPPT	≥ 90.2% (below 5 hp) ≥ 91.2% (above 5 hp)	All OK		Performance
16	Power Quality Test	At 25 % to 100 % load	IS 16221 (Part 2):2015, Clause 4.7.5)	< 10 % in case of sinusoidal output < 40 % in case of Nonsinusoidal Controller and peak voltage should be below 620 V	All OK		Aging of the Motor

Post-Test Protocol *(MANDATORY after EVERY test)*

1. **Dielectric**: Repeat Seq 3 → PASS *(IS 16221-1:4.2.2)*
2. **IR**: >50 MΩ @500 VDC *(IS 16221-1:7.5.3)*
3. **Visual**: No char/melt/deform *(IS 16221-1:4.4.3)*
4. **Function**: Basic PV→motor OK

FAIL = ANY violation above

13. **Display, Remote Monitoring System and Alarm:**

Controller shall be integrated with Remote Monitoring System with GSM/GPRS and Geo tagging. On the Display and in the remote monitoring various parameters should be present on the SPV Pump Controller display/screen such as:- Pump On/Off status, Fault Name (Such as Dry Run, Short Circuit and low irradiance etc.), Array Input DC Voltage, DC/AC output Current & voltage, operating frequency, Latest RMS Latitude, Latest RMS Longitude, Pump Capacity (HP), PV Module Capacity (KW), Current Generation (kW), Today Solar Generation (kWh), Cumulative Solar Generation (kWh), Today Runs Hours (Hrs.), Cumulative Pump Run Hours (Hrs.), Cumulative Water Discharged (Litres), Total Water Discharged (Litres), Peak Power (kW) supplied by the controller to Motor-Pump Set.

Annexure- I

1. Off-Grid Multi-Function Controller (Without Storage)

The proposed Off-Grid Multi-Function Controller is designed to operate without a dedicated battery energy storage system. Its primary application is the operation of agricultural pumps and motors through **Output-1**. However, modern agricultural practices involve a variety of electrical loads, including three-phase motor-driven equipment as well as small single-phase motor-operated loads commonly used by farmers.

Accordingly, the controller may be configured with the following outputs:

- **Output-1:** Dedicated for operation of Three-phase agricultural pumps/motors.
- **Output-2:** Three-phase output operating in **Voltage/Frequency (V/F) control mode**, capable of providing adequate starting and running torque for other agricultural three-phase loads.
- **Output-3:** Single-phase output operating in **V/F control mode**, capable of supplying sufficient torque for single-phase agricultural machinery and farm equipment.
- **Output-4:** Single-phase output operating at **fixed voltage and fixed frequency** for powering domestic household loads.

The Multi-Function Controller shall provide a total of **four independent outputs**, comprising:

- **Two three-phase outputs** rated at **400 V**, suitable for agricultural and motor-driven applications.
- **Two single-phase outputs** rated at **220 V, 50 Hz**, intended for domestic and other single-phase loads.

The three-phase outputs shall be interoperable and interchangeable with different pump and motor technologies, including:

- Conventional AC induction motor pump sets,
- Permanent Magnet Synchronous Motor (PMSM) pump sets, and
- Brushless DC (BLDC) motor pump sets,

irrespective of the pump controller technology employed.

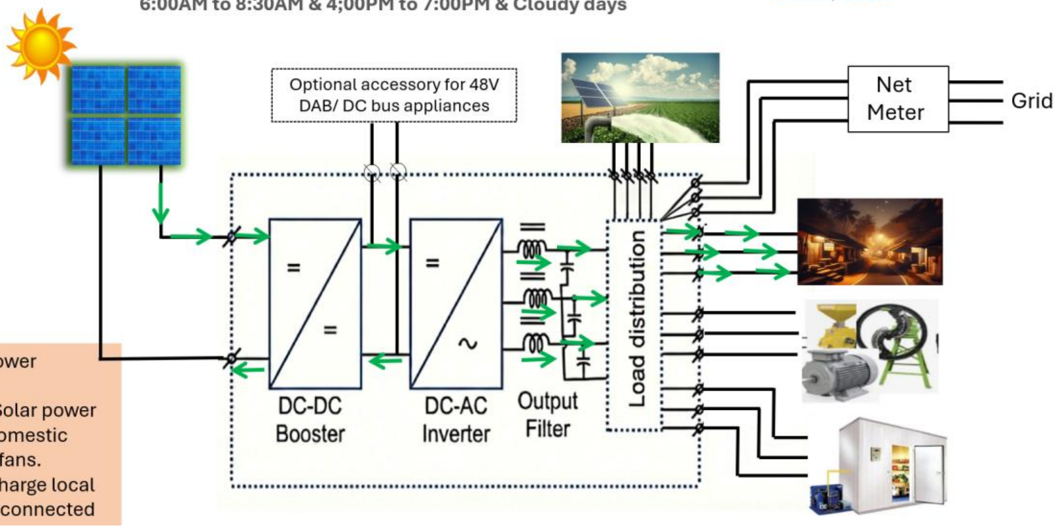
The single-phase outputs may be utilized for operating heavy-duty single-phase agricultural machinery, farm equipment, and household appliances. For domestic applications, the single-phase outputs shall provide a stable **220 V, 50 Hz supply** suitable for powering standard residential loads.

This configuration enables efficient utilization of available solar power for both agricultural and domestic applications, thereby enhancing system flexibility and maximizing the benefits of off-grid solar installations. Examples are as below.

Off-Grid Mode

PV Power
Grid
Load

Condition # 1- Early morning light Domestic use mode
PV Present but not sufficient
6:00AM to 8:30AM & 4;00PM to 7:00PM & Cloudy days

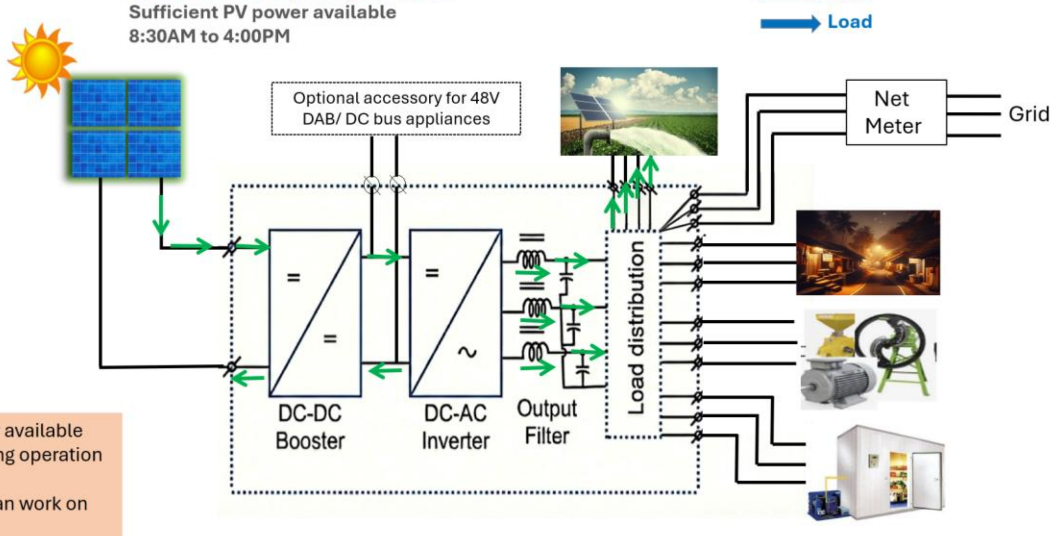


* Partial PV power available
- Whole of Solar power used for domestic lights and fans.
- can also charge local Inv+batt if connected

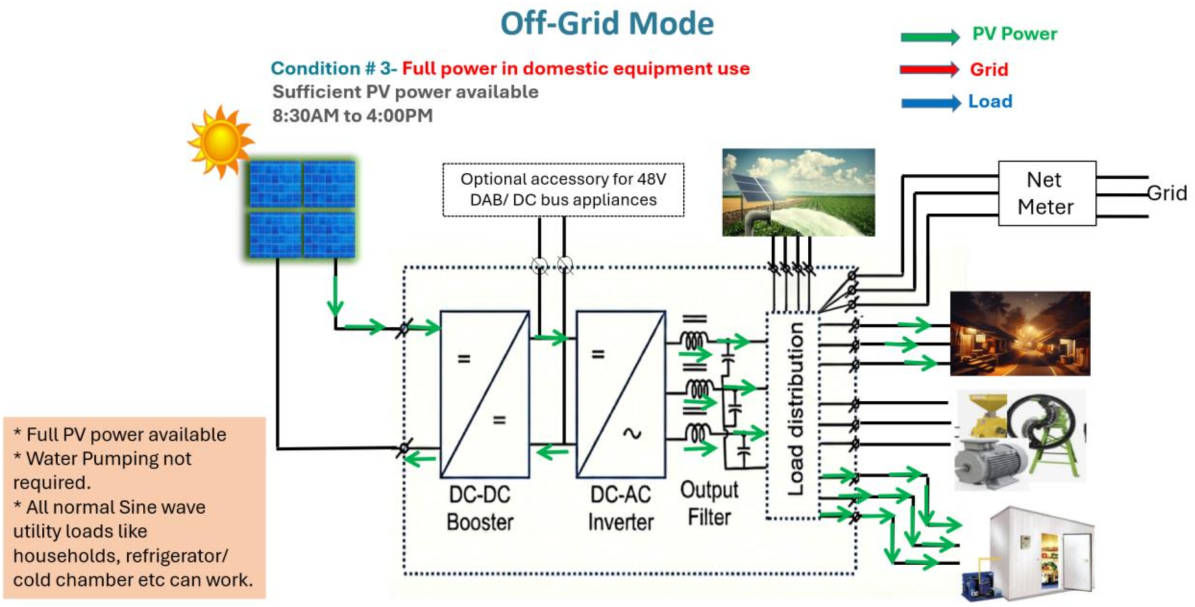
Off-Grid Mode

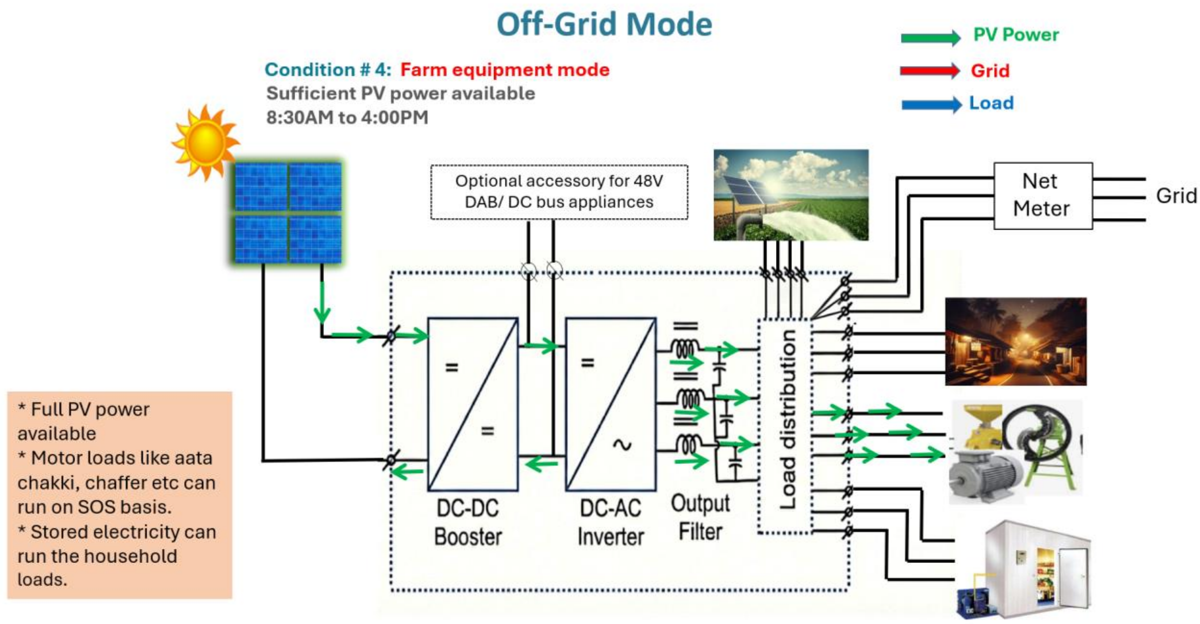
PV Power
Grid
Load

Condition # 2- Only Pump use mode
Sufficient PV power available
8:30AM to 4:00PM



* Full PV power available
* Water Pumping operation to give water.
* Household can work on stored energy





2. Off-Grid Multi-Function Controller with Dedicated Battery Storage

In addition to the above configuration, a dedicated battery energy storage system (BESS) may be integrated to enhance energy security, reliability, and system availability. The battery bank shall be connected to the DC bus through a **Dual Active Bridge (DAB) converter**, enabling bidirectional power flow between the battery storage system and the controller.

The output voltage of the DAB converter connected to the battery bank may vary depending on the battery technology, battery-bank configuration, and storage capacity adopted for the system.

With the integration of the battery storage system, the overall solution shall operate as a unified **Solar PV + Battery Energy Storage System**, capable of supplying power during periods of low solar irradiance, transient load variations, and non-sunshine hours. This arrangement significantly improves the continuity of power supply and enhances the utilization of the installed solar generation capacity.

For functional verification, the complete system, comprising the Solar PV array, DAB converter, battery bank, and multi-function controller, shall be tested as an integrated system. During such testing, both the solar generation source and battery storage system shall remain active while evaluating the operation of various controller modes and output configurations.

For performance evaluation, however, the system shall be assessed under the following operating conditions separately:

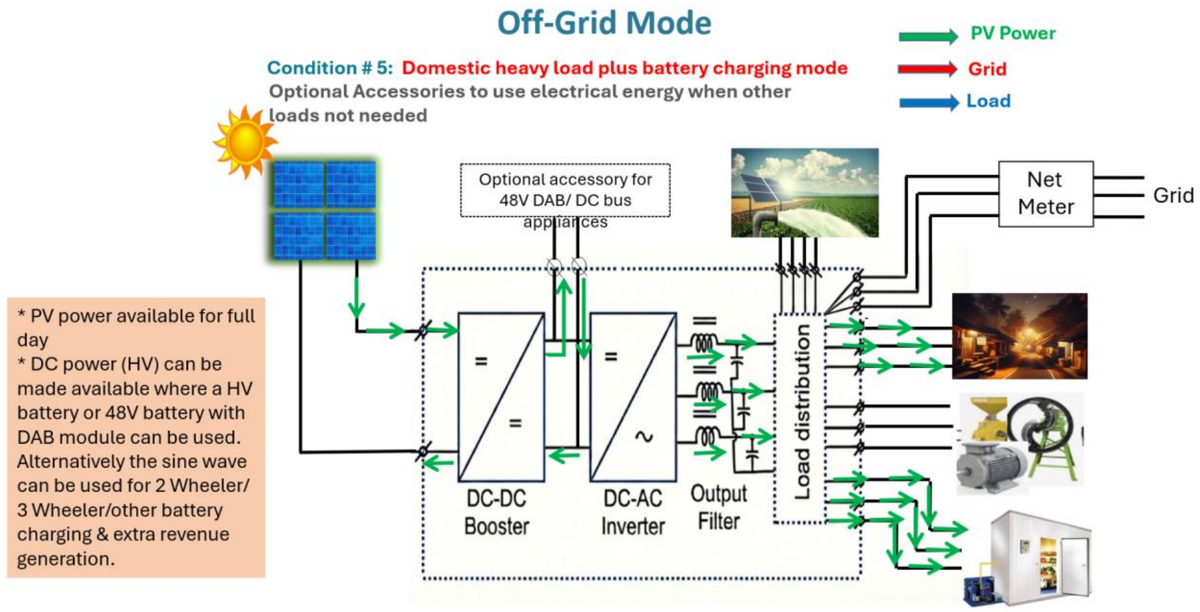
1. **Solar-Only Mode:** Performance testing with power supplied exclusively from the Solar PV system.
2. **Battery-Only Mode:** Performance testing with power supplied exclusively from the battery energy storage system through the DAB converter.

In both operating conditions, the system shall comply with the prescribed performance and efficiency requirements.

The inclusion of dedicated battery storage substantially enhances the usability and operational flexibility of the system by:

- Providing uninterrupted power during low solar generation periods and nighttime operation.
- Supporting critical agricultural and domestic loads during grid outages or adverse weather conditions.
- Improving energy availability and reliability for irrigation and farm operations.
- Enabling better utilization of surplus solar energy through storage and subsequent use.
- Enhancing overall system resilience and energy security for rural and off-grid applications.

The key benefits and use cases of the storage-integrated system are described below.



3. Hybrid Multi-Function Controller with Grid Import and Export Capability

In addition to the off-grid configurations described above, a **Hybrid Multi-Function Controller** may be developed to operate in conjunction with the utility grid. This configuration incorporates both **grid import and grid export functionality**, thereby providing enhanced operational flexibility and improved utilization of available solar energy.

The Hybrid Multi-Function Controller shall be capable of:

- Exporting surplus solar energy to the utility grid when local load demand is lower than the available solar generation.
- Importing power from the utility grid whenever solar generation and/or battery storage are insufficient to meet the connected load demand.
- Seamlessly managing power flow among the Solar PV system, battery energy storage system (where applicable), utility grid, agricultural loads, and domestic loads.
- Ensuring uninterrupted operation of critical loads through intelligent source prioritization and energy management.

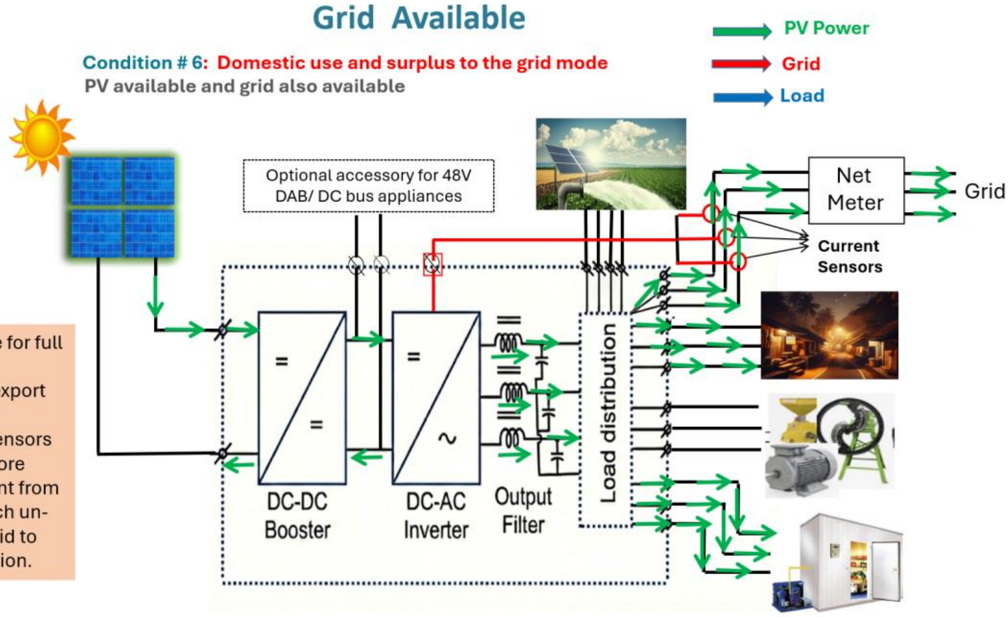
Depending on the regulatory framework and installation requirements, the system may support the operation in the net metering mode or behind the meter operation mode as described below image.

Grid Available

Condition # 6: Domestic use and surplus to the grid mode

PV available and grid also available

* PV power available for full day
* Excess PV power export to grid
* External current sensors used not to allow more than sanction current from grid to avoid any such un-authorised use of grid to avoid feeder disruption.



Annexure- II

Testing Format for the off-Grid Multifunction controller

S.No.	**Test Performed**	**Expected result**	**Test Lab Observation**	**Remarks**
1	Application description on screen and selection of applications	LCD screen provided on controller need to shows various applications which can be selected by keypad using up-down and enter key		
2	Mode operation of applications (Automatic: through keypad or remote / Manual: control switches)	Multi-function controller should come with multiple outputs which can be permanently connected to the application by selecting appropriate options for example following applications should automatically started by appropriate mean such as keypad or remote for selection. (i) Chaffcutter & Atta Chakki (ii) Farm Equipment (iii) Deep fridge/ Cold Storage (iv) 3 and 1 phase load/Pump (v) Domestic Loads Manual changeover is not allowed.		
3	Application Specific output (Application specific software)	Multi-function controller should have inbuilt individual application specific software to run the agrarian applications and Domestic Loads (Up to the Output Power Claimed by Manufacturers) other than pumps and output of the controller should be suitable for above mentioned applications	-	
4	Input PV voltage range Minimum – Voc at STC Nominal – Voc at STC Maximum – Voc at STC	Controller should operate at declared PV input voltages (nominal ±15%). For multi-function controller with storage solution, also test battery input/output charging/discharging mode i.e. programable for the battery bank charging and discharging current and voltage cutoffs.		Functional verification, the complete system, comprising the Solar PV array, DAB converter for battery bank, and multi-function controller, shall be tested as an integrated system. During such testing, both the solar generation source and battery storage system shall remain active while evaluating the operation of various controller modes and output configurations

5	a). Multi-function controller Efficiency measurement in Hot and cold profile should be measured as per IS17980/IEC 62891	**Efficiency of the Controller at minimum……… VOC**

Load %	**Charge controller eff (%)**	**Power tracking Efficiency (%)**	**Overall charge controller efficiency (%)**
10			
25			
50			
75			
100			
Efficiency of the Controller at Nominal ……… VOC			
10			
25			
50			
75			
100			
Efficiency of the Controller at 90 % of Max ……. VOC			
10			
25			
50			
75			
100			
Dynamic MPPT Efficiency			
Hot Profile			
Cold Profile			

b). Only for multi-function controller with storage

For simplicity performance evaluation, the system shall be assessed under the following operating conditions

1.Solar-Only Mode as per detailed in 5 a: Performance testing with power supplied exclusively from the Solar PV system.
2.Battery-Only Mode (as per 5 b). Performance testing with power supplied exclusively from the battery energy storage system through the DAB converter.

Inverter Efficiency Test Result as per IEC-61683 for Standalone mode (for details,

Resistive Load

	Load %	**System Efficiency (%) at pf 1**
Partial output	5	
	10	
	25	
	50	
	75	
Rated output	**100**	

Reactive load

	Load %	**System Efficiency (%) at pf 0.8**
Partial output	25	
	50	
	75	
Rated output	**100**	

6	Ripple and distortion at output on full load	Should below 5 % after 25 % loading condition		
7	Measurement of Output voltage waveform	Three phase output with up to 440 V rms pure Sine Wave to be measured at least 4 times between 300W/m2 irradiance and maximum irradiance as per the irradiance profile. Single-phase domestic output 230 V rms pure sine wave, measured under the same irradiance conditions.	CF value should be provided by lab for voltage and current	
9	Operation at different output from array (Array wattage as MNRE model: Example 4800 Wp array) At 10 % Power At 25 % Power At 30 % Power	Load Operation and Functional Verification Requirements The Multi-Function Controller shall be capable of operating all designated agricultural three-phase loads and one single-phase load operating under variable-frequency control, even at lower solar irradiance levels within the specified operating range. For laboratory verification of functionality, it shall not be mandatory to connect actual field equipment such as atta chakkis (flour mills), chaff cutters, deep freezers, or other agricultural machinery. Instead, equivalent load conditions may be simulated using controlled laboratory test setups as follows: a). The dedicated water-pumping output shall be tested using a suitable motor-pump arrangement b). The three-phase and		Three Phase /single phase Motor current should be recorded (for torque behavior) as it is a function of V/F ratio controlled by Multifunction controller

		single-phase variable-frequency outputs shall be tested by connecting appropriate motors coupled to dynamometers capable of simulating the required load torque characteristics. c). The fixed-voltage/fixed-frequency single-phase output intended for domestic loads shall be tested using resistive and/or programmable load banks. The ability of the controller to operate agricultural loads and handle varying torque demands may be verified by progressively increasing the dynamometer load beyond 150% of the rated motor torque. The test shall determine the maximum torque level that can be sustained before motor stalling or shutdown occurs. Upon exceeding the permissible torque limit, the controller shall initiate appropriate protective action and generate a "Torque Overload" alarm or fault indication. The overload condition may be verified through: Measurement of motor torque using the dynamometer system; and/or Monitoring the corresponding increase in		

		motor current, since motor current is directly related to the developed torque under the specified operating conditions. Successful completion of these tests shall be considered adequate evidence of the controller's capability to operate equivalent agricultural and rural loads without requiring the testing laboratory to procure and operate actual field equipment.		
Basic Battery Charging Function as per IS 16797: 2019/IEC 62509: 2010 Clause No.4.3.2.				
10.	Protect battery from over-charge	Should be Provided through Settable charging logic a). For LFP battery CC - CV mode charging CC:……..I CV……..V b). lead acid battery Boost- ……V Float- …….V		
11.	Protect battery from over-discharge	Load Disconnect	……V	
12.	Set-point accuracy	± 1% for charge control	Complied / Not complied	
		± 2 % for load disconnect	Complied / Not complied	
13. Charging regime as per IS 16797: 2019/IEC 62509: 2010 Clause No.4.3.3				
			Settable	
a).	Required charging stages	**LFP:** CC - CV mode **lead acid battery:** Bulk + Float	LFP Lead Acid	CC : ……(Amp) CV: ……..V Boost: ….. V Float: ….. V
b).	Adjustable charging set-points		Provided / Not provided	
c).	Temperature-compensated charging set points		Provided / Not provided	
d).	Voltage drop compensation for set point measurement		Provided / Not provided	
14. Set-point security as per IS 16797: 2019/IEC 62509: 2010 Clause No.4.3.4				
	Charging set points shall be secured against		Provided / Not provided	

	change other than by deliberate and qualified action			
15. Load disconnect capability as per IS 16797: 2019/IEC 62509: 2010 Clause No.4.3.5				
	Load disconnect	-	…….. V	
16. Energy performance requirements as per IS 16797: 2019/IEC 62509: 2010 Clause No.4.4				
	Stand by self-consumption NO PV I/P, No load, Battery voltage 2.1 V/cell	Max permissible self-consumption 0.1 % of nominal charging current 5Amp ≤ I ≥ 50 Amp	……. Amp @ ….. V	
17. Protection and fail-safe requirements as per IS 16797: 2019/IEC 62509: 2010 Clause No.4.5.1				
	BCC shall be capable of handling input current /power from the generator and load simultaneously for at least 1 h at the manufacturer's specified max rated ambient temp **± 2 °C**		Tested at ….. °C Satisfactory / Non Satisfactory	
18. Over-current protection as per IS 16797: 2019/IEC 62509: 2010 Clause No.4.5.2				
18.	PV side over-current (125 % current rating)	Should be provided		
	Load side	Should be provided		
	PV generator and battery reverse polarity	Should be provided		
	Open ckt on the battery terminal	Should be provided		
19. Over-current protection as per IS 16797: 2019/IEC 62509: 2010 Clause No.4.5.2				
	PV side over-current (125 % current rating)	Should be provided		
	Load side	Should be provided		
	PV generator and battery reverse polarity	Should be provided		
	Open ckt on the battery terminal	Should be provided		
20. Recommended operation information as per IS 16797: 2019/IEC 62509: 2010 Clause No.4.6.2.2				
	Charging indication	Should be provided through display or LED		
	Load disconnect state	Should be provided		
	State of charge of the connected battery	Should be provided		
21. Alarms as per IS 16797: 2019/IEC 62509: 2010 Clause No.4.6.4				
	Low battery voltage	Should be provided (Settable)		
	Load disconnect	Should be provided		

22.	Safety markings and compliance	Verify rating plate (manufacturer, model, PV input ratings, motor output ratings, safety symbols). Must comply with IS 16221 and IEC standards.		
23.	Touch current test	≤3.5 mA AC / ≤10 mA DC leakage under rated load.		
24.	Impulse voltage withstands	Apply 6kV surge (PV ↔ Motor, PV ↔ Earth, Motor ↔ Earth). No flashover or breakdown.		
25.	Thermal test	Under full load, surface temps within limits: metal ≤65°C, plastics ≤75°C, windings ≤155°C.		
26.	Total circuit protection observation	• Soft Startup, • low radiation protection, • overload protection, • Open circuit protection • Reverse polarity protection • Output Short Protection for Domestic Loads		