Design, Supply and Installation of Rooftop Solar Hybrid PV System at Jigme Wangchuck Power Training Institute, Dekiling, Sarpang

1. Background

Jigme Wangchuck Power Training Institute, Sarpang incurs significant electricity costs for office, workshops, hostels, street lights and guest house use, relying fully on the BPC power grid. To reduce costs and dependence on conventional power, the Department of Energy, Ministry of Energy and Natural Resources (MoENR), Royal Government of Bhutan, with funding from the Government of India under Project Tied Assistance (GoI-PTA), is implementing a grid-connected Rooftop Solar Photovoltaic (SPV) system at the Institute. This project aims to lower operational expenses, enhance energy sustainability, and demonstrate renewable energy adoption within TVET Institutions.

2. Site Location

The rooftop Hybrid SPV system is to be installed on building roof tops within the Institute Campus. The following two buildings are identified as suitable site:

- **Site 1(Plumbing and Solar Technology Building) – Hybrid-grid PV generator of 150 KWp. With AC inverter 30KVA**
- **Site 2(Academic Building) – Hybrid-grid PV generator of 150 KWp. With AC inverter 30KVA**

3. Scope of Work

The scope of work shall include the design, planning, engineering, procurement (manufacturing/supply), roof integrity testing, installation, testing, and commissioning of a minimum 150 KWp hybrid SPV system. The hybrid SPV system shall comprise the following:

- Main electrical system including solar PV modules, inverters, battery bank, cables, and protection equipment.
- Solar PV module mounting structures suitable for rooftop installation.
- Energy Storage system
- Lightning protection system.
- Earthing system.
- Data Acquisition system.

All components and works shall comply with applicable standards and ensure the integrity and safety of the rooftop and electrical systems.

4. Solar PV System Overview

Figure 1 shows a schematic diagram of a typical Rooftop Hybrid SPV System. The SPV modules generate DC power, which is fed into at least **three parallel hybrid string inverters**, each with 4–6 MPPTs. The inverters are connected to a battery bank and synchronized with the three-phase grid, then routed through the AC distribution board. A bi-directional meter manages power exchange with the utility grid. Essential safety components, including disconnect switches and earthing points, are installed throughout, while a monitoring unit tracks overall system performance.

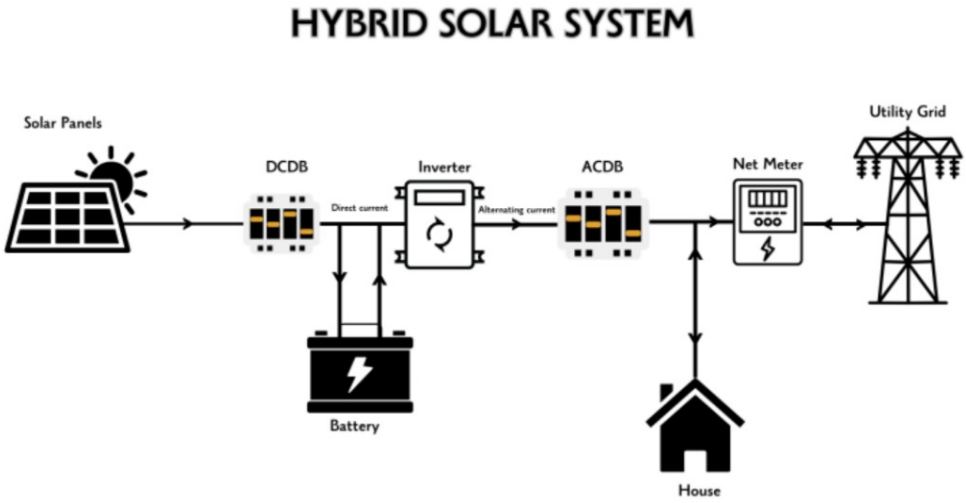

Figure 1: Schematic diagram of a typical Hybrid SPV system.

5. Evaluation of Bids

The evaluation criteria listed below are critical and prerequisite to fulfilling this contract. Therefore, non-fulfillment of any of these requirements may lead to rejection of the bids.

i. *Bidding will be conducted through the National Competitive Bidding procedures specified in the RGoB Procurement Rules and Regulations, and is open to all Bidders as defined in Section V of the Bidding Documents. If deemed necessary, the International/National Bidder may enter JV with National/International firms/suppliers while still being the lead firm for bidding.*

ii. *The Bidder should have 3-5 years' experience in the design, procurement, supply, installation, testing and commissioning of the Rooftop SPV System.*

iii. *At least one key personnel should be certified with a minimum of two years of experience in installation, or have more than five years of experience in the installation, testing, and commissioning of rooftop solar PV systems if not certified.*

iv. *Plans on how the firm will provide hands-on training/skills to the TVET trainers and Trainees.*

The bidders are recommended to propose the methodology in maximum of two pages, which must include capacity building methodologies in the following areas:

1. Installation of SPV System,
2. Testing and commissioning of SPV System,
3. Operation and Maintenance of SPV System.

v. Work plan and time schedule with clear indication of weeks/months and achievable milestones.

Other required documents:

1. Valid Trade License and Tax Clearance Certificate.
2. Certification of installers engaged in the installation, testing, and commissioning of the SPV system.
3. Detailed plans and strategy for providing hands-on training and skills development to the beneficiaries.
4. Proof of the firm's experience in executing similar SPV projects.

The successful bidder shall provide a warranty period for each piece of equipment listed in the Bill of Quantity (BoQ) and conduct hands on training for the basic O&M training for the beneficiaries during the project execution.

6. Instruction to the Bidder

- The bidder shall be responsible for the design, supply, installation, testing, and commissioning of the complete rooftop SPV system, including all necessary civil, mechanical and electrical works for proper functioning.
- The bidder must conduct a site inspection prior to bid submission and present their technical and financial proposal, including system design and equipment selection, to the client on a notified date with at least five days' advance notice.
- All technical documentation, such as design calculations, drawings (including overall dimensions and sectional views), and technical literature necessary for installation, operation, and maintenance of the system and accessories, must be provided. Operation and maintenance manuals, including repair instructions and any other relevant technical data for efficient system operation, shall be submitted before project completion.
- The bidder shall perform system simulation using recognized software (e.g., PVSyst or SAM) to estimate annual energy generation.
- The bidder must submit an experience certificate demonstrating successful execution of a similar rooftop grid-tied SPV project, either as a joint venture or single entity. Failure to provide this will render the bid Non-Responsive.

- Civil, mechanical and electrical works include all installations associated with the SPV system, ensuring alignment with existing structures without compromising structural integrity.
- The bidder is solely responsible for any material shortages during contract execution.
- Upon completion, the site must be cleared of all temporary works and debris, maintaining cleanliness and aesthetics during all phases.
- Warranties shall include a minimum one (2) year defect liability period covering manufacturing, design, and installation defects from the date of system handover. The main components, such as modules and inverters, shall carry warranties as specified in the technical requirements.
- During the one-year defect liability period, the bidder must ensure satisfactory performance, operation, and regular maintenance, including prompt rectification of defects within fourteen (14) days of notification.
- The bidder shall submit quarterly performance reports during the defect liability period, detailing functionality, efficiency, operations, maintenance or repairs needed, status of key components, and recommendations for system optimization. These reports shall continue for three (3) years post-commissioning as part of performance compliance monitoring.
- All components and spare parts must comply with applicable BIS, IEC, BEE, or other recognized national/international standards and certifications.

7. Technical Specification of the Rooftop SPV System

The Rooftop SPV Project shall be executed on a turnkey basis, which includes design, construction, installation, testing and commission. All the materials and equipment supplied under this tender shall conform to the latest editions of the International Electrotechnical Commission (IEC) Specifications or any other international standards. If equipment is not covered by IEC then other national standards are accepted if it confers equal or superior quality and performance than IEC or other international standards.

7.1. PV Modules

7.1.1. General Requirement

Monocrystalline PV modules shall be used, complying with the latest editions of relevant IEC qualification and safety standards for crystalline silicon solar cell modules. Modules shall be manufactured to ensure reliable performance, durability, and safety throughout their service life. The entire rooftop area shall be optimally utilized.

7.1.2. Standard Compliance

The PV modules shall conform to the following IEC standards:

- IEC 61215: Design Qualification and Type Approval for Crystalline Silicon Terrestrial PV Modules
- IEC 61721: Photovoltaic Module Safety Qualification - Requirements for Construction (Part 1)
- IEC 61730-1 and IEC 61730-2: PV Module Safety Qualification - Requirements for Construction and Testing
- IEC 61853-1: PV Module Performance Testing and Energy Rating
- IEC 62804: Test Methods for Detection of Potential - Induced Degradation

7.1.3. Electrical and Performance Parameter

PV modules of minimum 600 Watts power rating and minimum 20% module efficiency should be used.

The rated output power of each supplied module shall have a tolerance of +3%.

The peak-power point voltage and current of any module or series-connected module string shall not vary by more than ±2% from their respective arithmetic means.

7.1.4. Module Construction and Accessories

- Module frames shall be constructed from corrosion-resistant anodized aluminum with a minimum anodization thickness of 15 micrometers (μm) and shall include provisions for earthing grid connection.
- Each module shall be supplied with factory-installed, stranded, UV-resistant output cables terminated with DC plug-in connectors compatible with MC4-type connectors. The positive terminal shall have a male connector and the negative terminal a female connector. Cable lengths shall be determined by the Contractor per installation requirements and any variations must be approved during detailed engineering.
- Modules shall include a junction box with either external screw terminal connections or be sealed, equipped with bypass diodes to reduce voltage drop. The junction box shall have a hinged, weatherproof lid with captive screws and cable gland entry points or be IP-65 rated sealed type.
- High-quality surge protection devices shall be integrated at module level. Low voltage drop bypass diodes must be provided.
- Interconnections between modules must use high-quality, industry-standard male-female connectors (MC4 or TC4).

7.1.5. Warranty

- Material Warranty: The manufacturer shall warrant the modules against defects and failures attributed to manufacturing or material quality for a minimum period of five (5) years from the date of sale to the bidder. Any malfunctioning modules shall be replaced by the manufacturer with identical or improved designs.
- Performance Warranty: The modules shall have a power output warranty guaranteeing at least 90% of rated power for 10 years, with a maximum degradation of 2.5% in the first year, and thereafter degradation between 0.5% and 0.7% per year.
- Both material and performance warranties shall be transferable to the end-owner assuming legal title of the system or modules.

7.2. Junction Box

The module's junction box must be constructed from UV-resistant material and possess a minimum IP 67 rating. It shall house a minimum of three bypass diodes and include two IS 16781/IEC 62852 certified MC4-compatible connectors factory-attached to IS 17293/IEC 62930 certified copper cables (2.5 mm^2 or 4 mm^2 minimum), with the final cable length being determined by the Bidder based on project requirements.

7.3. String Combiner Box (SCB)

The SCB is essential for multi-string PV systems, serving to electrically combine strings and connect them to inverters. It must include surge protection devices for module safety. All components must be rated for the 1000 V DC system requirement. The specific number of inputs will be determined during detailed engineering based on the approved SLD. The offered SCB model is required to be type-tested and have a track record of satisfactory operation in an existing 1000 V DC Solar PV plant.

7.4. String Fuses

String fuses are mandatory for protecting cables and modules from overcurrent, requiring the PV category suitable for solar applications and adherence to IEC 60269-6 or UL-2579 standards (with fuse bases complying with IEC 60269). They must be designed to protect modules from reverse current overload and must be mounted in pull-out type holders suitable for DIN rail mounting; PCB-mounted fuses are not permitted. For 1000 V crystalline modules, the fuse rating must be suitable for 1000 V and be a minimum of 1.56 times the Isc, with an additional 10% gain accounted for bi-facial modules. Negative grounded systems will require string and inverter input fuses on the negative side, as per the Inverter manufacturer's recommendation.

7.5. DC/AC Disconnect

Both AC and DC lines require Miniature Circuit Breakers (MCB), Molded Case Circuit Breakers (MCCB), a DC/AC Surge Protection Device (SPD), and High Rupturing Capacity (HRC) Fuses to ensure a safe start-up and shut-down of the system. For maintenance and safety, the PV system must include at least one fused DC disconnect and one fused AC disconnect, with the AC disconnection switch installed next to the inverter. Additionally, the Switchgears are necessary to guarantee trouble-free isolation of equipment and to enhance system availability by allowing the load to be fed from more than one source. Finally, the complete operation process and safety instructions must be clearly printed on a sticker and visibly affixed near the inverters.

7.6. DC Distribution Board (DCDB)

- DC Distribution panel to receive the DC output from the array PV rooftop field.
- DCDBs shall have a sheet from enclosure of dust & vermin proof conform to IP 65 protection.
- The bus bars are made of copper of desired size.
- Suitable capacity Miniature circuit breakers (MCB) and Molded Case Circuit Breaker (MCCB), shall be provided for controlling the DC power output to the inverter along with necessary surge arrestors.

7.7. 3-phase Hybrid String Inverter

7.7.1. General Description

The plant shall be equipped with at least three **3-phase string inverters (3x50kVA**), with following technical specifications. They must operate automatically, including wake-up synchronization and shutdown, to minimize losses during nighttime and ensure grid resynchronization upon restoration after failure.

- Technical Specifications – 50 kVA Solar String Hybrid Inverter
- Parameter Requirement
- Rated Power 50 kVA (≈40 kW), Three-phase
- Inverter Type String Hybrid (PV + Battery + Grid)
- PV Input Voltage Max 1100 V DC, MPPT 600–1000 V, 3–6 MPPTs
- Max PV Current 16–18 A per MPPT
- Battery Lithium-ion, 600–800 V DC, AC & DC coupling
- AC Output 220/380/400/415 V, 50/60 Hz, PF >0.99, THD <3%
- Efficiency Max ≥98%, European ≥97.5%
- Protections Anti-islanding, over/under voltage, overcurrent, reverse polarity, surge
- Monitoring RS485/Wi-Fi, remote monitoring
- Cooling Fan/natural, -10°C to 60°C, IP65
- Standards IEC 62109, IEC 61727, CE/UL or equivalent
- Warranty minimum 5 years, transferable to the end-owner of the PV system.
    - Control: Microprocessor or Digital Signal Processor (DSP)
    - Built-in meter and data logger for system performance monitoring via external computers

- LCD display for instantaneous measurement of power, voltage, current, and energy parameters
- Capability to reduce or increase generation based on pre-set voltage thresholds (e.g., generation reduction at +10% voltage)
- Communication: Support for SCADA via Modbus protocol, Wi-Fi connectivity, and interfacing with monitoring software/hardware
- Protection Features: AC/DC overcurrent, loss of synchronism, over-temperature, AC/DC overvoltage and undervoltage, underfrequency and over-frequency, cooling system failure, PV array ground fault, anti-islanding protection, internal protections against feeder faults and lightning surges.
- Automatic isolation provisions on DC and AC sides by DC isolators and AC circuit breakers (integrated or externally connected)
- Earthing shall comply with manufacturer recommendations
- Protection degree: minimum IP-20 for indoor installation, minimum IP-65 for outdoor installation.

7.8. Bi-directional meter

The grid bi-directional meter for the rooftop solar PV system shall comply with the following requirements:

- The meter shall be an approved bidirectional energy meter, capable of accurately measuring energy flow in both import (from grid) and export (to grid) directions.
- It shall conform to relevant international standards such as IEC 62053-21 or equivalent.
- The meter shall be compatible with the plant's low voltage grid and capable of handling the rated voltage and current of the rooftop solar system.
- Communication capability shall be provided to enable interface with the plant's SCADA or energy management system, supporting protocols such as Modbus or DLMS/COSEM.
- The meter shall ensure reliable, tamper-proof energy measurement with an accuracy class of Class 1 or better.
- Installation shall comply with all applicable safety and wiring standards, including proper earthing and protection measures.
- The Contractor shall be responsible for the supply, installation, testing, and commissioning of the meter, including provision of all necessary documentation and calibration certificates.
- The meter shall support remote reading and data logging functionalities to facilitate operational monitoring and billing.
- The meter shall be installed in an accessible location that allows for regular inspection and maintenance.
- The bidder should ensure precise measurement of energy exchange between the rooftop solar PV system and the grid, enabling accurate billing and efficient energy management

7.9. PV Module Mounting Structure

7.9.1. Design and Material

The module mounting structure shall be a fixed-axis, prefabricated system designed specifically for rooftop installation, with no on-site fabrication allowed. All structural members must be factory-fabricated and assembled exclusively on-site using standard or module manufacturer-recommended accessories such as clips, rails, and racks. The structure shall be fabricated from corrosion-resistant aluminum of minimum alloy grade AA6063 or better, with surface protection by anodization or coating. Fasteners shall be stainless steel and electrolytically compatible with the module frame materials to prevent galvanic corrosion. The design must ensure adequate mechanical strength to support the PV modules and withstand wind speeds up to 120 km/h and applicable seismic loads, with a safety factor of 1.5. The Contractor shall provide detailed structural calculations and design drawings.

7.9.2. Installation and Structural Requirements

Foundations may be ballasted or mechanically anchored based on the roof's structural capacity, wind, seismic loads, and building code requirements. For metal sheet roofs, mounting may be directly on the sheet metal ensuring stability and wind resistance or by penetrating the sheet metal to a sub-structure, maintaining waterproofing and mechanical stability. The structure shall optimize rail span lengths, orientation, and attachment methods based on building characteristics, roof type, environmental conditions, and required capacity, minimizing shading and maximizing performance. It shall allow easy module replacement and minimize rooftop space usage. Adequate clearance for panel cleaning and maintenance shall be provided, with a minimum of 30 mm and maximum of 120 mm space between the structure and roof when parallel and facing south. Adjustable tilt mounting shall be used if oriented differently to reduce wind exposure and optimize positioning.

7.9.3. Orientation Access and Safety

The PV array orientation shall be based on site measurements or drawings, with azimuth facing south (0°), southeast (~45° east of south), or southwest (~45° west of south). The panel must be tilted to the angle of the roof (or parallel to the roof). Installation must ensure the roof remains waterproof, provide sufficient ventilation, and protect the structure from excessive wind forces. Panels must be accessible from above for cleaning and from below for maintenance of modules and junction boxes. Compliance with all safety and installation requirements is mandatory as part of the technical tender and contract documents.

7.10. AC Distribution Board (ACDB)

- The AC distribution board shall control the AC power from the inverter and should have necessary surge arrestors. Interconnection from ACDB to mains at LT Bus bar while in grid tied mode.
- All switches and the circuit breakers, connectors should conform to IEC 60947, part I, II and IIII.
- The ACDB shall be designed for minimum expected ambient extreme temperatures (−20∘C and 75∘C) a height percent humidity.
- All indoor panels will have protection of IP54 or better. All outdoor panels will have protection of IP65 or better.
- All the 415 AC or 230 volts devices / equipment like bus support insulators, circuit breakers, SPDs, VTs etc., mounted inside the switchgear shall be suitable for continuous operation and satisfactory performance under the following supply conditions:
    - Variation in supply voltage: ±6%.
    - Variation in supply frequency: −2% and +1%

7.11. Earthing

- The entire rooftop solar photovoltaic (SPV) system, including modules, mounting structures, inverters, control systems, and associated electrical equipment, shall be properly earthed to ensure safety and equipment protection in accordance with relevant standards. The earthing system must comprise a complete network of copper conductors, electrodes, and bonding connections to all non-current carrying metallic parts, eliminating potential differences and electrical hazards.

- Each array structure must be grounded with copper conductors, ensuring every module within the array is interconnected using copper wires and lugged with toothed washers. Lightning arrestors or masts shall be installed within the array field for additional protection. The cross-sectional area of earthing conductors for PV equipment shall be no less than 6 mm^2 (copper), while the earth conductor for lightning arrestors shall have a minimum cross-section of 16 mm^2 (copper). The earthing system shall provide a mechanically and electrically continuous independent return to earth.

- A dedicated earth electrode shall be installed, either rooftop-mounted or ground-installed near the building foundation. The earth electrode shall consist of a copper plate or rod at least 2.5 meters in length, securely connected using corrosion-resistant fittings. Ground-level electrodes must be housed in masonry enclosures measuring no

less than 300 mm x 300 mm, constructed with cemented brickwork at least 150 mm thick and plastered with cement mortar internally. Hinged, lockable inspection covers of at least 300 mm x 300 mm with a welded handle shall be provided for maintenance access. All earth conductors must be adequately protected from mechanical damage, corrosion, and environmental exposure.

- All metal casings and shielding of the rooftop SPV system shall be thoroughly earthed. The complete earthing system must comply with IEC 60364 standards and be interconnected to provide a continuous electrical path. AC electrical lines must include proper earth connections, and all DC grounding from array junction boxes should be grounded separately to an independent earth.

- The earthing system shall be tested to ensure the ground resistance does not exceed 5 ohms. Where applicable, the system must integrate with the building's lightning protection system. The Contactor shall be responsible for the design, installation, testing, and documentation of the earthing system in full compliance with these specifications.

7.12. Lightening Protection

- The entire rooftop SPV installation shall be protected against lightning strikes using a comprehensive lightning protection system. This system shall employ early streamer emission (ESE) lightning conductor air terminals capable of providing an effective protection radius of up to 60 meters, thereby creating a protective coverage umbrella over the rooftop area. The lightning protection system must be designed, installed, and tested in accordance with applicable standards, including IEC 62305-3, IEC 61173, IEC 60099, and IEC 60255. The air terminals shall be robust enough to withstand multiple lightning strikes and require no maintenance after installation.

- Earthing stations for lightning discharge shall include phosphorus bronze test links installed at least 150 mm above ground or rooftop level in accessible locations to facilitate periodic testing.

- The rooftop SPV system must also be equipped with lightning surge arresters and overvoltage protection devices. The primary objective of these measures is to reduce overvoltage to a safe level before it reaches the PV modules or other subsystem components.

- If the building is already fitted with a lightning protection system (LPS), the SPV array frame shall be connected to the existing LPS. In such cases, PV system components

should be mounted away from lightning rods and associated conductors to prevent risk—for example, inverters should not be installed on interior walls that have LPS down conductors running immediately adjacent on the outer side.

- Where the PV installation increases the risk of direct lightning strikes, consultation with specialists in lightning protection is required to consider installing a dedicated lightning protection system compliant with relevant standards, including IEC 62305-4, IEC 60364-5-53, IEC 61643-11-2011, IEC 62561-1, IEC 62561-2, and IEC 62561-7, covering design, equipment selection, surge protection, connection components, conductors, earth electrodes, and earthing enhancing compounds.

7.13. Cables

For the rooftop solar PV system, the following wiring requirements and cable specifications shall be strictly adhered to to ensure safe, reliable, and maintainable electrical installations:

- All external control cables and wires shall enter the panel from the bottom and be routed through suitable cable glands designed to prevent contact with sharp metal edges; these gland-plate assemblies must be vermin-proof.
- Single-core wiring shall not pass through grommets. AC and DC wiring shall be bundled separately even if running in the same raceway.
- Shielded signaling cables shall run in separate raceways and, if spaced less than 300 mm from low-voltage power cables, be routed at right angles and physically separated as far as practical.
- All wires shall be adequately rated and sized to withstand thermal stresses due to short-circuit currents, taking into account backup tripping times.
- Wiring for lighting and convenience outlets may share a raceway within individual panels and can be routed using rigid or PVC-jacketed flexible conduits between panels.
- Wiring for meters and relays mounted on panel doors shall be mechanically protected.
- Panels and circuits must be clearly labeled, with color coding used to differentiate AC and DC wiring.
- Internal wiring terminations shall use solderless crimped tinned copper lugs or equivalent reliable methods at both ends of inter-component wiring, with insulating sleeves covering exposed lug parts as much as possible.
- All cables shall be copper and comply with international standards such as IEC 60227, IEC 60502 (Part 1 & 2), IEC 69947, BS EN 50618 (for DC cables), IEC 60228, IEC 60332-1 (fire tests), IEC 61034-2 (smoke density), IEC 60754 (halogen-free tests), IEC 60216 (thermal endurance), IEC 60811-2-1 (elastomeric compounds), and IEC 60502-

1 (power cables rated 1-30 kV).

- All connections must be properly made through suitable lugs or terminals crimped with appropriate cable glands.
- Cable and wire sizes shall be designed considering line losses, maximum load, and permissible voltage drop, with cables sized to maintain overall voltage drop between the array and inverter within 2% at standard test conditions.
- Minimum suggested cable sizes for a typical configuration are:
    - Module to module/SJB/AJB: 4 sq mm (single-core)
    - AJBs to MJBs/DCCB: 10/16 sq mm (two-core) per current-design requirements
    - MJBs to DCCB: minimum 25 sq mm (single-core) or as per design
    - DCCB to Inverter: minimum 25 sq mm (single-core) or as per design
    - Inverter to ACCB: as per design and rating
- PV DC cable runs should be kept as short as practicable, with cables selected to withstand environmental, voltage, and current stresses including solar heating and current flow.
- Cables shall be selected and installed to minimize risk of earth faults and short circuits by reinforcing wiring protection. Cables behind the PV array must be rated for -15°C to 80°C temperature range.
- External cables must be UV stable and water resistant. Flexible (multi-stranded) cables are recommended where movement due to thermal or wind effects may occur, especially behind arrays.
- PV cables rely on double or reinforced insulation for shock protection and should not be buried in walls or hidden inside building structures to prevent undetectable damage.
- Conductors must be suitably protected from mechanical damage, for example, by using cable trays and trunking complying with IEC 61537.
- Exterior cable color coding is generally not required for PV systems; black cables are common to enhance UV resistance.
- Cable junctions shall generally be by approved plug/socket connectors or housed within DC junction boxes. In-line cable junctions should be avoided but, if unavoidable, must maintain double/reinforced insulation with appropriate strain relief using rated heat shrink sleeving and fittings, preferably completed off-site.

These requirements ensure the wiring and cables for the rooftop solar PV system meet international quality, safety, and reliability standards.

7.14. Grid Islanding

- The Rooftop SPV system must be equipped with islanding protection to ensure disconnection from the grid, a safety feature that must be complemented by automatic disconnection for both under- and over-voltage conditions.
- In addition to this automatic grid disconnection, a manual disconnect isolation switch must be provided at the utility end, allowing utility personnel to isolate the grid connection for any maintenance; this manual switch shall be locked by the utility personnel.

7.15. Battery Bank (Energy Storage System)

The battery bank shall be lithium-ion (LiFePO4/LFP) stackable modules compatible with a 150-kW hybrid solar PV system, designed **for 2–4 hours of backup**. Each module shall have a nominal voltage of 48–100 V DC and be stackable in series/parallel to achieve a total bank voltage of 600–750 V DC and total capacity of 375–820 kWh depending on backup duration. Batteries shall support AC/DC coupling, have a minimum depth of discharge of 80%, cycle life ≥4000 cycles, and round-trip efficiency ≥95%. Protection features shall include overcharge, over-discharge, overcurrent, short-circuit, and temperature monitoring. The stackable modules shall be IP65 rated for indoor/outdoor installation, integrated with the inverter for state-of-charge and health monitoring, and backed by a minimum 5-year warranty with local service support.

- Battery Bank Specifications – Lithium-ion (Stackable)

Parameter Requirement

- Battery Type Lithium-ion (LiFePO4/LFP), stackable modules
- Nominal Module Voltage 48–100 V DC per module
- Total System Voltage 600–750 V DC
- Total Capacity 375–820 kWh (depending on 2–4 hr backup)
- Configuration Series/parallel stacking to meet voltage and capacity
- Depth of Discharge (DoD) ≥80%
- Round-Trip Efficiency ≥95%
- Cycle Life≥4000 cycles at 80% DoD
- Operating Temperature -10°C to 50°C
- Protection Overcharge, over-discharge, overcurrent, short-circuit, temperature monitoring
- Enclosure IP65 rated, suitable for indoor/outdoor installation
- Monitoring Integrated with inverter for SOC and health tracking
- Warranty Minimum 5 years, with local service support

7.16. Data Acquisition System

- The required PV rooftop system must incorporate data monitoring, remote diagnosis, data storage and visualization.
- The Contractor is responsible for providing a web-based monitoring software

capable of collecting data directly from the inverter at all times. The data collected must include, but is not limited to:

- Site information
- Generation metrics, specifically DC (before inverter) and AC (after inverter) generation in kWh, along with voltage and current.

- The program must be able to display both instantaneous and historical data.
- Furthermore, this system is required to provide information for each installation and offer the capability to add different installations.
- The monitoring information must be accessible on a single computer at RBE premises.
- The Contractor is responsible for providing data connection for each site. Communication methods must be the most effective way in each location.
- The system must display data in real time and record and log performance data at regular intervals for a minimum of two years. This data must be downloadable at any moment in a format compatible with MS EXCEL.
- Finally, the contract requires the Contractor to specify the system and demonstrate the features of the software as a DEMO to Purchaser for approval during the design stage.

8. General Responsibility

8.1. Site Accessibility

- The Contractor shall be fully responsible for the transportation of all materials, equipment, and personnel to and from the site. This includes the establishment of temporary storage and the payment of any associated rents, handling fees, or incidental charges necessary for the proper execution of the contract.
- Wherever applicable, the Contractor shall ensure that all materials are properly packed in new containers to protect them from deterioration and damage during transportation. Groups of containers or cartons may be further packed into boxes with appropriate weight and size to ensure safe handling and transport.
- All containers, cartons, and boxes shall be constructed to be strong and sturdy enough to withstand multiple loadings and unloadings during urban transport, handling on site rooftops, and storage for the duration of the project. Additionally, the boxes must be reinforced with suitable protective measures such as lagging or galvanized steel strips to prevent damage.
- A layer of waterproof material shall be placed inside all containers, cartons, and boxes to protect the equipment from water seepage.
- Each case must be clearly labeled with the manufacturer's name and the type of equipment. All identification marks on the exterior shall be permanent and waterproof. Electrical equipment should be adequately sealed, and desiccating agents used as necessary to prevent moisture damage.
- The Contractor shall bear full responsibility for any damage resulting from improper packing or handling during transportation and onsite storage.

8.2. Mobilization and Demobilization

- All costs related to mobilization and demobilization, including the transportation of equipment, materials, workforce, and the clearing of the site upon completion of works, shall be deemed included in the Contractor's financial offer. No separate payment shall be entertained under any circumstances.
- The Contractor shall make all arrangements for any temporary electricity supply and adequate supply of water for construction and drinking purposes that he may require for the execution of the works.
- The Contractor shall ensure that a competent and authorized representative is always present at the site during execution to ensure smooth execution and timely completion of all activities.

8.3. Site Cleanliness and Safety

- Upon completion of the works, the Contractor shall ensure the site is left clean, orderly, and safe to the full satisfaction of the Purchaser. Failure to do so will result in withholding of the final payment.
- During contract execution, the Contractor shall have a responsible person with decision-making authority available on site. This person must report to the Purchaser to ensure smooth execution and timely completion of the works.

9. Operational and maintenance Training

- The Contractor shall be responsible for providing on-site training to the beneficiary on the basic operation and maintenance (O&M) of the SPV system and all associated equipment.
- The Contractor shall ensure that the training is thorough and practical, enabling end users to independently perform routine O&M activities to maintain the system's long-term performance and sustainability.

10. Occupational Health and Safety

- In accordance with the Labour and Employment Act of Bhutan and related regulations, the Contractor shall provide all employees with appropriate Personal Protective Equipment (PPE), including helmets, footwear, protective clothing, and other necessary items to be used at the workplace. The Contractor must ensure that employees wear the PPE at all times while performing work on site. All PPE shall be regularly inspected to verify proper use and condition, and any damaged equipment shall be replaced without delay.
- The Contractor shall ensure the availability of trained first-aiders and adequately stocked first-aid boxes at the project work site. The names of designated first-aiders shall be displayed prominently. First-aid boxes must clearly indicate their contents along with the quantities of medical and medicinal supplies, which shall be maintained at all times. The Contractor is responsible for the prompt replenishment of any depleted items to ensure continuous readiness.
- The Contractor shall designate an emergency response team at the work site tasked with coordinating all emergency actions in liaison with the Purchaser and local health authorities. The emergency telephone and mobile numbers of key contact persons, including police, ambulance, and other relevant services, shall be clearly displayed and accessible at all times.

11. Labor Work Permits, Accommodation and Insurance

In the event that immigrant laborers are employed, the Contractor shall be fully responsible for ensuring that all categories of expatriate labor possess valid work permits and/or visas, and that all immigration and emigration regulations are strictly complied with. The Contractor shall further ensure compliance with all applicable labor laws of the country, including but not limited to provisions relating to leave, accommodation, and insurance for all employees, including those of any sub-

contractors. In all dealings with labor under his employment, the Contractor shall also give due regard to recognized festival days, rest days, and religious or customary observances.

12. Environmental Protection

The Contractor shall take all reasonable steps to protect the environment on and off the site and to avoid damage or nuisance to persons or to property of the public or others resulting from pollution, noise or other causes arising as a consequence of his methods of operation, and shall preserve and protect all existing vegetation and trees on or adjacent to the Site which do not unreasonably interfere with the execution of the project. The Contractor shall be held responsible for all unauthorized cutting off and damage to trees, by careless operation of his plant, equipment or materials and stockpiling of materials etc. and Purchaser shall have no responsibility on this account.

13. Marking & Levelling

The following information shall be clearly marked on all containers, cartons, and boxes:

- Supplier's name
- Identification number
- Net and gross weight
- Purchaser's name along with other dispatch details such as destination

All equipment shall be provided with labels or nameplates that include a description of the equipment, as well as information regarding components such as the solar module, inverter, mounting structure, combiner box, and other relevant operational details. These labels shall be approved by the Purchaser prior to packaging. Nameplates or labels must be made of non-corrodible, non-hygroscopic materials with lettering in a contrasting color to ensure durability and legibility.

14. Installation and Commissioning of Rooftop SPV System

- The solar photovoltaic (SPV) panels shall be fixed parallel to the angle of the roof, following its slope. The orientation of the panels shall be between South-South-East (SSE) and South-South-West (SSW) on the magnetic compass, with true south being the preferred direction for optimal solar energy capture.
- No shading shall occur on the panels between 09:00 and 17:00 hours.
- All exposed metallic parts of the rooftop SPV system, including panel frames, mounting structures, junction boxes, and any auxiliary electrical components, shall be properly earthed to ensure safety and prevent electrical shock hazards.
- Electrical safety must be rigorously maintained throughout the installation, following all applicable safety rules and regulations.

15. Completion Period

The completion period for the rooftop Solar Photovoltaic (SPV) system installation shall be five (5) months from the date of signing the Contract Agreement. If the Contractor fails to complete the work or fulfill related obligations within the stipulated time, the Purchaser reserves the right to contract the work from the open market at the Contractor's risk and cost, without calling for a tender and after providing notice to the Contractor. Any additional costs incurred by the Purchaser will be recovered from the Contractor.

If the cost of completing the work exceeds the balance payments due to the Contractor and the Contractor does not cover the additional cost, the Purchaser may recover the amount from the Contractor's pending claims for any other works. The Purchaser's calculation of additional costs shall be final and binding. The Contractor shall have no right to dispute the amount or method of calculation in any forum, and the Purchaser's decision shall be conclusive.

16. Documents to be submitted as Annexure

The bidders shall submit the following documents:

- Annexure A: Employer's Requirements & Technical Specifications
- Annexure B: Drawings and Standards
- Annexure C: Contract Price Breakdown (BOQ, milestones)
- Annexure D: Project Schedule (Bar Chart/CPM)
- Annexure E: Performance Guarantee & Warranty Schedule
- Annexure F: Insurance Policies
- Annexure G: Safety & Environmental Management Plan
- Annexure H: O&M Manuals and Training Requirements