F. No. 32/5/2021-SPV Division
Government of India
Ministry of New & Renewable Energy
***

Block No. 14, CGO Complex
Lodhi Road, New Delhi

Date: 27 September 2021

Office Memorandum

Subject: Draft Testing Protocols for Solar Cold Storage with Thermal Energy Storage Backup – for comments of stakeholders.

To encourage use of solar based cold storage for minimizing the post harvesting losses, Ministry is working on guidelines for testing procedure to enable development of standardized product and large-scale adoption of these applications.

2. Draft Testing Protocols for Solar Cold Storage with Thermal Energy Storage Backup are hereby circulated for comments of all the stakeholders. It is requested that comments/ suggestions on the same may please be sent at **chaitanyavss.mnre@gov.in** by **11.10.2021**, positively.

(Shobhit Srivastava)
Scientist-D

To

All Stakeholders

Guidelines on Testing Procedure for
Solar Cold Storage with Thermal Energy Storage Backup

1. Scope

These Guidelines lays down basis for testing set up and testing procedures for Solar Cold Storage with Thermal Storage Backup. The Solar Cold Storage which runs on SPV and have Thermal Storage Backup for chilling of commodities up to zero degree Celsius is covered.

2. Definition of System and Parameters

System: Solar Cold Storage with Thermal Energy Storage Backup System

The solar cold storage enables effective use of solar energy for cooling of fruits/vegetables/other perishable items so as to store and preserve them for longer duration. The cold storage unit in off-grid operation, primarily runs on power generated from Solar Photovoltaic and can be switched to grid during cloudy days. During sunshine hours the electricity generated from solar photovoltaic is used to provide cooling through a vapor compression refrigeration cycle to cool a cold room as well as store cooling energy in a Thermal Energy Storage (TES) System. In Thermal Energy Storage (TES) system the cold energy is stored in phase change material such as water or water salt eutectic mixture and transferred to the cold storage unit depending on the usage needs. During non-solar hours, the cooling needs of cold storage unit are met through the stored cooling in the thermal energy storage system. Use of solar photovoltaic and thermal energy storage backup eliminates dependency on grid and need of diesel generator as a backup device.

The system comprised mainly of the following components and equipment:

Cold Room, SPV System, Solar Controller, Refrigeration System, Thermal Energy Storage (TES) System, Batteries for Auxiliary Load. Combination of all these components shall be unique. Any change in combination will be treated as different model of Solar Cold Storage System.

2.1 Cold Room

The cold room is a PUF insulated room that maintains desired temperature and humidity for storage of commodities. The cold room is equipped with refrigeration unit which provides necessary cooling by circulating cold air to the commodities for preservation.

2.2 Solar Photovoltaic System

The SPV system generates electrical powers during sunshine hours which is used to operate the cold storage system. It provided electricity for running refrigeration system and auxiliary load. The SPV system shall have following specifications:

- Crystalline silicon cell PV modules of 300Wp or higher capacity.
- The PV module have IEC 61215 qualification certification for solar PV modules.

- The PV module conforms to IEC 61730 Part-1 requirements for construction & Part-2 requirements for testing for safety qualification.
- The PV modules qualifies relevant IEC standard.
- The PV modules used in solar power plants/ systems are warranted for their output peak watt capacity, which is not less than 90% at the end of 10 years and 80% at the end of 25 years.
- All PV modules should have STC testing certificate from an NABL accredited test laboratory

2.3 Solar Controller

The controller converts the DC power (DC voltage & Current) of the PV array into a controlled high or low DC voltage power, or converts this DC power into single -phase or multi-phase alternating-current power (voltage or alternating current) suitably for driving the refrigeration system.

NOTE — The Controller may also include equipment for MPPT, monitoring, metering and sine wave filters.

2.4 Refrigeration System

Refrigeration system consisting of condensing unit and evaporating unit working on vapor compression cycle. The condensing unit generates cooling energy which can be used for charging the thermal energy storage system and to provide cooling to the cold storage depending upon design of Solar Cold Storage system.

2.5 Thermal Energy Storage (TES) System

In Thermal Energy Storage (TES) system the cold energy is stored in phase change material such as water or water salt eutectic mixture and transferred to the cold storage unit depending on the usage needs. During non-solar hours, the cooling needs of cold storage unit are met through the stored cooling in the Thermal Energy Storage (TES) system.

2.6 Solar System and Electric Battery System for Auxiliary Components

The auxiliary power system consists of following equipment - solar photovoltaic system, MPPT based inverter/ MPPT charge controller, chemical batteries. These are meant to provide electricity for auxiliary electrical loads such as fans of evaporator unit, thermal energy storage control panel, temperature controller unit, lighting, and data monitoring system.

3. Test Setup

3.1 Cold storage Temperature Measurement

The cold storage temperature needs to be recorded for the test by using a temperature sensor with minimum repeatability of $\pm 0.1^{0}$C. The sensor should be placed at the suction of evaporator fans to measure the return air temperature inside cold storage. The sensor should not be in contact of any surface which can cause error in room temperature measurement.

3.2 Electric Air Heater with Energy Meter

An electric air heater shall be placed inside the cold storage which will be treated as heat load to measure the TES system capacity. A 1 kW capacity electric heater shall be used whose operating switch should be located outside the cold storage, such that the heater can be switched ON/OFF from outside without disturbing the inside temperature of cold storage (the 1kW heating rate of electric heater is meant for 5MT to 10MT cold storage capacity, and will be appropriately scaled for larger or smaller units). To measure energy consumption of the electric heater, an energy meter, with accuracy class of 0.5 as prescribed in IEC/AS Standard 62053-11, shall be used separately and the heater should be connected to electric supply through energy meter. This energy meter is termed as Heater Energy meter and energy consumption should be measured in kWh. This heater energy consumption will be used to analyze the TES system storage capacity as explained in Test 1 and Test 2 procedure.

3.3 Energy Meter on system

TES charging performance shall be monitored by providing electrical energy through grid connection for data repeatability. An energy meter, with accuracy class of 0.5 as prescribed in IEC/AS Standard 62053-11, will be installed to monitor the total energy consumption by the complete system. It will correlate to the energy consumed by system in charging the TES system as explained in Test 1. This energy meter is termed as Grid Energy meter and the TES system energy consumption shall be measured in kWh.

3.4 Energy Meter for Auxiliary load

Auxiliary load in a solar cold storage system includes electro-mechanical components other than compressor and condensing fan, which are necessary to operate the system as per design. The auxiliary load will be powered through a Solar Inverter / Charge controller / Converter or their combination (to be done as per system wiring diagram provided by the manufacturer). Energy requirement for auxiliary load shall be measured as explained in Test 2. An energy meter should be used separately to measure energy consumption by auxiliary load. To measure the energy consumption of auxiliary load, the energy meter is connected on the output of chemical batteries during the discharge tests.

4 Test Precautions

Before conducting the test of Solar Cold Storage system with Thermal Energy Storage (TES), following precautions must be followed:

1. The cold storage door should always be kept close during the test except when required by the test procedure.
2. All sensor devices should be calibrated to avoid error in recording test data with an accuracy of ±0.1^{o}C.
3. Connection of sensor devices to monitor and recording test data should be proper.
4. All electrical connections shall be proper to avoid any spark due to lose connection or wire break.
5. Earthing process should be strictly adhered for system protection and human safety.
6. Check cold storage system is working as per design like automatic operation of evaporator fans to circulate air inside cold storage, TES discharging to provide cooling to cold storage working as per cold storage set temperature automatically.
7. Electrical continuity shall be verified to ensure electrical connections are made as per design electrical diagram.
8. TES capacity indication shall be monitored during the test. TES capacity indication will be provided by the manufacturer which shall be a numerical value.
9. All temperature monitoring shall be on every 5 seconds basis.

5. Test Procedure for Performance Evaluation

5.1 Test 1: Thermal Energy Storage (TES) system capacity and Performance Test

This test is to ascertain the cooling capacity of Thermal Energy Storage (TES), minimum temperature achievable in cold room when cooling through thermal storage system and efficiency of thermal storage system.

Below is the stepwise procedure for carrying out the test -

A. Identify 0% level of Thermal Energy Storage (TES) system

- Switch OFF grid/solar supply to refrigeration condensing unit.
- Switch ON grid supply to air heater placed inside the cold storage.
- Switch ON grid supply to auxiliary power system equipment.
- Change cold storage set point temperature to 10 ^{O}C and switch ON cooling.
- This automatically starts the discharging of TES. Continue the discharging to an extent that cold storage temperature is already above 15 ^{O}C or reaches above 15 ^{O}C after some time and TES is not able to pull down the temperature to below 15 ^{O}C.
- Switch ON grid supply to refrigeration condensing unit.
- This starts the charging process of TES while discharging is still kept ON, trying to achieve set point temperature of 10 ^{O}C inside the cold storage.
- After cold storage temperature attains set point value of 10 ^{O}C, TES is assumed to be 0% charged at this energy level.
- Note Grid energy meter reading as Initial Grid Energy (I_{GE}).

- Switch OFF grid supply to air heater placed inside the cold storage.
- Switch OFF the cooling requirement of cold storage from set point controller.

B. Charging Thermal Energy Storage (TES) system to 100%

- Monitor and note down the reading of Grid Energy meter, Air Heater Energy meter, ambient temperature, TES capacity indication and cold storage temperature at the start and at fixed repeated intervals during the test.
- Note ambient temperature at fixed repeated intervals to record average ambient temperature during the test.
- When TES is completely charged (100% capacity), the operation of condensing unit should automatically turn OFF.
    - Note down the grid energy meter reading - Final Grid Energy (F_{GE}).
    - Note down average ambient temperature during the test.
    - The difference between F_{GE} and I_{GE} will be total electrical energy consumption (E_{GE}) by TES during charging of energy storage.
- Switch OFF grid supply to refrigeration condensing unit.

C. Placement of water balls inside the cold storage for further testing

- Once TES is 100% charged, place 500 kg of water balls in the following configuration
    - Crate size and model – 400 mm X 325 mm X 250 mm Supreme (STP-4032225)
    - Each crate maximum water ball handling capacity – approx. 25 kg water ball
    - Crates should be placed and distributed uniformly inside the cold storage across all its floor area.
    - Continuous monitor temperature of 5 samples kept on the top crate (sample size should be of 1-inch diameter with +/- 5% error)
- Initial core temperature of water balls has to be in the temperature range of 25 to 30 ^{O}C.

D. Discharging of Thermal Energy Storage (TES) system to characterize system cooling rates and minimum achievable temperature inside the cold storage

- The minimum time difference required to start the discharging test (Step D) from the completion of charging test (Step B) is 2 hours.
- Switch OFF grid/solar supply to refrigeration condensing unit.
- Change cold storage set point temperature to 0 ^{O}C.
- During discharging process, monitor temperature of 5 samples of water balls in fixed repeated intervals.
- Once the average temperature of water balls has achieved 20 ^{O}C, note down the time as start of cooling rate test – T_i
- Switch OFF grid supply to auxiliary power system.

- Note Energy meter reading on the auxiliary load meter as initial auxiliary load reading (I_{AE})
- Monitor the temperature of water balls sample till average temperature has achieved 7 ^{O}C.
- Note the time as finish of cooling rate test - T_f
    - The difference between T_f and T_i will be total time taken for water ball (T_c) to attain 7 ^{O}C from starting temperature of 20 ^{O}C.
    - T_c characterizes the cooling rate performance of the system.
- Note Energy meter reading on the auxiliary load meter as final auxiliary load reading (F_{AE}).
    - The difference between F_{AE} and I_{AE} will be total electrical energy consumption (E_{AE}) by auxiliary load in time T_c
    - Power requirement of auxiliary load can be calculated as $P_{AE} = E_{AE}/T_c$
- Monitor the room temperatures to test the lowest achievable temperature. If the rate of decrease in room temperature is less than 0.1 ^{O}C in 5 minutes, it is assumed that the cold room has achieved the minimum achievable temperature.
- Note the cold storage temperature reading as minimum temperature achievable - T_{min}

E. Discharging of Thermal Energy Storage (TES) system to test energy storage capacity

- After completion of minimum achievable temperature and cooling rate test, switch ON the electric air heater in the cold room and set cold storage temperature to 7 ^{O}C.
    - When air heater is switched ON, note down the heater energy meter reading and it will be termed as Initial Heater Energy (I_{HE}) in kWh.
- Continue the cooling until cold storage temperature achieves a value higher than 10 ^{O}C. This indicates TES is fully discharged and at this state TES can be assumed to have reached the condition at 0% TES charge level.
    - Switch OFF the electric air heater and note down heater energy meter reading. It will be termed as Final Heater Energy (F_{HE}) in kWh.
    - The difference between F_{HE} and I_{HE} will be total electrical energy consumption (E_{HE}) by the air heater.
- Storage capacity of TES will be assumed to be the sum total of energy used to cool water balls and the energy consumed by air heater. Leakage of energy from room due to conduction via walls and due to door openings will be ignored for this analysis.
- Plot graph between TES capacity indication and cold storage temperature along with time.
- Efficiency of TES can be estimated here (there has to be a scaling parameter for correct ambient temperature and reported at 30 ^{O}C): efficiency is defined as cooling stored / electricity consumed while charging. Heat Losses of cold room are already accounted in the TES capacity.

Note:

1. *In regard to the measurement of Storage Capacity of thermal storage system the temperature of the outer temperature surface is monitored, a lookup table will be made to account for the*

heat influx. The heat influx energy can be calculated as an integration of conducted heat kA (delta T) where delta T is the difference between the room temperature and the cold room's outer body temperature. The conductivity of the room shall be fixed at 0.027 W/m2K irrespective of the insulation used. The surface area of the room would be the sum total of all surfaces of the cold room exposed to the ambient environment. This is being proposed to bring repeatability and an improvement on accuracy of the test.

2. *Correction factor in COP with respect to ambient temperature shall applied based on compressor data sheet as provided by the original equipment manufacturer*

5.2 Test 2: Solar Performance Testing- Simulator Based

This test is carried at the end of test procedure 1. Switch OFF the cooling for the entire duration of this test. This test is to ascertain the performance of solar system including SPV system and solar controller. This test is carried out by using a SPV simulator.

Simulation methods are the easiest and fastest way of estimating SPV performance. However, in these methods actual PV array is not used, instead a PV array simulator is used. Here, a Programmable SPV array simulator capable of generating power output equal to actual SPV array under the given radiation and temperature conditions for given SPV array configuration (i.e. the number of modules, the type and the series / parallel combination) will be used. Although any radiation & temperature can be created, for the purpose of testing, one conditions of hot summer day conditions (hot profile) shall be used. A typical hot day profiles is shown Figure 1. The profile of full day solar irradiance and temperature shall be loaded in PV array simulator, sequentially one after the other. The simulator output is connected to the system through the controller and the profiles are run on 8X speed. The following performance parameters are collected for the entire duration of run time (per profile) – Irradiation (kWh/m2), Electricity generated by panels (kWh).

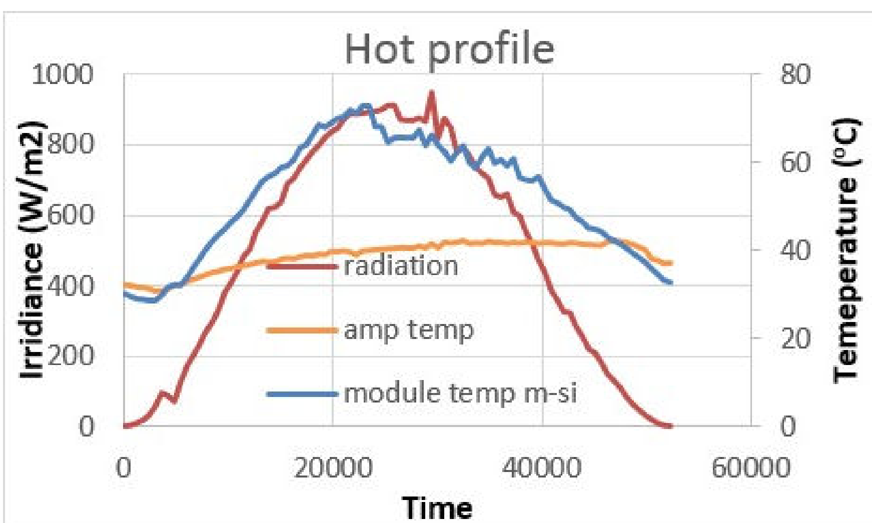

Figure 1 – Typical Solar Radiation Hot Profile

5.3 Power Source Switching Operation Testing - Grid to Solar to Grid (Automatic)

The system would be tested for switching from solar operation to grid operation and via versa automatically when solar power becomes unavailable and cooling is not sufficient and should switch back to solar in presence of solar power

This can be done by connecting both the power sources (solar simulator and a three phase grid supply).

1. First switch on solar power. Let the system run.
2. Switch on grid supply.
3. Turn off solar supply. The refrigeration system should start running on grid power.
4. Switch on solar power. The system should switch back on solar power.

6. Measurements and Apparatus

6.4 Measurement of Temperature

- Cold storage temperature needs to be monitor at the suction of air circulation fans mounted on evaporator inside the cold storage
- Ambient temperature
- Temperature of core of water ball of at least 5 samples at different locations.

6.4 Measurement of Electricity Load

- Electricity load should be measured by using an electric meter at following loads
- A 1 kW capacity Electric Heater (non-radiator based) used in testing
- Refrigeration Unit load includes (Compressor, Condenser fan and evaporator fans load)
- Auxiliary load of system

6.4 Observations

- Following parameters should be monitored and all the readings taken throughout the test should be present in the test record sheet.
- Temperature (^{O}C) Reading of cold storage
- Temperature (^{O}C) Reading of ambient
- Time taken to cool water ball – T_c
- Minimum cold storage temperature achieved - T_{min}
- Generation and Irradiation readings from solar simulator
- Electric Air Heater energy (E_{HE})
- Grid Energy consumption for condensing unit (E_{GE})
- Auxiliary load energy (E_{AE})

6.4 Calibration of Apparatus

All measuring instruments i.e. temperature sensors, electric meters etc. are to be calibrated periodically as per requirement.

7. Computation of Test Readings

a) Storage Capacity of thermal storage system in KJ or kWh.

i. Storage Capacity of TES will be the sum total of cooling load of water ball and the electrical energy consumed by air heater (E_{HE}).

ii. Change in temperature of water ball, dT = Initial core temperature of water ball – 7 ^{O}C

iii. $\text{Storage Capacity in kWh} = (\text{mass of water ballwater ballWater ball} * \text{Specific heat of water ballwater ballwater ball} * \text{dT}) + E_{HE}$

b) **Minimum temperature inside cold room** = T_{min}

c) Efficiency of the thermal storage system

i. $Efficiceny\ of\ TSS = \frac{\text{Storage capcity of TES}}{E_{GE}}$

E_{GE} is the energy consumed by refrigeration unit during charging of TES.

ii. The charging efficiency can be scaled for standard ambient temperature of 30 ^{O}C. This can be done by finding out the % change in cooling efficiency (COP) of the compressor with the ambient/condensing temperature, as per the manufacturer datasheet.

d) Power requirement of auxiliary load = P_{AE}

Number of hours of power backup for auxiliary load via fully charged chemical battery

$$= \frac{\text{Capacity of chemical battery (VAh)}}{P_{AE} * 3600}$$

e) **Efficiency of Solar charge controller** $= \frac{\text{Energy generation from PV simulator in kWh}}{Total\ energy\ irradiation\ in\ kWh}$ %

f) **Cooling rate in ^{O}C per min** = $\frac{20-7}{T_C}$

8. Use of Other Brand of Solar Modules

In case a test lab has tested and issued approval certificate for a particular model of solar cold storage using a particular brand of SPV Modules, the applicant may use SPV Modules of other brand for the same model of solar cold storage without going for retesting of solar cold storage system with other brand of SPV Modules provided the test lab certifies that the SPV Module of other brand is at-least of same wattage capacity and its parameters and characteristics are not inferior to the brand of SPV Module with which the model of solar cold storage system was tested and certified by the testing lab. In addition, configuration of solar array i.e. the number of solar modules in series and/or parallel combination will remain unaltered. Further, in each case the SPV module shall follow the quality control order issued by MNRE from time to time. Following criterion shall be followed:

i. Solar Array Maximum voltage Vmpp with new brand module shall be within ±2% of earlier module. Modules Efficiency and Fill Factor shall qualify minimum requirement of MNRE specifications

ii. Array and module Mismatch shall meet the MNRE specifications.

Minimum Specifications and Requirements for Solar Cold Storage with Thermal Energy Storage Backup for 5MT and 10 MT Capacity

Particulars	Version 1	Version 2	Version 3	Version 4
Indicative Storage Capacity	5 MT	5 MT	10 MT	10 MT
Min Solar Photovoltaic Capacity	5 KWp	7 KWp	10 KWp	14 KWp
Min Thermal Backup	125 MJ	175 MJ	250 MJ	350 MJ
Min Compressor Capacity	2 TR	2 TR	4 TR	4 TR
Minimum Pre-cooling capacity only with thermal back-up	500 kg within 12 hours	750kg within 12 hours	1000 kg within 12 hours	1500 kg within 12 hours
Min Internal Volume of Cold Room	750 cuft	750 cuft	1500 cuft	1500 cuft
Insulation	100m PUF or 150mm EPS or equivalent			
Refrigerant	R407F / R134A or any other with Zero ODP and GWP <2000			
Operation of compressor power circuit	Compressor power line should not be operated using batteries			
Remote Monitoring	GPRS or Wifi Connectivity			
Remote Monitoring parameters	Cold Room temperature Cold Room humidity Ambient temperature Solar Energy Generation Grid Energy Consumption Compressor speed and on-off state			
Power Supply	Solar PV as well as grid with auto-switching based on power availability			