



# **Smart Controller Laboratory (SCLab)**

**TREE Building, TERI Gram**

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## 1. Introduction

Energy growth in India is increasing day by day and expected to grow at higher rate in next 10 years. And conventional sources of energy are depleting day by day and it is expected that these source will only last for 40-50 years also conventional source like coal, nuclear emit highly polluted material when burning and even threat to human society. Now the trend is to switch from conventional source of energy to clean energy based power plant to reduce the carbon foot print on the earth and make the energy generation clean and pollution free.

TERI -under Norwegian Framework Agreement (NFA) has established a state of art independent laboratory for Testing, Evaluation and Research laboratory for Distributed Power Systems (Wind, Solar and many other renewable energy sources), Smart Controllers and clean energy based technology.

This is one of the pioneer laboratory in India in design, testing and performance assessment of the research activities related to Off-grid PV plant, AC or DC Microgrid ,Smart Micro/Mini Grid. The main objective of this state-of-art lab is to Design and develop innovative, cost effective smart and sustainable distributed power solutions for various applications in vertical domains.

Major Laboratory Goals:

- To develop various smart controller in the field of clean and green technology.
- To develop testing protocol for clean energy based components like Photovoltaic, PV inverter, Batteries etc.
- To assess the long term performance of the various components in the field of renewable energy.

## 2. Infrastructure Facilities

Smart controller lab is basically a R&D laboratory which conducts various type of testing in the field of solar photovoltaic, wind and many more renewable energy technologies. It conducts testing for reliability and performance evaluation of the equipment in the field as well as in lab environment related to the clean and renewable technology.

PV module performance evaluation is very important for system integrator; it helps in ensuring the quality, efficiency and reliability of the product. Tests are also conducted to validate the presence of any opens and shorts to detect manufacturing defects that may contribute to decreased energy conversion efficiency.

This laboratory provides testing facility for batteries of various technology; it's charging-discharging efficiency testing, its performance with different charging algorithm etc. The laboratory also provides the testing facility for grid tied inverter; the inverter will be tested for islanding condition, various grid scenarios like voltage sag, voltage rise, transient, frequency fluctuations etc.

Also smart controller lab has distinctive facility for designing and developing customized PV plant solution. It provides solution for DC microgrid, Off-grid PV plant solution etc.



**Figure 1: Smart Controller Layout**

The lab has following facilities to carry out above discussed testing and research activities

**List of equipment /Instrument in the lab:**

1. Solar PV array simulator
2. Grid Simulator
3. Load emulator
4. Digital Oscilloscope
5. Embedded system and controller
6. PV inverter and Off-Grid inverter
7. Batteries

DRAFT

## 1. Solar Array Simulator

The SAS is provides turn-key solution for testing grid tied inverters, DC charge controllers and batteries and Photovoltaic modules.

### Introduction:

**TerraSAS** is a programmable system designed to simulate the electrical behaviour of a photovoltaic array. The System provides an integrated hardware and software platform to deliver all the functionality required to test the maximum peak power tracking (MPPT) characteristics of the solar inverters and charge controllers. The ability to simulate any fill factor and material technology allows the system to characterize the inverter MPPT algorithm performance quickly and efficiently. Test software including items based on the **Sandia National Labs** “Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic System” is incorporated to allow easy programming of the various test requirements.

The TerraSAS software allows modelling a PV panel from data normally found in the manufacturer data sheet. These parameters are  $V_{OC}$  (open circuit voltage),  $I_{SC}$  (short circuit current),  $I_{MP}$  (current at maximum power point),  $V_{MP}$  (voltage at maximum power point),  $\beta_V$  (voltage temperature coefficient) and  $\beta_P$  (power temperature coefficient).

### Main Components of the system:

1. System Controller
2. PV Simulator Engine
3. DC Power Sources
4. TerraSAS Software

#### 1. System Controller

The system controller is a rack mounted industrial computer running on Microsoft Windows 7 Professional. It is a primary interface for controlling the operation of the

TerraSAS system and reading back measured data. The user interacts with the system through the controller's LCD monitor and keyboard or remotely through an Ethernet port located on the cabinet's rear panel.

The System controller communications with one or more PV simulators via an auxiliary Ethernet port and local network designated "TerraSAS Net". On large multi-channel systems, the System Controller is augmented with an industrial grade Ethernet switch, which connects to the simulators. Up to 48 simulators may be connected to a single system controller.

TerraSAS Net may be extended to one or more slave cabinets on high-power systems, where more than one cabinet is required to house the simulators and power sources. On smaller systems, the System Controller is typically augmented with a 5 or 8-port Ethernet switch.



**Figure2. Solar Array Simulator (SAS)**



## **2. PV Simulator :**

The PV Simulator is at the heart of the TerraSAS Simulator system. It receives IV curve data from the system controller and continually monitors and influences the output voltage and output current being delivered by its associated power sources.

At the centre of PV simulator there are two 80 MIPS RISC microcontrollers. One processor interferes with a 16-bit measurement system that monitors the DC power supply's output voltage and current at 40  $\mu$ s intervals.

At each interval, the processor sends computed analogue input controls to precisely follow the IV curve loaded in curve memory. The second processor is dedicated to the Ethernet interface and digital I/O. While in static simulation mode, the PV Simulator executes a single IV curve. In the PV Simulator system, an IV curve is represented at 1,024 data pairs or the points. Each pair of values corresponds to a single set of voltage-current point on the IV curve. For any given voltage on the curve there is a corresponding current value. The PV Simulator retains the active curve in memory and continuously programs the power supply to respond to changes measured in output voltage and current. The PV Simulator interpolates the 1,024 points in its curve memory with 16-bit accuracy, delivering an actual curve resolution of 65,536 points.

## **3. DC Power Sources:**

The DC power source(s) used in the TerraSAS system are enhanced versions of the Sorensen models DCS580- 15, SGA600 - XX and SGA1000 - XX power supplies. Modifications have been made to improve the output response time by a factor of 10, compared to standard models available in market.

On DCS power supplies, mainly used on micro-inverter test systems, the PV controller is embedded into the power supply, providing a complete in 1U chassis.

#### 4. TerraSAS Software:

TerraSAS software is user friendly, multipurpose simulation software which based on pre-set logic and defined IV curve output regulates the operation of different hardware automatically as well as based on manual instructions.

TerraSAS is designed to provide powerful features and ease of use. Its main design goals are:

- Import photovoltaic curves created with third party applications
- Easily create photovoltaic curves from manufacturer supplied data
- Import irradiance / temperature profiles created in Microsoft Excel, third party applications or using real-time data acquisition from actual solar panels
- Organize any number of curves and profiles into graphic, filmstrip like pools for intuitive, easy access
- Create any number of solar array configurations, organized into a graphic, filmstrip like pool.
- Intuitive drag-and-drop interface to easily assign curves and profiles to individual array elements, to support accurate modelling of array shadowing patterns
- Static and dynamic simulation preview of each configured array
- Comprehensive remote interface based on the SCPI Language
- Fully configurable real time trigger, measurement and data logging features
- Full hardware monitoring and fault reporting system
- Real time control of TerraSAS digital photovoltaic simulator systems (up to 100 channels)
- Real time control of standalone, desktop TerraSAS digital photovoltaic simulator units

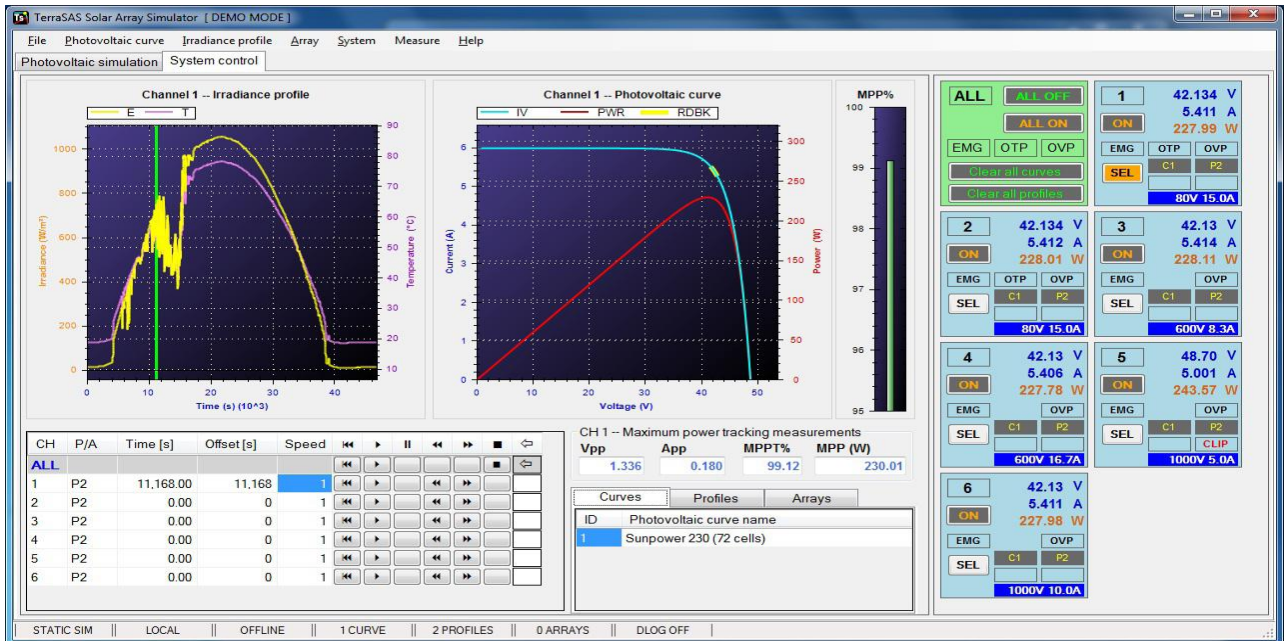


Figure 3: TerraSAS software main screen

**System Specifications:**

Number of PV simulator Channels: 2

Remote Control: Through remote desktop connected through Ethernet

Operating System: Microsoft Windows 7

**Ac Input:**

Line Voltage: 380/400VAC±10%, 3-phase, 50/60Hz, 4-wire (L<sub>1</sub>, L<sub>2</sub>, L<sub>3</sub>, Ground )

Max input current at 342 VAC (Low Line): 70A per phase

Main Circuit breaker: 125A, 600V



### **DC Output:**

Open Circuit Voltage,  $V_{OC}$ : 0-600VDC

Short Circuit Current,  $I_{SC}$ : 0-25A (per channel)

Maximum output power per channel at MPP: 12.75 kW at fill factor of 0.85

### **Accuracy:**

Voltage: 1% error of calculated curve formula at  $E > 250\text{W}/\text{m}^2$

Current: 2% error of calculated curve formula at  $E > 250\text{W}/\text{m}^2$

Voltage Read-back: 0.2% of maximum voltage

Current Read-back: 0.5% of maximum current

### **Curve Equations:**

Equations used to calculate the IV curves are found in Appendix A1 and A2 of the publication "Performance Test protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems", October 2004, Sandia national Labs.

### **PV Array Parameters:**

Irradiance Level: 0 to 1999  $\text{W}/\text{m}^2$

Temperature Value:  $-100^\circ\text{C}$  to  $+100^\circ\text{C}$

Voltage level: 0 to 600VDC

Current Level: 0 to 25A (per channel)

Voltage and power temperature coefficients:  $-1.99\%/^\circ\text{C}$  to  $+1.99\%/^\circ\text{C}$

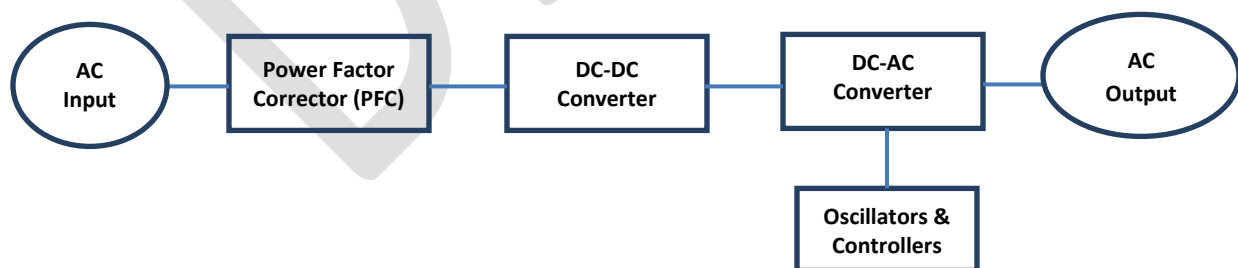
## 2. Grid Simulator

### Introduction

The Grid simulator is a MX Series programmable Power Sources, by AMETEK Programmable Power (AMETEK), which can be specified with either Source (Normal) or Regenerative Mode (SNK) options. With the latter, the MX Series can “sink” rather than “source” power, hence the “SNK” designation for this option. In operation, SNK settings determine how the MX performs in the Regenerative Mode when the MX receives power returning from the equipment to which it is connected. This application note describes the typical operational characteristics of the MX in Regenerative Mode, using either the front panel or the MXGUI control software to implement the desired test procedures. The examples provided in this application note include tests and measurements with an actual solar inverter test setup, one of the more common applications for which regenerative power sources are used.

### Principle of Operation

An explanation of the circuits in the AC Source is given in this section. Refer to Figure 1 for a block diagram of the system.



**Figure 4: AC Source block diagram**



**Figure5. Grid Simulator**

### **Overall Description**

The AC input is fed to the power factor correction, boost type converter. The converter steps the voltage to 385 VDC while drawing near sinusoidal current from the input power line.

The DC to DC converter provides isolation and changes the voltage to 250 VDC or 400 VDC depending on whether the low output range or high output range is selected.

The DC to AC converter develops an AC sine wave voltage at the output frequency and amplitude programmed by the oscillator.

The oscillator board provides the reference signal to the DC to AC converter and has the front panel shuttles and switches to control and view the setting of voltage, frequency and current limit.

## Power Factor Correction Module (PFC)

The PFC consists of the boost converter circuitry. The boost converter is PWM controlled by a single chip that adjusts the pulse width during the cycle so that near sine wave current is drawn from the supply. An auxiliary winding on the boost inductor provides “bootstrap” power to the logic circuits and is self-sustaining.

## DC - DC Converter Module

The 385 VDC from the PFC is fed to the DC to DC module. It first supplies 385 volts DC to the auxiliary power supply. When the auxiliary power supply starts, it supplies six isolated DC supplies to the AC module. It also supplies 15 volts to the DC converter on the same DC module. The DC to DC converter will then start operating. The DC converter supplies either 250 volts DC or 400 volts DC to the DC to AC module.

The DC to DC converter is a full bridge converter and the auxiliary converter is a two FET forward converter.

All the eight LEDs on the DC-DC board should be lit under normal operation. The LED DS200 is lit when the DC output is up and within regulation. The amber LEDs DS5, DS4 and DS3 indicate that the 15V power to the Optocouplers on the AC converters is within regulation. The red and green LEDs, DS7 and DS6 indicate logic power to the AC converter is ok. The red LED DS8 indicates that logic power to the DC converter is within specification at 15 volts. The LED DS2 shows that 24 volt fan power is available.

**Table 1: Logic Board LED's**

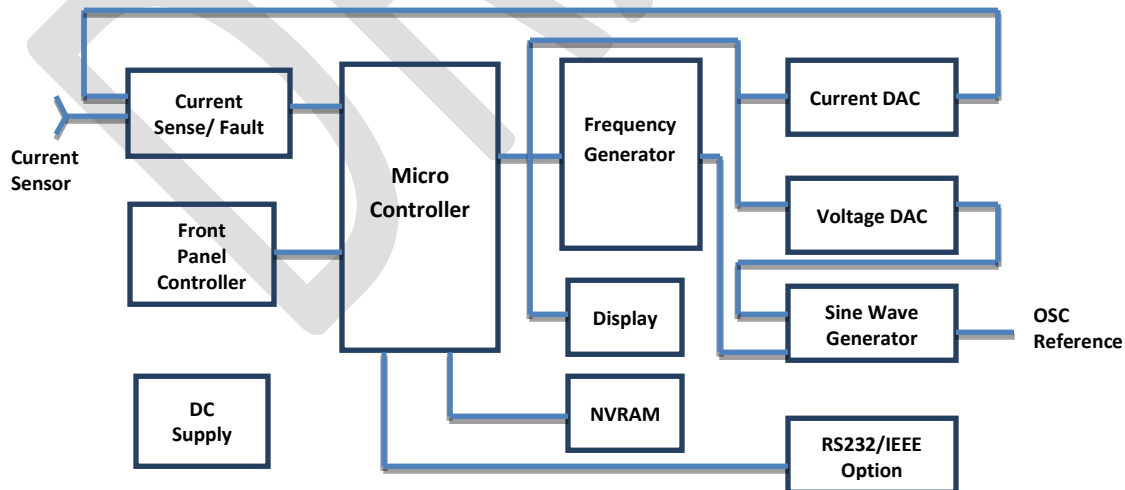
LED#	FUNCTION	COMMENTS
DS2	24V ok	24 volt fan power is available.
DS3	15V ok	15V power to the optocouplers on the AC converters is within regulation

DS4	15V ok	15V power to the optocouplers on the AC converters is within regulation
DS5	15V ok	15V power to the optocouplers on the AC converters is within regulation
DS6	power ok	logic power is ok to the AC converter
DS7	power ok	logic power is ok to the AC converter
DS8	power ok	logic power is ok to the DC converter
DS200	DC bus ok	DC output is up and within regulation

### Oscillator Control Board

The Oscillator control board has the Microcontroller and all the control logic to generate a programmable sine wave reference of the correct amplitude and frequency. It includes all the control logic to respond to user commands from the front panel or the remote control interface. It also updates the displays to show the programmed settings and current measurements. Refer to Figure 2 for a block diagram.

When the output is programmed above 5.0 volts, the multicolour LEDs, DS10 and DS9, on the oscillator board will illuminate.



**Figure 6: Oscillator and controls**



## DC to AC Power Module

The DC to AC power Module takes a 250V DC input and generates 0 to 135 volts AC, directly coupled, low range output. When the DC to AC module is supplied with 400 volts DC, the AC module generates 0 to 270 volts AC. The output converter is a PWM full bridge topology with an LC filter on the output. The switching frequency is 34.6 kHz.

This module has pulse by pulse peak current limit and sinusoidal average current limiting to protect the power transistor and load.

## IEEE 488/ RS232

The RP can optionally be outfitted with a combined RS232C and IEEE 488 interface board. This board assembly has optocouplers for interface isolation.

The interface in use is selected by a DIP switch on the rear panel. Only one interface can be active at any given time.

## System Specifications:

All specifications at 25.5 C unless noted otherwise.

- **Electrical**

- 1. **Input**

- Line Voltage: 85V to 264V maximum.
    - 100V to 240V nominal.
    - Line Current: 15 A RMS max.
    - Line Frequency: 47-63 Hertz.
    - Efficiency: 80% (typical) depending on line and load.
    - Power Factor: 0.95 or greater typical.
    - Inrush Current: 70 A peak max. at 260V input.
    - Hold-Up Time: 20 ms (with no effect on output).

- Isolation Voltage: Input to output = 2200 VAC, input to chassis = 1350 VAC.

## 2. Output

- Voltage Range: 0 to 135 V rms or 270 V rms
- Voltage Resolution: 0.1 volt
- Voltage Accuracy: 1% of range, 50 to 60 Hz.
- 2% at 400 Hz
- Line & Load Regulation: 1% of FS on low range, 0.5% of FS on high range.
- Voltage Distortion: 0.5% typical. THD at 50/60 Hz.
- Total Power: 800 VA maximum at full scale voltage, either range (Model 801RP).
- 1250 VA maximum at full scale voltage either range (Model 1251RP).

**Note:** On the 1251RP, the maximum output power is limited to 1000VA when the input Voltage is below 120VAC.

- Current: 6.0 A rms, 18 A peak (low range, Model 801RP)
- 3.0 A rms, 9 A peak (high range, Model 801RP)
- 9.2 A rms, 27.6 A peak (low range, Model 1251RP)
- A rms, 13.8 A peak (high range, Model 1251RP)
- Current Limit: 801RP 1251RP
- 135V range: 0.0 to 6.0 9.2
- 270V range: 0.0 to 3.0 4.6
- Accuracy: Programmed value +5% of maximum current
- Frequency Range: Range Resolution
- 16.0 - 99.9 Hz 0.1 Hz
- 100 - 500 Hz 1 Hz
- Frequency Accuracy: 0.02% of programmed value.

- DC Offset Voltage: Less than 25 mV with linear load.
- Output Noise: <0.2 volts RMS on 135 range, <0.5 volts RMS on 270 range.

### 3. Measurements

- Current (TRMS)
- Resolution: 0.1 amp
- Accuracy: 0.2 amp
- Voltage Accessible only through RS232/ IEEE 488 Interface
- 0 - 250V 251 to 270V
- Resolution 1 Volts 2 volts
- Accuracy: 4 Volts 6 volts
- Environmental
- Operating Temp: 0 degrees to +40 degrees Celsius.
- Storage Temp: -40 degrees to +85 degrees Celsius.
- Humidity: Operating: 90% RH up to 40 C.
- Storage: 90% RH up to 40 C, 75% RH up to 70 C.
- Creep-age and
- Clearance: Rated for Pollution Degree 2.
- Insulation: Rated to Installation Category (Over Voltage Category) II
- Vibration: Designed to meet NSTA 1A transportation levels.
- Shock: Designed to meet NSTA 1A transportation levels.

### 3. Load Emulator

#### Main Functions

1. ABC three phase resistive, inductor capacitive load active power direct independently display, symptoms of the resonant point will be directly in testing interface.
2. The minimum standard power of the internal resistive load ,inductive load and capacitive load is 0.001K ,stepping amplitude is 0.001 load power is adjustable and it may simulate the occurrence of the resonance accurately and satisfy the requirement of the protection of inverter anti islanding function testing .
3. Resistive load adopts alloy resistance components to make sure the impedance values should not cause change when the temperature of resistive load component goes too high during the test.
4. The internal inductance adopts the inductive load component that is magnetic circuit and controlled, it satisfies the requirement that capacity control of the line voltage 400V/50Hz under the working conditions of 0.0001KVA .It satisfies that the power of inductive impedance would not be changed after a long term of loading process.
5. The internal capacitance adopts the capacitance components that are standard CBB; it satisfies the requirement that capacity control of the line voltage 400V/50Hz under the working conditions of 0.0001KVA .It satisfies that the power of capacitive impedance would not be changed after a long term of loading process.
6. Each sub circuit in the internal capacitive load have an extra circuit protection modules which is specially for preventing short circuit in case that capacitive component burns the host when the short circuit happens during the test or the time that load switch closed.

7. The power of ABC three phase resistive load, inductive load, capacitive loads could be independently controlled and adjusted, it satisfies that adjust the AC resonant point accurately when the voltage of three phase was unbalanced.
8. According to the test requirements of the performance parameters, user could get relevant power combined willfully and set the discharge power through the remote PC.
9. The host adopts electronics circuit; it has the self-protective function that it would be alarmed automatically when the temperature goes too high; it would cut out the load automatically when it was too hot or overcurrent.
10. New type of power dissipation components with high power density, it doesn't have the red-hot phenomena. The machine is consisted of resistive load, inductive load and capacitive loads.
11. The input power adjustable continuously. Work load by the way of dissipation, heat dissipation adopts the air-cooled way.
12. The RLC load power can be adjusted by the software of the remote PC.
13. The test data in the test process could be recorded and saved to the remote PC.
14. Using the background software, the test data would become the test report in the way of EXCEL.
15. It satisfies the requirements of test of the grid inverter anti-islanding experiment; it satisfied the requirement of test IEC 62116-2008 standard experiment, software with standard test steps (31 times) of IEC62116-2008.

#### Technical Parameter:

1. The loop is consist of resistive load, inductive load and capacitive load
2. The three parts of load is controlled by switches piecewise

**Resistive load R:** ABC three phase each phase has 0.001-0.01kW, 0.01-0.1kW, 0.1-1kW, 1-10kW. Three-phase of ABC has 33.33kW totally;

**Capacitive load C:** ABC three phase each phase has 0.001-0.01kvar, 0.01-0.1kvar, 0.1- 1kW, 1-10kvar.Three-phase of ABC has 33.33kvar totally;

**Inductive load L:** ABC three phase each phase has 0.001-0.01kvar, 0.01-0.1kvar, 0.1- 1kvar, 1-10kvar.Three-phase of ABC has 33.33kvar totally;

3. The internal load of host adopts the method of three phase wire system, Three-phase of A, B, C could be controlled independent.
4. Resistive part, inductive part and capacitive part could be combined willfully ,the minimum stepping amplitude of 0.001k
5. The range of applicable environment temperature: 10-40 degC
6. Input voltage :Three phase AC400V or single phase AC230;
7. The way of connection: Three -phase four wire ,single phase two wire;
8. Precision of voltage is  $\pm 0.5\%$  ,resolution of voltage is 0.1V;
9. Current measurement range 0-200A,precision of current is  $\pm 1A$ ;
10. The range of frequency measurement is 45-65Hz (label the inductive load and the capacitive load with 50Hz)
11. Type of cooling :Forced air cooling ;
12. Connect with PC,RLC load power can be adjusted by software;
13. Working power supply :ac 230V/50Hz
14. Appearance size: 1250\*600-1600,Net Weight :500kG



Figure 7: Load emulator software control panel



Figure 8: Load Emulator

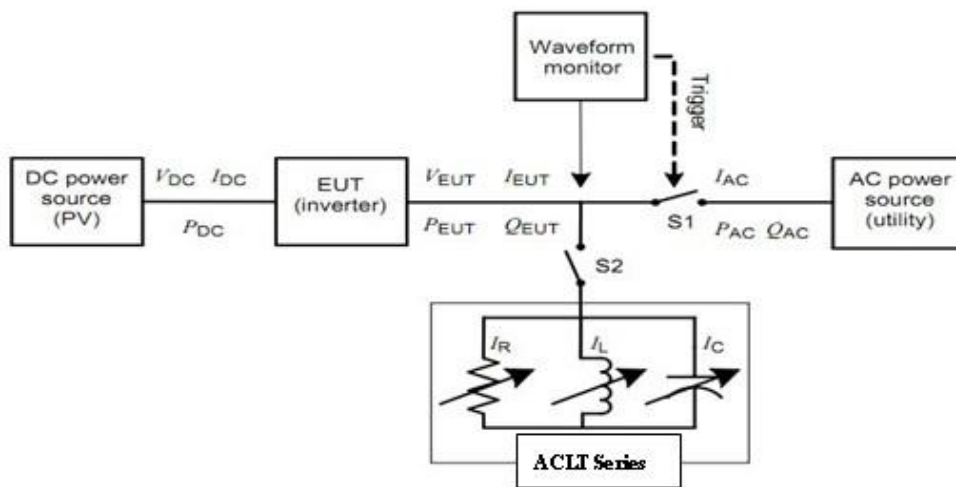


Figure 9: Inverter test setup



## 4. Embedded System and Controller

### NI cRIO-9074:

Integrated 400 MHz Real-Time Controller and 2M Gate FPGA

- Rugged, embedded control and monitoring system
- 400 MHz industrial real-time processor for control, data logging, and analysis
- 2M gate, 8-slot FPGA chassis for custom I/O timing, control, and processing
- Two 10/100BASE-T Ethernet ports; RS232 serial port for connection to peripherals
- -20 to 55 °C operating temperature range; single 19 to 30 VDC power supply input

### NI PS-15 Power Supply:

5 A, 24 VDC

- 1-phase, 115/230 VAC input; 24 to 28 VDC, 5 A output
- Power supply for CompactRIO, Compact FieldPoint, NI Single-Board RIO, NI Smart Cameras, and NI TPCs
- Full 120 W output power between -25 and +60 °C, (de-rated 3 W/°C from 60 to 70 °C)
- 20 percent power reserve for dynamic loads can be used continuously up to 45 °C
- Tool-less spring-clamp terminals for easy field connectivity
- DIN-rail mounting included and panel/side mount accessories available

### NI LabVIEW Electrical Power Suite:

Power and Energy Analysis for Compact RIO Hardware

- Measure power quality and energy features to IEC, EN, and IEEE standards
- Harmonics (IEC 61000-4-7) and Flicker (IEC 61000-4-15)
- PMU (C37.118) [Professional Edition Only]

- Sag/swell/interruption with standard or custom levels (IEC 61000-4-30)
- Rapid voltage change with standard or custom levels (IEC 61000-4-30)
- Compatibility with the COMTRADE (IEEE 37.111) file format

#### **NI 9227:**

##### 4-Channel Current Input C Series Module

- 5 Arms measurement (14A peak)
- 50 kS/s/ch simultaneous inputs
- Built-in anti-alias filters
- Screw terminal connectors included, protective back shells sold separately
- 250 Vrms channel-to-channel isolation

#### **NI 9225:**

##### 3-Channel, 300 Vrms Analog Input Module

- 600 Vrms channel-to-channel isolation
- 50 kS/s/ch simultaneous inputs
- Built-in anti-alias filters
- 300 Vrms measurement range
- Connectors and high-voltage backshells included

#### **NI 9481:**

##### 4-Channel Relay [30 VDC (2 A), 60 VDC (1 A), 250 VAC (2 A)]

- Hot-swappable operation
- Extreme industrial certifications/ratings
- -40 to 70 °C operating range
- 4-channel, EM Form A electromechanical relay outputs

- 30 VDC (2 A), 60 VDC (1 A), 250 VAC (2 A) SPST relay
- 250 Vrms channel-to-channel isolation

#### **NI 9211:**

4-Channel, 14 S/s, 24-Bit,  $\pm 80$  mV Thermocouple Input Module

- 4 thermocouple or  $\pm 80$  mV analog inputs
- 24-bit resolution; 50/60 Hz noise rejection
- Hot-swappable operation
- $-40$  to  $70$  °C operating range
- NIST-traceable calibration

#### **NI 9205:** Taken from TERI SMG.

32-Ch  $\pm 200$  mV to  $\pm 10$  V, 16-Bit, 250 kS/s Analog Input Module

- 32 single-ended or 16 differential analog inputs
- 16-bit resolution; 250 kS/s aggregate sampling rate
- $\pm 200$  mV,  $\pm 1$ ,  $\pm 5$ , and  $\pm 10$  V programmable input ranges
- Hot-swappable operation; over-voltage protection; isolation; NIST-traceable calibration
- $-40$  to  $70$  °C operating range
- Spring terminal or D-Sub connectivity

#### **NI 9403:**

C Series 32-Ch, 5 V/TTL Bidirectional Digital I/O Modules

- 32-channel digital I/O module for NI CompactDAQ or CompactRIO
- 5 V/TTL, sinking/sourcing digital I/O
- Bidirectional, configurable by line

- 1000 Vrms transient isolation,  $\pm 30$  V over-voltage protection
- Hot-swappable operation
- -40 to 70 °C operating range

### **NI 9870:**

4-Port, RS232 Serial Interface Module for CompactRIO

- 4 RS232 (TIA/EIA-232) serial ports for CompactRIO
- Baud rates from 14 b/s to 921.6 kb/s
- Data bits: 5, 6, 7, 8; Stop bits: 1, 1.5, 2; Flow control: XON/OFF, RTS/CTS, None
- Individual 64 B UART FIFO buffers per port
- 8 to 28 VDC externally powered; PC-MF4-PT cable included
- -40 to 70 °C operating range

### **SA 1802, GSM/GPRS:**

SEA cRIO Modules expand the National Instruments CompactRIO Platform by interfaces for

- Wireless communication via GSM, UMTS, EDGE
- Position determination by GPS
- Communication with position sensors (EnDat) or
- Bus systems (LIN bus, ARINC 429-81)

### **NI LabVIEW Developer Suite:**

- Bundles LabVIEW Professional with the most popular add-ons for up to 74% savings
- Features tools for building rich interfaces in LabVIEW, Visual Basic .NET, and C for large-scale application development

- Includes add-ons for Microsoft Word and Excel, database and Internet connectivity, and code validation
- Includes add-ons for advanced signal processing and digital filter design, PID control and fuzzy logic tools

### **NI LabVIEW Real-Time Module:**

- Design deterministic real-time applications with LabVIEW graphical programming
- Download to dedicated NI or third-party hardware for reliable execution and a wide selection of I/O
- Take advantage of built-in PID control, signal processing, and analysis functions
- Automatically take advantage of multi-core CPUs or set processor affinity manually
- Includes real-time operating system (RTOS), development and debugging support, and board support
- Purchase individually or as part of an NI Developer Suite bundle

### **NI LabVIEW FPGA Module:**

- Create your own I/O hardware without VHDL coding or board design
- Graphically configure FPGAs on NI reconfigurable I/O (RIO) hardware targets
- Define your own control algorithms with loop rates up to 300 MHz
- Execute multiple tasks simultaneously and deterministically
- Implement custom timing and triggering logic, digital protocols, and DSP algorithms
- Incorporate existing HDL code and third-party IP including Xilinx CORE Generator functions

**NI LabVIEW Data-logging and Supervisory Control (DSC) Module:** Procured earlier.

- OPC-UA server/client, Classic OPC client, and Mod-bus for data sharing with third-party devices
- Built-in networked database for distributed data logging
- Graphical development for HMI and distributed monitoring and control applications
- Configuration-based real-time and historical trending, alarms, and event handling
- Unlimited tags to connect to NI hardware, PLCs, and other third-party hardware
- Deployment requires a LabVIEW DSC Module Run-Time System license



**Figure 10: NI cRIO kit and Power Supply**

## 5. Digital Signal Oscilloscope:

To measure and observe various signal and waveform in the electrical network, DSO is highly required device. Normal measuring device can not measure high frequency signal very accurately. The transient and surge event can easily be logged using DSO for example islanding condition in PV inverter etc.

## Features:

- 500 MHz, 300 MHz and 100 MHz Bandwidths
- Sample Rates up to 5 GS/s
- 2 or 4 Channels
- Full VGA Color LCD on all Models
- Built-in Floppy Disk Drive For Easy Storage and Documentation
- 21 Automatic Measurements
- Centronics Port Standard on all Models for Quick, Convenient Hardcopies
- 9-Bit Vertical Resolution
- Multi-language User Interface
- Quick Menu User Interface Mode for Quick, Easy Operation
- Advanced Triggers such as Glitch, Width and Logic Standard on 4 Channel Models
- Telecommunications Mask Testing (TMT)
- Fast Fourier Transform (FFT) for Frequency and Harmonic Analysis Standard on 4 Channel Models
- Extended Video Application Module
- Support for Active Probes, Differential Probes and Current Probes that Provide Automatic Scaling and Units



**Figure 11: Digital storage Oscilloscope**

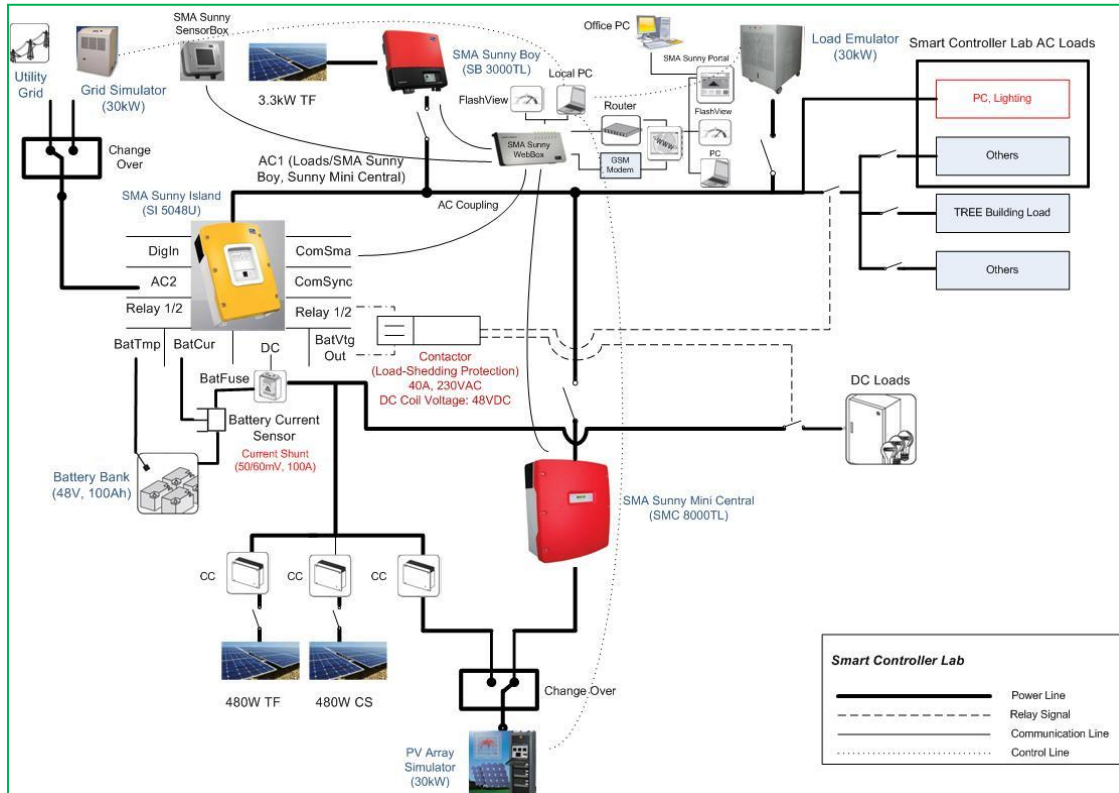
## **Layout/System Configuration of the Lab**

The laboratory would work towards achieving following goals during its operation:

1. Testing and long term performance assessment of different PV technologies in lab and field environment
2. Testing and long term performance assessment of different battery technology
3. Testing and full assessment of solar based hybrid systems (Micro/Mini-Grids) under different operating conditions
4. Design of solar based off-grid power plant and DC Micro-grid
5. Developing renewable energy packages catering to different energy requirements
6. Testing and performance assessment of inverters i.e. islanding testing etc
7. Working on increasing the efficiency of different renewable based power system



8. Customization of existing technology to suit the ecological needs of application
9. Experiments on Load management and resources management.



**Figure 12: Layout or system configuration of lab**

## Experiment 1

Performance assessment of different PV technology using PV array simulator.

### General:

With the recent booming of photovoltaic (PV) installations across the world, a realistic outdoor performance analysis of various types of modules is needed. This action supports both the scientific community and the different player in the PV environment, such as developers, producers, installers, financing institutions, as well as decision-makers and customers.

The possibility to assess the performance of different types of modules in a specific geographical location, under various irradiance levels is very important to evaluate the energetic behavior of future installations and direct them toward the most suitable technology to be used. Practically it is not possible to get the all possible environmental scenario at a single geographic location, but using solar array simulator we can create different irradiance profile and apply it on the profile of the solar module and modules performance for different profile can be tested.

**Apparatus/Instrument Required:**

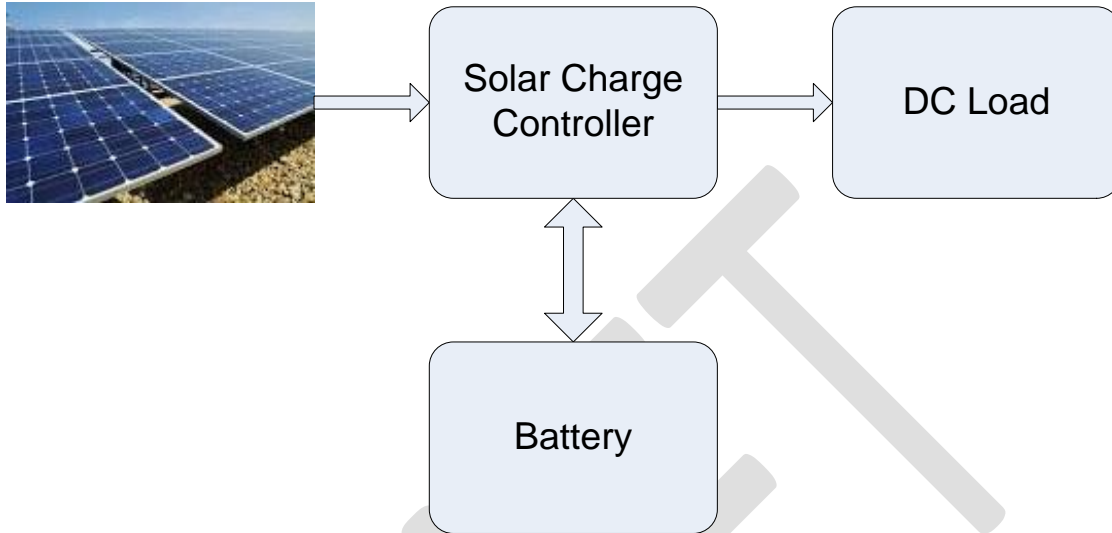
S.No	Apparatus	Rating
1.	Solar array simulator	30kW
2.	Load Emulator	30kW
3.	Charge controller	
4.	Batteries	
5.	Multimeter	

**Following are the test related to the Experiment No1.**

<b>Test 1</b>	Performance evaluation of a solar module under different irradiance profile using solar array simulator. (Figure 13)
<b>Procedure</b>	<p>This test evaluates the performance and behavior of the solar module in different irradiance profiles.</p> <p>Solar PV model (commercially available) is selected in the simulator and various irradiance profiles are applied on it. Then its performance is assessed in term of maximum power point, total power output, energy output, Isc and Voc etc. for different irradiance profile.</p>
<b>Performance</b>	<ul style="list-style-type: none"> <li>• Maximum Power Output</li> </ul>

<p><b>Or Observation parameter</b></p>	<ul style="list-style-type: none"> <li>• Total Power Output</li> <li>• Total energy output</li> <li>• Short circuit current</li> <li>• Open circuit Voltage</li> <li>• Total Energy Generated</li> </ul>
<p><b>Observation Table</b></p>	<p>Profiles:</p> <ul style="list-style-type: none"> <li>• Cloudy day</li> <li>• Fast ramp</li> <li>• Heavy clouds day</li> <li>• Slow ramp</li> <li>• Sunny day</li> <li>• Triangle ramp</li> </ul>
<p><b>Precautions</b></p>	<ul style="list-style-type: none"> <li>• Parallel-connected channels must have the same maximum voltage rating. For instance, a 600V SG cannot be paralleled with an 80V DCS.</li> <li>• Series-connected channels should have identical voltage and current ratings. This is strongly recommended and delivers the best performance. However, the software allows connecting 600V and 1000V PV simulators in series. It also allows mixing power ratings (i.e. 600V/17A in series with 600V/25A). When mixing ratings, the overvoltage protection might behave incorrectly when simulators are back-fed from the inverter under test. There could also be stability issues in some cases.</li> <li>• The maximum number of series-connected channels is 3. This is to limit the IV curve distortion that occurs when many channels are wired in series.</li> </ul>
<p><b>Conclusion</b></p>	

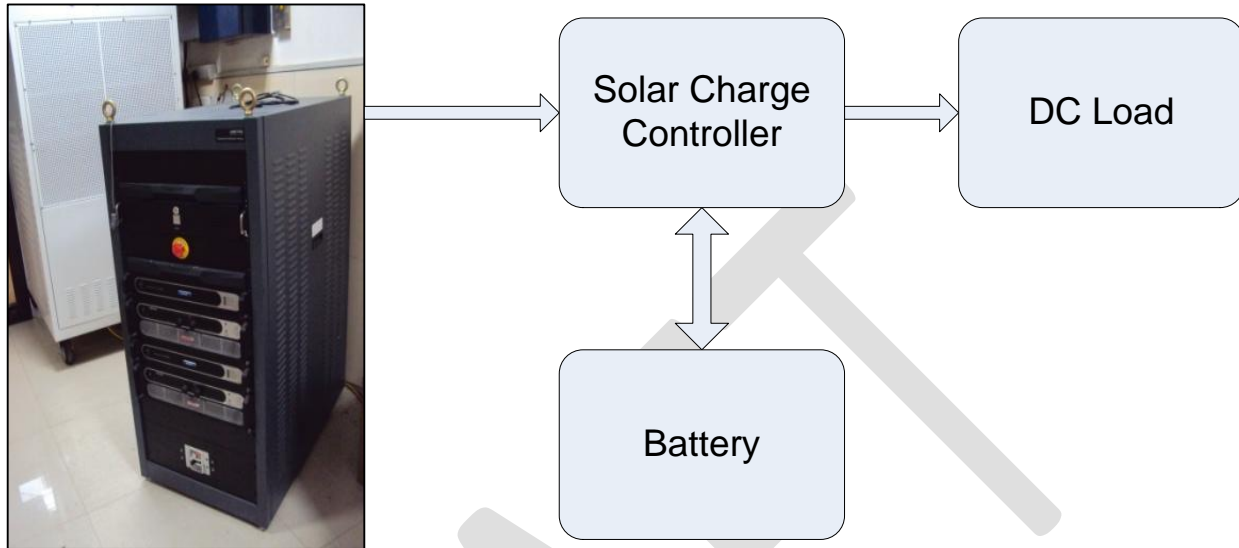
**Test set up 1:**



**Figure 13: On-field PV module test bed schematic diagram**

DRAFT

**Test Set Up 2:**



**Figure 14: PV technology assessment using PV array simulator**

<b>Test 2</b>	Comparative performance evaluation of different PV technology
<b>Procedure</b>	<p>This test evaluates the performance of the different solar modules in different irradiance profiles.</p> <p>In PV array simulator, different PV technologies solar modules of same power ratings are simulated and different irradiance profiles are applied on PV profiles of solar modules.</p>
<b>Performance parameter</b>	<ul style="list-style-type: none"> <li>• Energy generated (Watt-hour) in a day</li> <li>• MPP of PV modules</li> <li>• Power output of modules</li> </ul>
<b>Precautions</b>	
<b>Conclusion</b>	

<b>Test 3</b>	To assess the performance of PV array under partial shading conditions using solar array simulator
<b>Procedure</b>	<p>This test evaluates the performance of the solar modules in different partial shading conditions. In PV array simulator, different PV technologies solar modules of same power ratings are simulated.</p> <p>Various series parallel combinations are made and their performance is evaluated under partial shading conditions.</p>
<b>Performance parameter</b>	<ul style="list-style-type: none"> <li>• MPP of PV modules</li> <li>• Global and local maxima</li> <li>• Total Energy output in shading</li> <li>• Voc</li> <li>• Isc</li> <li>• Vmp</li> <li>• Imp</li> </ul>
<b>Precautions</b>	
<b>Conclusion</b>	

## Experiment 2

Performance evaluation of different PV technology for battery charging application and comparison of watt-hours delivered to the batteries.

### General:

To properly select batteries and PV technology for use in solar PV systems, it is important that system designers have a good understanding of their design features, performance characteristics and operational requirements. In stand-alone photovoltaic systems, the electrical energy produced by the PV array cannot always be used when it is produced. Because the demand for energy does not always coincide with its production, electrical storage batteries are commonly used in PV systems.

### Apparatus Required:

S.No	Apparatus	Rating
1.	Different Technology Solar PV modules	
2.	PV array simulator	30kW
3.	Load Emulator	30kW
4.	Charge controller	
5.	Batteries	
6.	Multimeter	

Following are the test related the Experiment No2.

<b>Test 1</b>	Performance evaluation of solar module under different irradiance profile. (Figure 2)
<b>Procedure</b>	This test evaluates the PV performance for battery charging application.

<b>Performance parameter</b>	<ul style="list-style-type: none"> <li>• Watt-hour delivered to the battery in a day</li> </ul>
<b>Precautions</b>	

<b>Test 2</b>	Performance evaluation of different solar module under different irradiance profile. (Figure 14)
<b>Procedure</b>	In PV array simulator, different PV technologies solar modules of same power ratings are simulated and used for battery charging application.
<b>Performance parameter</b>	<ul style="list-style-type: none"> <li>• Watt-hour delivered to the battery in a day</li> <li>• Power output of modules</li> </ul>
<b>Precautions</b>	
<b>Conclusion</b>	



### Experiment 3

To assess the performance of the solar charge controller using the PV array simulator.

#### General:

Charge controller is the important component in every Solar PV system. Battery performance entirely depends on functioning of the solar charge controller. It is separately designed of individual battery. There is great importance of charge controller in PV plant .Hence it very essential to test and assess the performance of the charge controller before actually putting in the field.

#### Apparatus Required:

S.No	Apparatus	Rating or Range
1.	PV array simulator	30kW
2.	Charge controller	
3.	Batteries	
4.	Multimeter	

<b>Test</b>	To evaluate the performance parameter of the charging controller.(Figure 14)
<b>Procedure</b>	In PAS a PV profile (compatible with solar charge controller) is generated and different irradiance profiles are applied .Then charge controller is connected to PV and battery.
<b>Observation Parameter</b>	<ul style="list-style-type: none"> <li>✓ Efficiency</li> <li>✓ Protections               <ul style="list-style-type: none"> <li>• HVD</li> <li>• Short Circuit Protection</li> <li>• LVD</li> <li>• Reverse polarity protection etc.</li> </ul> </li> </ul>

## Experiment 4

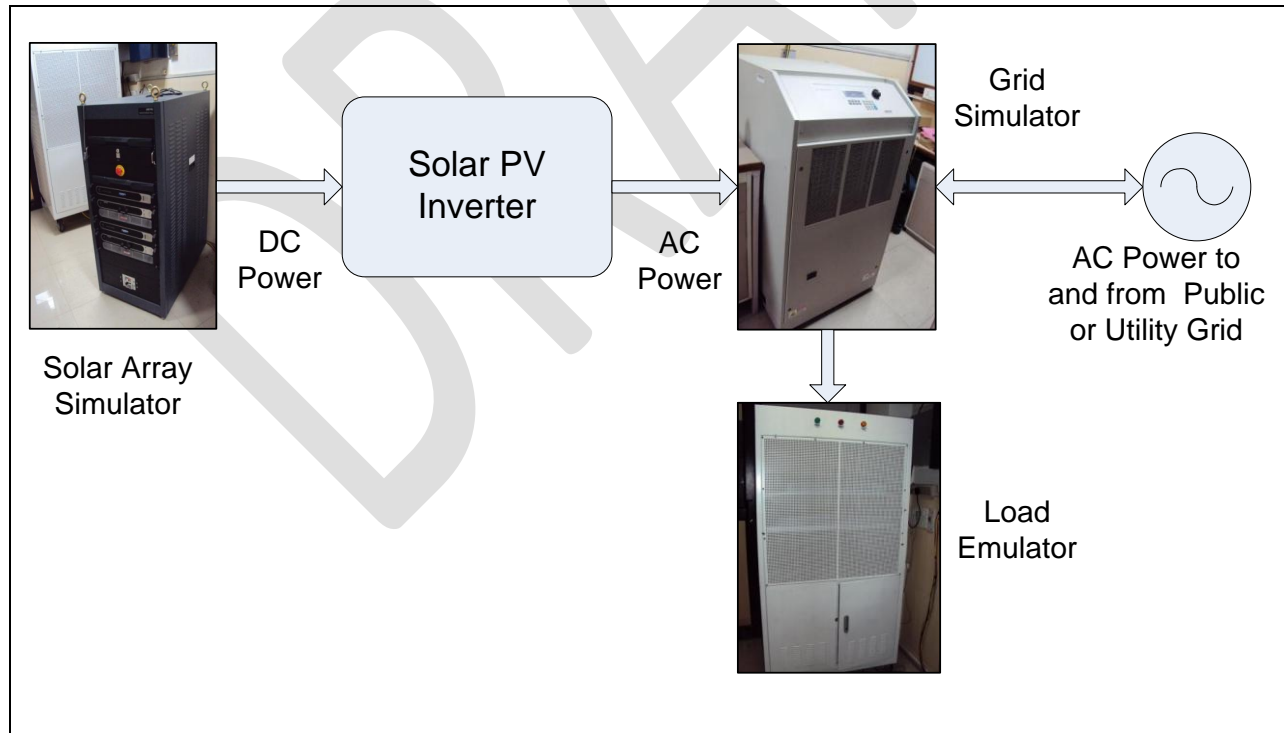
To assess the performance of Solar Photo-voltaic Inverter used in solar PV plant.

### General:

Testing of grid-tied inverters used in solar energy systems is emerging as a major application for highly repeatable ac power sources. These power sources are used both in the design phase as well as in production testing to confirm their ability to withstand variations in utility line power and demonstrate conformance to applicable standards.

Test issues dictate the need for power source features that make testing easier, as well as more accurate and more repeatable. Furthermore, the environmental and economic impact of wasting electrical energy demands that considerable attention is given to reduce energy consumption. Both aspects define the requirements for an advanced power source

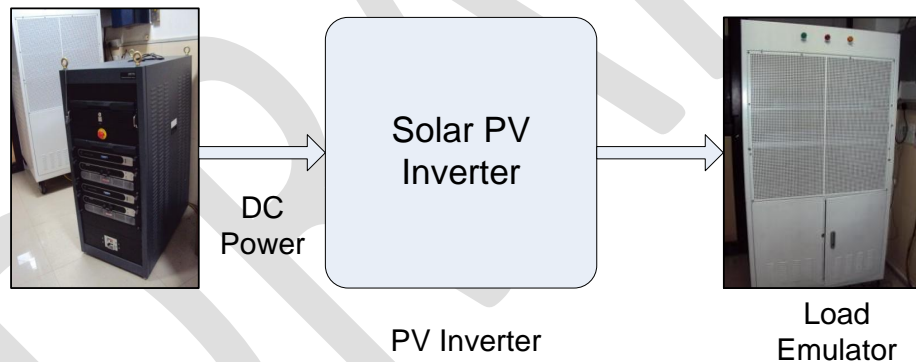
### Test Setup for inverter testing:



**Figure 15: Schematic of test setup for inverter testing**

### Apparatus Required:

S.No	Apparatus	Rating or Range
1.	PV array simulator	30kW
2.	Grid tied inverter	
3.	Grid simulator	30kW
4.	Load Emulator	30kW
5.	Digital Storage Oscilloscope(DSO)	
6.	Power Quality Meter	
7.	Change Over switch	



**Figure 16: General Inverter Testing**

Following are the test related to the Experiment No4.

#### Static or steady state test:

<b>Test 1</b>	Performance evaluation of different PV inverter using PV array simulator(Figure 16)
<b>Procedure</b>	Through the PAS a suitable and proper PV profile is generated and feed to PV

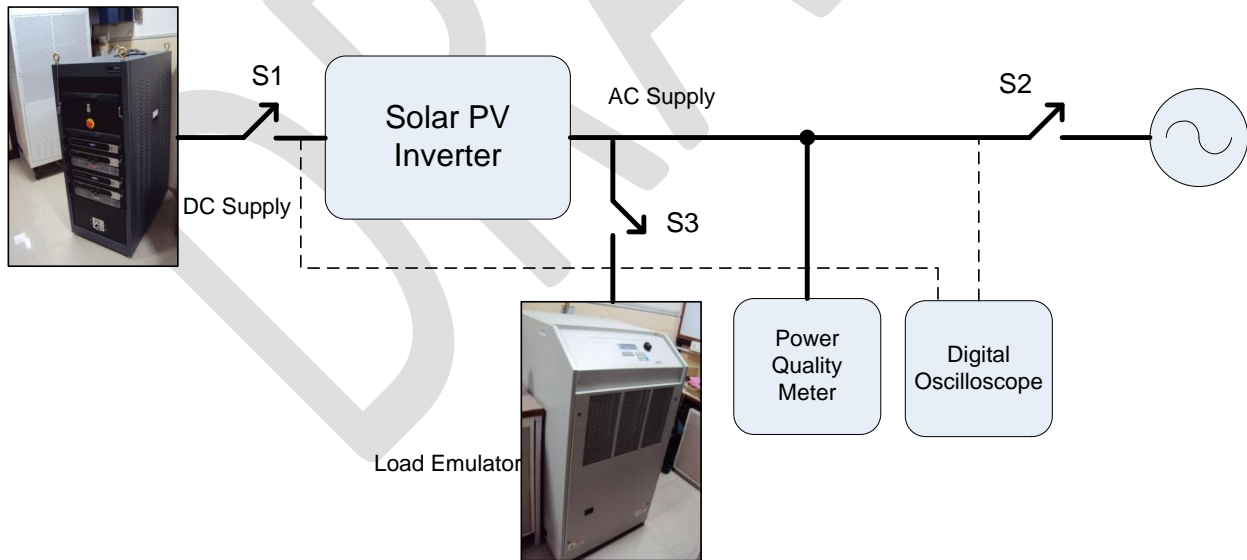
	inverter.
<b>Observation Parameter</b>	<ul style="list-style-type: none"> <li>• Minimum Voltage at which inverter operates</li> <li>• Maximum voltage</li> <li>• Accuracy of MPP tracking</li> <li>• Mpp tracking time duration</li> </ul>
<b>Standard to be followed</b>	

<b>Test 2</b>	Efficiency test for PV inverter at different loading 25%, 50% and full loading.
<b>Procedure</b>	<ol style="list-style-type: none"> <li>1. Through the PAS a suitable and proper PV profile is generated and feed to inverter. Further PV inverter is connected to Grid simulator.</li> <li>2. Grid simulator power rating must be greater than Inverter under testing.</li> <li>3. Inverter will be loaded 25%, 50% and 100%.</li> </ol>
<b>Observation</b>	<ul style="list-style-type: none"> <li>• Input and Output voltage of the Inverter(<math>V_{in}</math> and <math>V_{out}</math> )</li> <li>• Input and Output current of the Inverter(<math>I_{in}</math> and <math>I_{out}</math>)</li> </ul> $\eta = \frac{P_{AC}}{P_{DC}} * 100$ <p>Where <math>P_{ac}</math>-AC power generated by the inverter  <math>P_{DC}</math>-DC power input to the inverter</p> <ul style="list-style-type: none"> <li>• Adjust the PV array simulator output to 25% of the rated inverter power, observe the AC power output.</li> <li>• Adjust the PV array simulator output to 50% of the rated inverter power, observe the AC power output.</li> <li>• Adjust the PV array simulator output to 100% of the rated inverter power, observe the AC power output.</li> </ul>

	<p>Observation Table:</p> <table border="1" data-bbox="397 388 1477 619"> <thead> <tr> <th>S.No</th> <th>%Loading</th> <th>Efficiency</th> </tr> </thead> <tbody> <tr> <td>1.</td> <td>25</td> <td></td> </tr> <tr> <td>2.</td> <td>50</td> <td></td> </tr> <tr> <td>3.</td> <td>100</td> <td></td> </tr> </tbody> </table>	S.No	%Loading	Efficiency	1.	25		2.	50		3.	100	
S.No	%Loading	Efficiency											
1.	25												
2.	50												
3.	100												
<b>Standard followed</b>													

<b>Test 4</b>	Test of PV inverter for power factor
<b>Procedure</b>	<ol style="list-style-type: none"> <li>1. Through the PAS a suitable and proper PV profile is generated and feed to inverter. Further PV inverter is connected to Grid simulator.</li> <li>2. Grid simulator power rating must be greater than Inverter under testing.</li> <li>3. Power Quality meter is connected to the output of the inverter</li> </ol>
<b>Observation Parameter</b>	<ul style="list-style-type: none"> <li>• Reactive power generated by the inverter using power quality meter</li> <li>• Active power</li> </ul> $PF = \frac{P}{\sqrt{P^2 + Q^2}}$ <p>P --Active Power Output            Q – Reactive Power Output            PF- power factor</p> <ul style="list-style-type: none"> <li>• When the output rated power of system is 100%, observer the value of power factor and record the value of the active and reactive power quantity.</li> </ul>

	<ul style="list-style-type: none"> <li>When the output rated power of system is 50%, observe the value of power factor and record the value of the active and reactive power quantity.</li> </ul> <p>Observation Table:</p> <table border="1" data-bbox="397 441 1477 672"> <thead> <tr> <th>S.No</th> <th>%Loading</th> <th>PF</th> </tr> </thead> <tbody> <tr> <td>1.</td> <td>25</td> <td></td> </tr> <tr> <td>2.</td> <td>50</td> <td></td> </tr> <tr> <td>3.</td> <td>100</td> <td></td> </tr> </tbody> </table>	S.No	%Loading	PF	1.	25		2.	50		3.	100	
S.No	%Loading	PF											
1.	25												
2.	50												
3.	100												
<p><b>Standard Followed</b></p>													



**Figure 17: Anti- islanding test of PV inverter**

### Dynamic or transient test

<b>Test 3</b>	To test PV inverter for anti-islanding protection (Figure 17)
<b>Procedure</b>	<ol style="list-style-type: none"> <li>1. Through the PAS a suitable and proper PV profile is generated and feed to inverter. PV inverter is connected to Grid simulator.</li> <li>2. Grid simulator power rating must be greater than Inverter under testing.</li> <li>3. Connect the digital oscilloscope to both input and output side of the PV inverter</li> </ol>
<b>Observation</b>	<p>As the grid simulator is disconnected with the help of switch <b>S2</b>, observe the following parameter in DSO</p> <ul style="list-style-type: none"> <li>• Voltage Transient at the output side of the inverter</li> <li>• Frequency Fluctuation of the AC output</li> <li>• Voltage transient at the input of the Inverter</li> </ul>
<b>Standard Followed</b>	

<b>Test 5</b>	To observe the transient in PV inverter when PV inverter is disconnected from the PAS. (Figure 17)
<b>Procedure</b>	<ol style="list-style-type: none"> <li>1. Through the PAS a suitable and proper PV profile is generated and feed to inverter. PV inverter is connected to Grid simulator.</li> <li>2. Grid simulator power rating must be greater than Inverter under testing.</li> <li>3. Connect the digital oscilloscope to both input and output side of the PV inverter</li> </ol>
<b>Observation</b>	As the PVS is disconnected with the help of switch <b>S1</b> , observe the following parameter in DSO

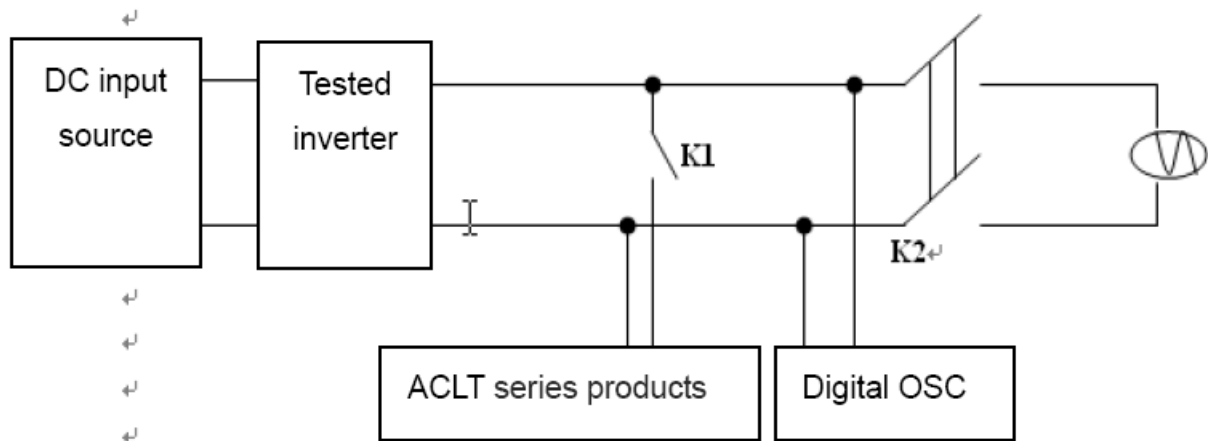
	<ul style="list-style-type: none"> <li>• Voltage Transient at the output side of the inverter</li> <li>• Frequency Fluctuation of the AC output</li> <li>• Voltage transient at the input of the Inverter</li> </ul>
<b>Standard Followed</b>	

<b>Test 6</b>	To assess the performance of PV inverter under different grid scenario. (Figure 17)
<b>Procedure</b>	<ol style="list-style-type: none"> <li>1. Through the PAS a suitable and proper PV profile is generated and feed to inverter. PV inverter is connected to Grid simulator.</li> <li>2. Grid simulator power rating must be greater than Inverter under testing.</li> <li>3. Connect the digital oscilloscope to both input and output side of the PV inverter</li> <li>4. Parameter(Voltage ,frequency) of Grid simulator are varied</li> </ol>
<b>Observation</b>	<ol style="list-style-type: none"> <li>1. When voltage of grid is increased above rated and decreased below rated value of the inverter output ,then observe the following parameter in DSO <ul style="list-style-type: none"> <li>• Voltage Transient at the output side of the inverter</li> <li>• Frequency Fluctuation of the AC output</li> <li>• Voltage transient at the input of the Inverter</li> </ul> </li> <li>2. When frequency of grid is increased above rated and decreased below rated value of the inverter output ,then observe the following parameter in DSO <ul style="list-style-type: none"> <li>• Voltage Transient at the output side of the inverter</li> <li>• Frequency Fluctuation of the AC output</li> <li>• Voltage transient at the input of the Inverter</li> </ul> </li> </ol>
<b>Standard Followed</b>	

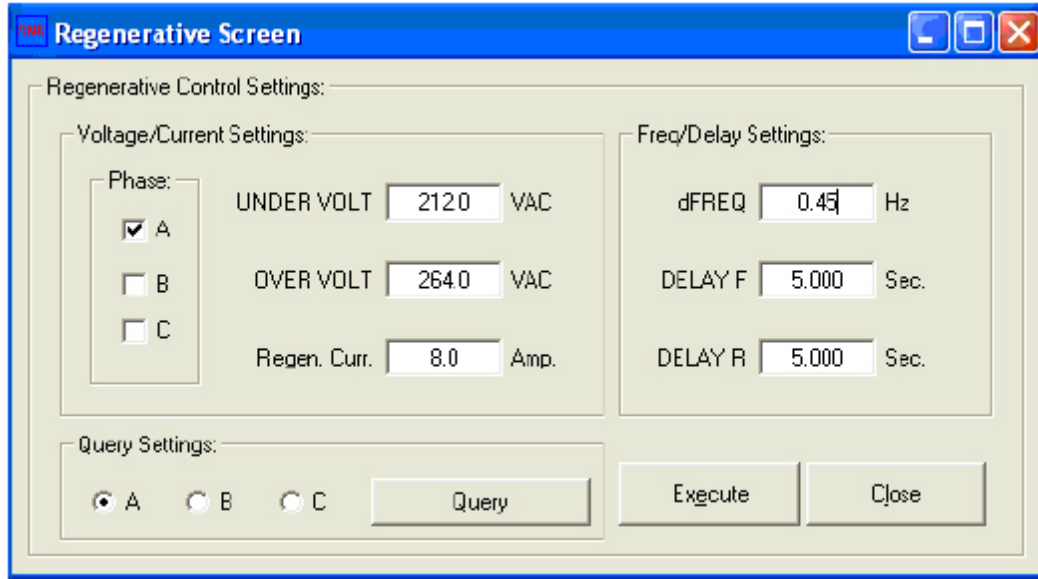


**Miscellaneous test:**

<b>Test 4</b>	To assess the performance of the inverter in overloading condition ( Load>Input power) (Figure 17)
<b>Procedure</b>	<ol style="list-style-type: none"> <li>1. Through the PAS a suitable and proper PV profile is generated and feed to inverter. Further PV inverter is connected to Grid simulator.</li> <li>2. Grid simulator power rating must be greater than Inverter under testing.</li> <li>3. Power Quality meter is connected to the output of the inverter</li> <li>4. Using the load emulator the load increased above input power from the PAS</li> </ol>
<b>Observation Parameter</b>	Using the load emulator the load is gradually increased , when it is greater than the input power observe input and output of the inverter in the DSO
<b>Standard Followed</b>	

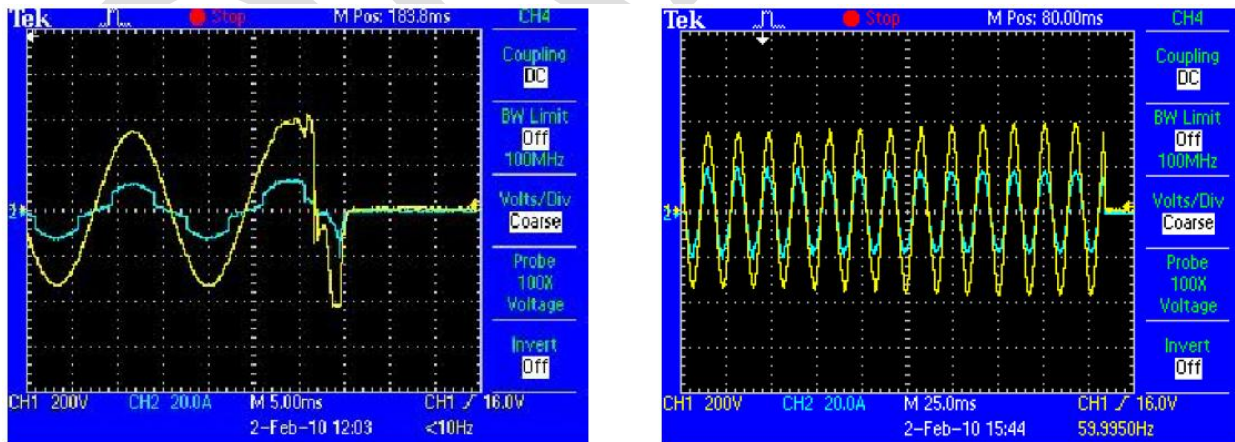


**Figure 18: Test procedure for PV inverter**



**Figure 19: Regenerative control parameter of Grid Simulator**

**Example Transient Observation in oscilloscope:**



**Figure 20: The difference between an inverter disconnecting with unbalanced (left) and balanced (right) load is an abrupt versus gradual event.**

## Experiment 5

To develop and test different configuration of DC microgrid and to evaluate the system performance under conditions

### General:

The electric power system has been designed in such a way that large AC power travels from high-voltage transmission lines and lower voltage distribution lines, to household and businesses that used the power in incandescent lights, AC motors, and other AC equipment. Today's consumer equipment and tomorrow's distributed renewable generation requires us to rethink this model. Electronic devices (such as computers, florescent lights, variable speed drives, and many other household and business appliances and equipment) need direct current (DC) input. However, all of these DC devices require conversion of the building's AC power into DC for use, and that conversion typically uses inefficient rectifiers. Moreover, distributed renewable generation (such as rooftop solar) produces DC power but must be converted to AC to tie into the building's electric system, only later to be re-converted to DC for many end uses. These AC-DC conversions (or DC-AC-DC in the case of rooftop solar) result in substantial energy losses.

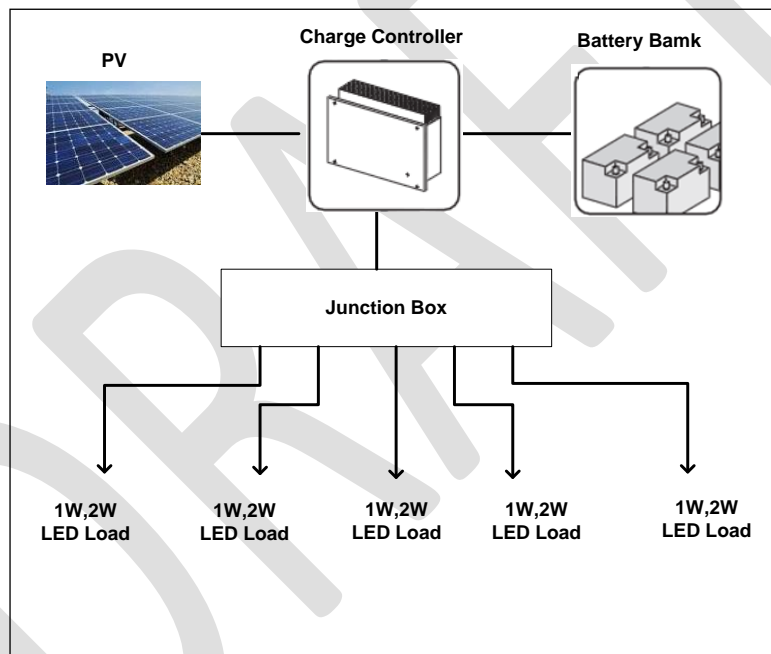
One possible solution is a DC microgrid, which is a DC grid within a building (or serving several buildings) that minimizes or eliminates entirely these conversion losses. In addition, rooftop photovoltaic (PV) and other distributed DC generation can be fed directly to DC equipment, via the DC microgrid, without the double conversion loss (DC to AC to DC), which would be required if the DC generation output was fed into an AC system. This concept reduces the transmission and distribution power losses to a very considerable level.

A microgrid is a low-voltage system with distributed generation, storage systems and loads. The major energy resources in a microgrid are clean energy, and power electronics converters are used to implement energy conversion. A microgrid can be balanced by itself

with some control strategies. It can be operated in independent mode or grid-connected mode. As an autonomic unit, it can meet the requirements of high quality and security power supply.

### 1. DC Micro-grid:

DC microgrid consists of interconnected distributed DC energy sources capable of providing sufficient and continuous energy to the load demand. It possesses independent control and minimum service interruption.



**Figure 21 : Schematic of a typical DC microgrid**

### Components required for developing a DC microgrid in the lab:

S.No	Apparatus	Rating or Range
1.	PV array simulator	
2.	Load Emulator	

3.	Charge controller	
4.	Batteries	

### DC microgrid Configuration 1

S.NO	Component	Rating
1.	Solar PV	75Wp
2.	Battery	12V,75Ah
3.	Charge controller	
4.	Loads	3W*10

### DC microgrid Configuration 2

S.NO	Component	Rating
1.	Solar PV	200Wp
2.	Battery	24V,100Ah
3.	Charge controller	
4.	Loads	3W*25

**Following are the test related to the DC microgrid.**

<b>Test 1</b>	To assess the charging time of the battery used in DC microgrid configuration 1 under different irradiance profile using PV simulator.																													
<b>Procedure</b>	<p>Microgrid components are connected as in figure 1. PV simulator is connected to the battery through charge controller.</p> <p>Using the PV simulator, a V-I profile of crystalline 75Wp module is created. Now to evaluate the charging time of the battery used in microgrid, different irradiance profile is applied to V-I profile of crystalline 80Wp module.</p> <p>Profiles:</p> <ul style="list-style-type: none"> <li>• Cloudy day</li> <li>• Fast ramp</li> <li>• Heavy clouds day</li> <li>• Slow ramp</li> <li>• Sunny day</li> <li>• Triangle ramp</li> </ul> <p>For every 15 Minutes measure the simulator voltage and current and battery voltage and current.</p>																													
<b>Observation parameter</b>	<p><b>Irradiance Profile : Sunny</b></p> <table border="1" data-bbox="407 1402 1453 1686"> <thead> <tr> <th>S.No</th> <th>Time</th> <th>Vp(Volt)</th> <th>Ip(Amp)</th> <th>Vb(Amp)</th> <th>Ib(Amp)</th> </tr> </thead> <tbody> <tr> <td>1.</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>2.</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>3.</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>						S.No	Time	Vp(Volt)	Ip(Amp)	Vb(Amp)	Ib(Amp)	1.						2.						3.					
S.No	Time	Vp(Volt)	Ip(Amp)	Vb(Amp)	Ib(Amp)																									
1.																														
2.																														
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	<p><b>Irradiance Profile : Cloudy</b></p> <table border="1" data-bbox="407 1743 1453 1900"> <thead> <tr> <th>S.No</th> <th>Time</th> <th>Vp</th> <th>Ip</th> <th>Vb</th> <th>Ib</th> </tr> </thead> <tbody> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </tbody> </table>						S.No	Time	Vp	Ip	Vb	Ib																		
S.No	Time	Vp	Ip	Vb	Ib																									

<b>Result or conclusion</b>	<b>Charging time for different irradiance profile</b>		
	S.No	Profile	Charging time
	1.	Sunny	
	2.	Cloudy	
	3.	Ramp	
4.			
<b>Precautions</b>	<ul style="list-style-type: none"> <li>Parallel or series connected modules must have the same VI characteristics. For instance, a 600V SG cannot be paralleled with an 80V DCS.</li> <li>Check the connection before turning on the power circuit.</li> <li>Make sure the components in the DC microgrid configuration are connected in the correct polarity</li> </ul>		

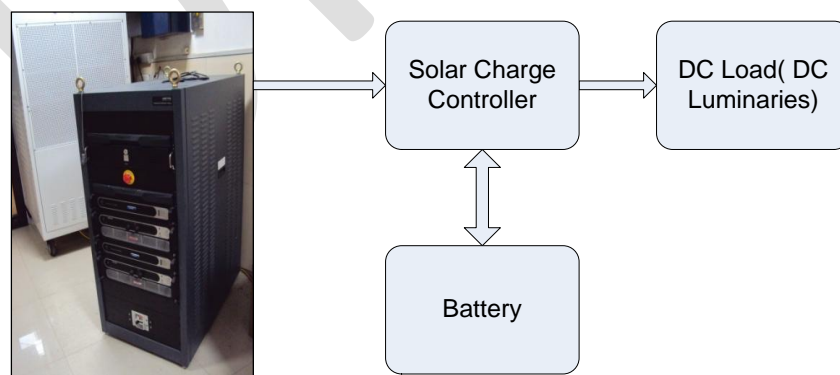
**Note:**

VP —Input voltage of the charge controller

Ip —Input current through charge controller

Vb —Battery Voltage

Ib —Battery charging current



**Figure 22: Experimental Setup for DC microgrid**

<b>Test 2</b>	To assess the autonomy time (discharging time of the battery) for load of different power in DC Microgrid.		
<b>Procedure</b>	Microgrid components are connected as in figure 1. The Charged battery is connected to the load through the charge controller. Different load are applied to the battery and its autonomy time is assessed by taking different Volt and current rating across the battery. When battery is discharged upto a certain level, it disconnects the load.		
<b>Observation Table</b>	Table 1: battery discharging profile for 10 W Load		
	S.No	Time	Vb
	1.		
	2.		
	3.		
	Table 2: battery discharging profile for 15 W Load		
	S.No	Time	Vb
	1.		
	2.		
	3.		
<b>Result or conclusion</b>	<b>Charging time for different irradiance profile</b>		
	S.No	Load Power	Autonomy Time of Load (Discharging time)
	1.	10W	
	2.	20W	
	3.		



<b>Precautions</b>	<ul style="list-style-type: none"> <li>• Never short circuit the battery terminal</li> <li>• Check the connection before turning on the power circuit.</li> <li>• Make sure the components in the DC microgrid configuration are connected in the correct polarity</li> </ul>
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<b>Test 3</b>	To evaluate the total voltage drop of the conductor form battery to the load for different conductor length and load.				
<b>Procedure</b>	<p>Microgrid components are connected as in figure 1 .Different power rating load will be connected to the battery through the charge controller through a conductor of different length like 20, 30 and 100 meter etc.</p> <p>The objective is to find the total voltage drop for across the line by measuring the load voltage and taking the different from battery voltage.</p> <p>The test will carried for the different load and different length of wire.</p>				
<b>Observation Table</b>	<b>Load</b>	<b>Length of conductor</b>	<b>Vb</b>	<b>Vl</b>	<b>Voltage drop</b>
	10W	10m			
	10W	20m			
	10W	50m			
	20W	10m			
	20W	20m			
	20W	50m			
<b>Precautions</b>	<ul style="list-style-type: none"> <li>• Never short circuit the battery terminal</li> <li>• Check the connection before turning on the power circuit.</li> <li>• Make sure the components in the DC microgrid configuration are connected in the correct polarity</li> </ul>				

## Experiment 6

To develop and test different configuration of AC microgrid and to evaluate the system performance under conditions

The concept of AC microgrid is considered as a collection of loads and micro sources which functions as a single controllable system that provides both power and heat to its local area. This idea offers a new paradigm for the definition of the distributed generation operation. To the utility the microgrid can be thought of as a controlled cell of the power system. To the customer the microgrid can be planned to meet their special requirements; such as, enhancement of local reliability, reduction of feeder losses, local voltages support, increased efficiency.

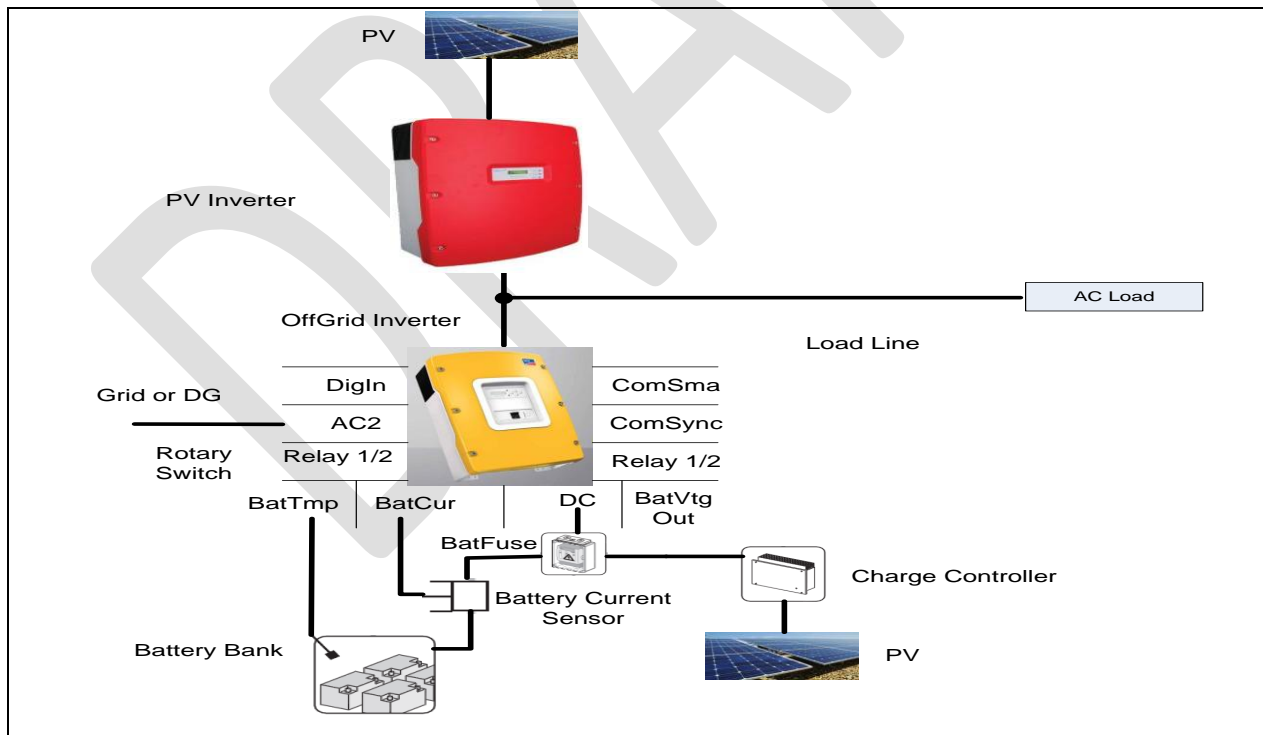


Figure 23: Schematic of AC Micro-Grid

### Components required to develop a AC microgrid in the lab:

S.No	Apparatus	Rating or Range
1.	PV array simulator	
2.	Load Emulator	
3.	Charge controller	
4.	DAQ	
5.	Batteries	
6.	PV Inverter	
7.	Hybrid or Off-Grid inverter	

Specific Test to be carried out on particular AC microgrid configuration:

1. Testing the off-grid (for e.g. SMA sunny island)
  - For the acceptance of different secondary AC sources (DG set, biomass gasifier etc.) for charging of battery
  - Battery charging mechanism (Type of algorithm etc)
  - Load management techniques etc
  - Power balance phenomenon (P-f or V-f control)
2. Analysis of the power flow
  - a) When there is not secondary AC connection
    - $P_{Load} < P_{pv}$
    - $P_{Load} > P_{pv}$
  - b) When there a back-up secondary AC source
    - $P_{Load} < P_{pv}$
    - $P_{Load} > P_{pv}$