Exp. No.	1	**I-V AND P-CHARACTERISTICS WITH SERIES AND PARALLEL COMBINATION OF MODULES**
Date		

AIM : To demonstrate the I-V and P-V characteristics of series and parallel combination of PV modules.

Theory :

PV module is characterized by its I-V and P-V characteristics. At a particular level of solar insolation and temperature it will show a unique I-V and P-V characteristics. These characteristics can be altered as per requirement by connecting both modules in series or parallel to get higher voltage or higher current as shown in Fig. 1.1(a) and
1.1(b) respectively.

Circuit Diagram :

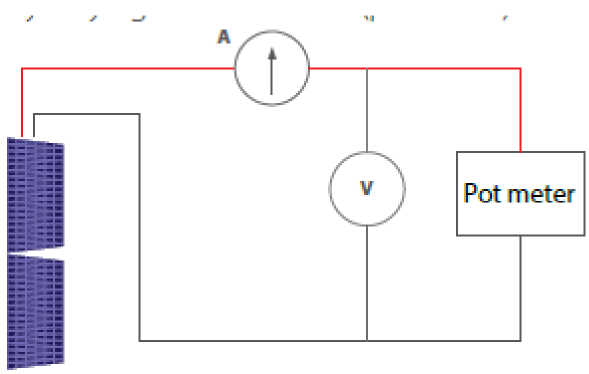


Fig. 1.1(a). Circuit diagram for evaluation of I-V and P-V characteristics of series connected module.

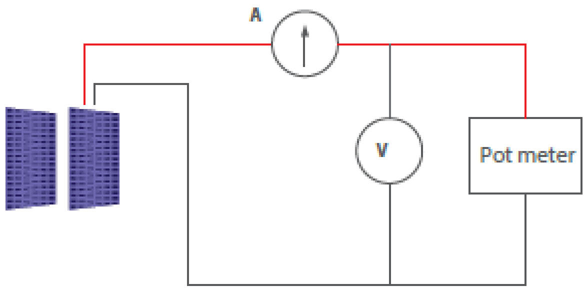


Fig. 1.2(b).Circuit diagram for evaluation of I-Vand P-V characteristics of parallel connected modules.

Connection Diagram :

Series connected modules Parallel connected modules

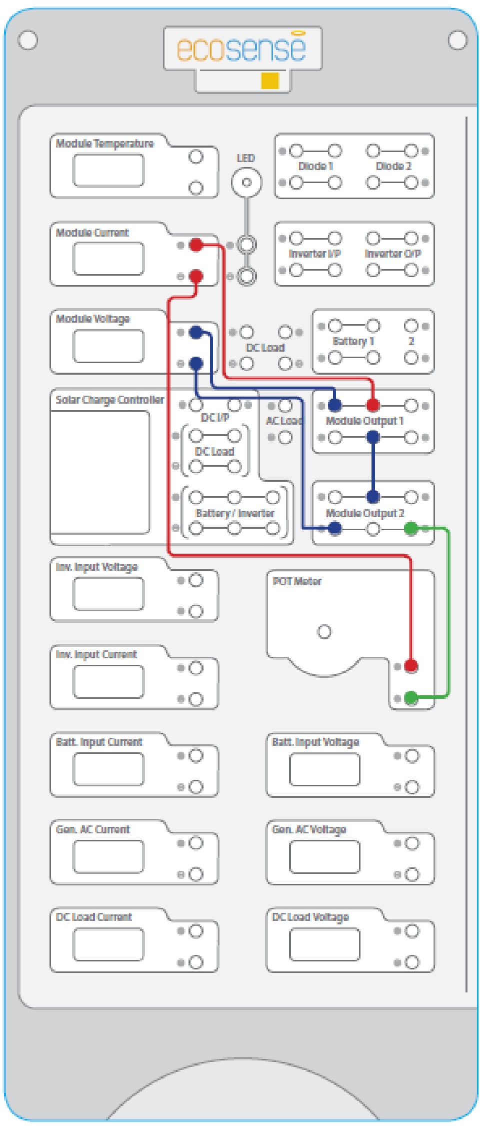


Fig. 1.3(a).Control board connections for modules connected in series.

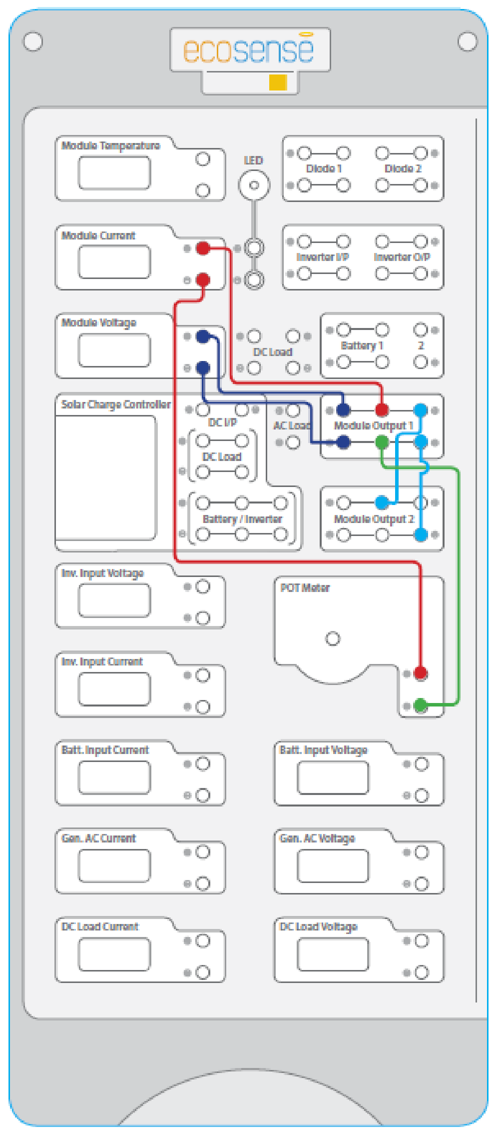
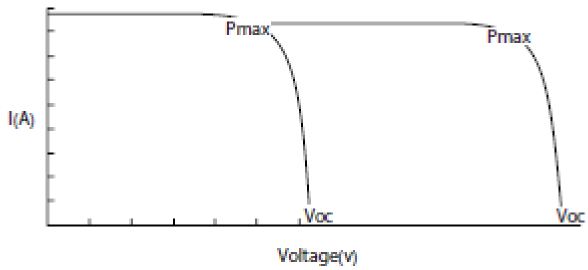


Fig. 1.3(b). Control board connections for modules connected in parallel.

Model Graph:



‘’’’

TABULATION:

Series Connection

S.No.	Voltage(V) (In Volts)	Current (I) (In Amps)	Power(P) (In Watts)
1			
2			
3			
4			
5			
6			
7			
8			

Parallel Connections

S.No.	Voltage(V)	Current (I)	Power(P)
1			
2			
3			
4			
5			
6			

Procdure

The circuit diagram to evaluate I-V and P-V characteristics of a module is shown inFig.1.1 & Fig. 1.2 . Form a PV system which includesPV module and a variable resistor (pot meter) with ammeter and voltmeter for measurement. Pot meter in this circuit works as a variable load for the module. When load on the module is varied by pot meter the current and voltage of the module gets changed which shift the operating point on I-V and P-V characteristics. PV characteristics evaluation can be achieved by following connections in control board.
One can also take I -V and P-V data from Logger and Plotter by connecting the Logger Plotter Box with module output. Values of current and voltages can be taken from the data logger and then I-V curve can be plotted at different radiation and temperature levels. One can also use Real time plotter which will plot the curve of I-V and P-V

Result

Exp. No.	2	TO SHOW THE EFFECT OF VARIATION IN TILT ANGLE ON PV MODULE POWER
Date		

AIM : To show the effect of variation in tilt angle on PV module power.

Theory

Tilt is the angle between the plane surface under consideration and the horizontal plane. It varies between 0-900. PV arrays work best when the sun's rays shine perpendicular to the cells. When the cells are directly facing the sun in both azimuth and altitude, the angle of incidence is normal. Therefore, tilt angle should be such that it faces the sun rays normally for maximum number of hours. The tilt angle settings for different seasons are shown in Fig. 2.1. PV systems that are designed to perform best in the winter, array should be tilted at an angle of equal to latitude +15°. If the array is designed to perform best in the summer, then the array needs to be tilted at an angle of equal to latitude−15°. In this way the array surface becomes perpendicular of the sun rays. For best performance throughout the year, tilt should be equal to the latitude angle.

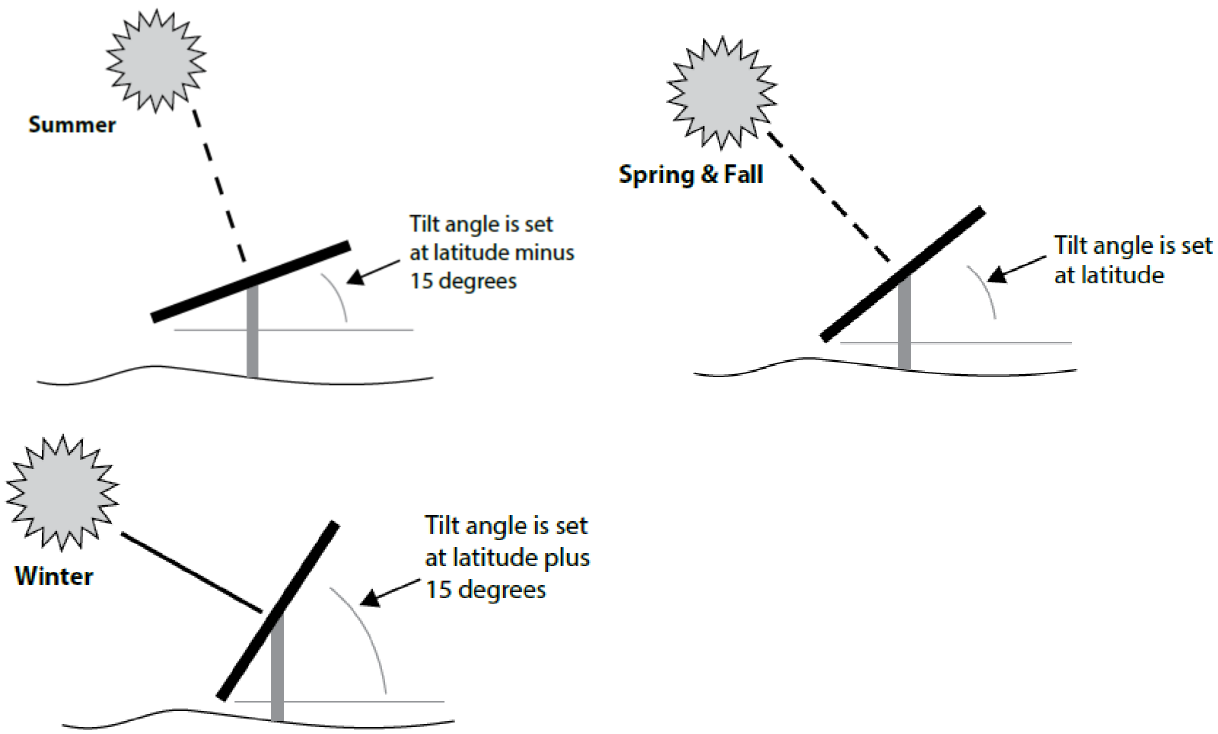


Fig.2.1 tilt angle setting for different sesson.

EXPERIMENTAL SETUP

The tilt angle of the module can be changed by rotating the lever below the module. Lit the halogen lamp and change the tilt of the module by rotating the lever. To evaluate effect of tilt on power output of the module, following connections are to be done in the control board as shown in Fig. 2.3. The pot meter in this case has to be fixed at constant position so that the effect of tilt can be seen.

Fig. 2.2 Arrangement to vary tilt of the module

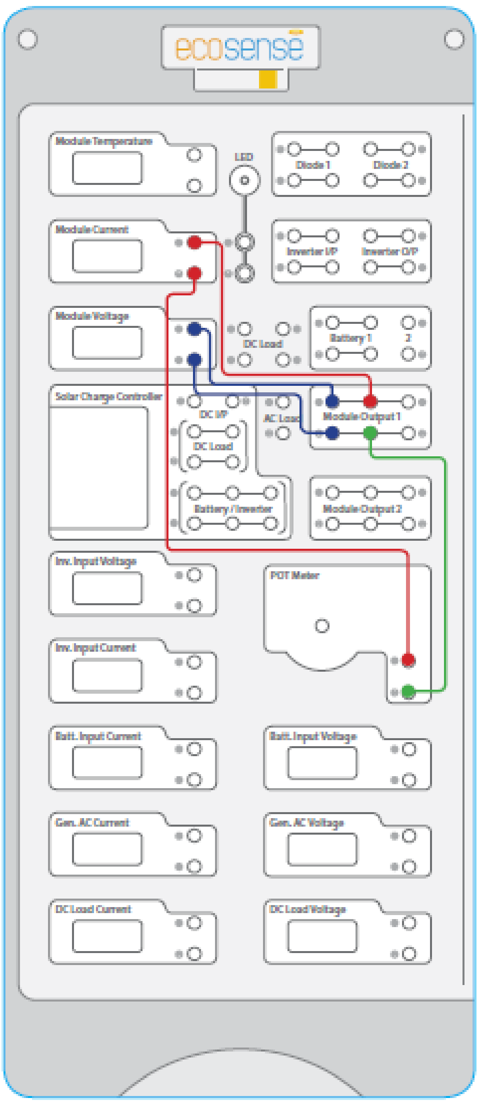


Fig.2.3 Control board connections to evaluate effect of tiil.

PROCEDURE

The tilt angle of the module can bechanged by rotating the lever below themodule. Lit the halogen lamp and change the tilt of the module by rotating the lever. To evaluate effect of tilt on power output of the module, following connections are to be done in the control board as shown in the digram. The pot meter in this case has to be fixed at constant position so that the effect of tilt can be seen.

Values of current and voltages can be taken from the data logger and then the curve between tilt and power can be plotted at different radiation levels. For each tilt angle, one has to keep constant resistance value. One can also use Real time plotter which will plot the curve of I-V and P-V (at each tilt value). Here, for each tilt angle, one has to change the resistance from maximum to minimum value.

TABULAR COLUMN:

Set 1					
S.No	**Tilt (Degree)**	**Radiation (W/m2)**	**V (Volts)**	**I (Ampere)**	**P (W)**
1					
2					
3					

Result.

Exp. No.	3	WORKOUT POWER FLOW CALCULATIONS OF STANDALONE PV SYSTEM OF DC LOAD WITH BATTERY.
Date		

AIM

Workout power flow calculations of standalone PV system of DC load with battery.

THEORY

Stand alone PV system (Fig. 6.1) is the one which can be used for both AC and DC loads and installed near the location of load. These systems are easy to install and understand. These systems can be used without batteries also, but these systems perform best with battery bank. These systems are best suited for the locations where grid connectivity is not present and these systems fulfill the requirements of these locations.

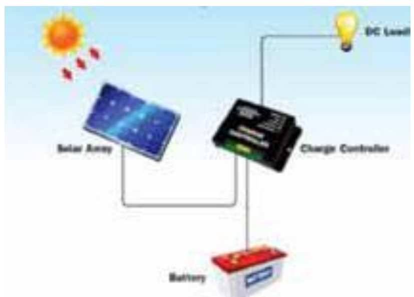


Fig. 6.1. Stand alone PV system

Stand alone PV system of DC type is used when local loads consist of DC equipments and battery storage only. This system consists of PV module, charge controller, battery and DC load.

Charge controller regulates the module voltage at 12V or any other value of voltage, required by the battery bank or load and then powered the load. In this system there is no need of Inverter so efficiency of system is high because DC to AC conversion stage is absent.

Experimental set-up

The demonstration of stand alone PV system with only DC load can be done in the following ways:

a) Using only single module (Fig.6.2a,b,c)

b) Using modules in parallel (Fig.6.3a,b,c)

c) Using modules in series (Fig.6.4a,b,

Controller connections

Demonstration of DC load with single module (12 V system).

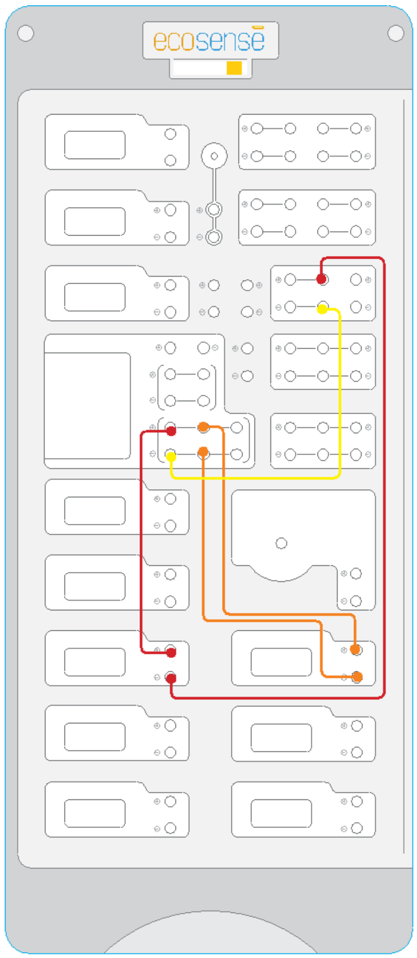


Fig.6.2 (a) Battery connections (Step I)

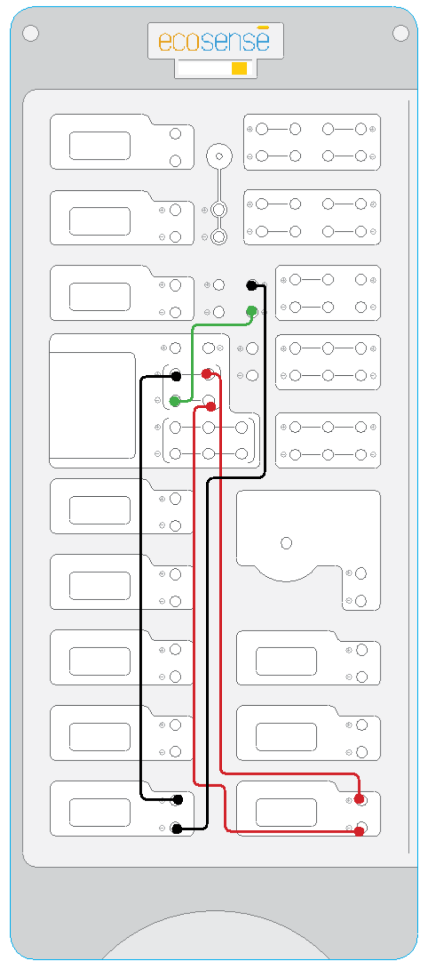


Fig.6.2 (b) DC load connections (Step II)

Controller connections

Demonstration of DC load with parallel connected modules (12 V system)

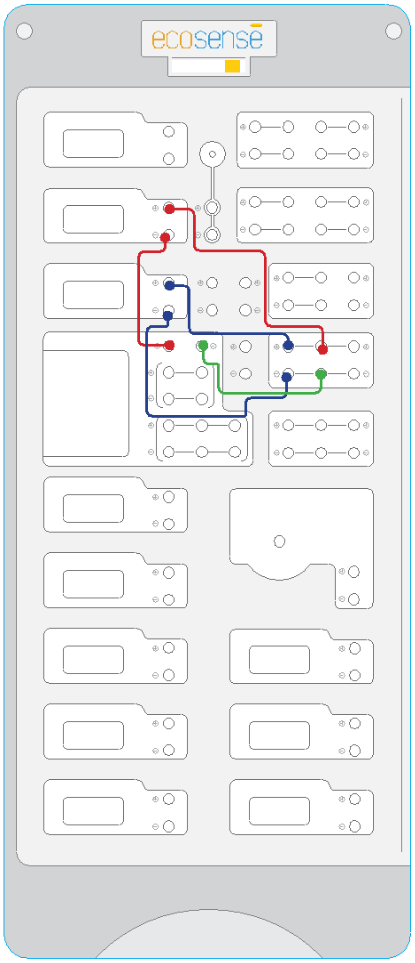


Fig.6.2 (c) Module connections (Step III)

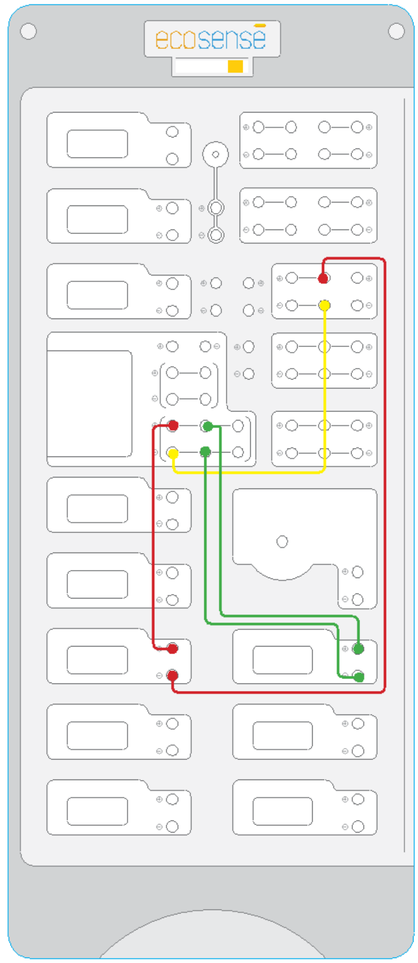


Fig.6.3 (a) Battery connections (Step I)

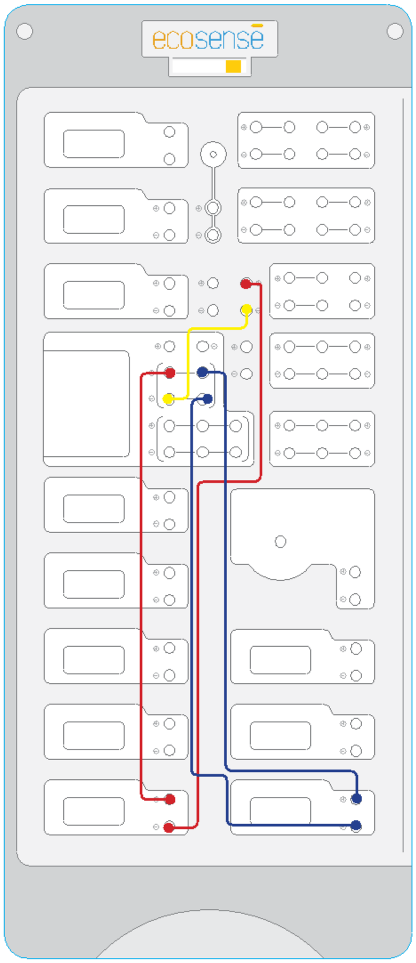


Fig.6.3 (b) DC load connections (Step II)

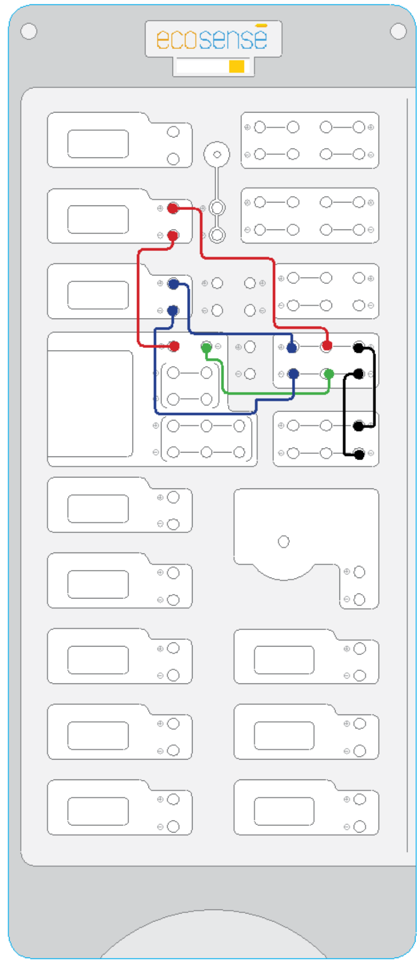


Fig.6.3(c) Module connections (Step III)

Controller connections

Demonstration of DC load with series connected modules (24 V system).

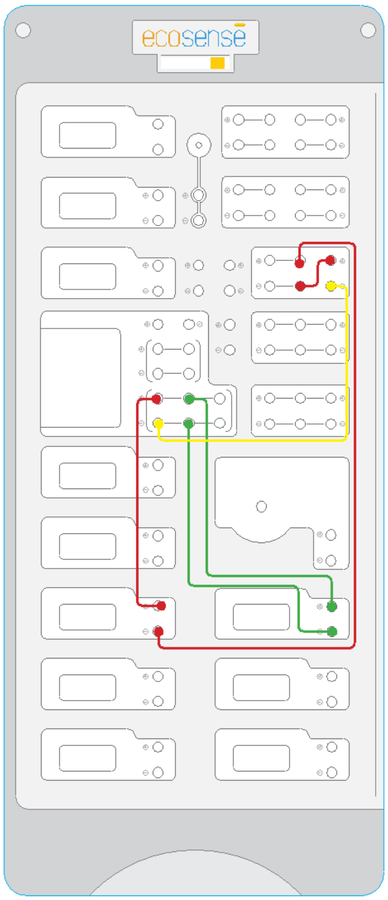


Fig.6.4 (a) Battery connections (Step I)

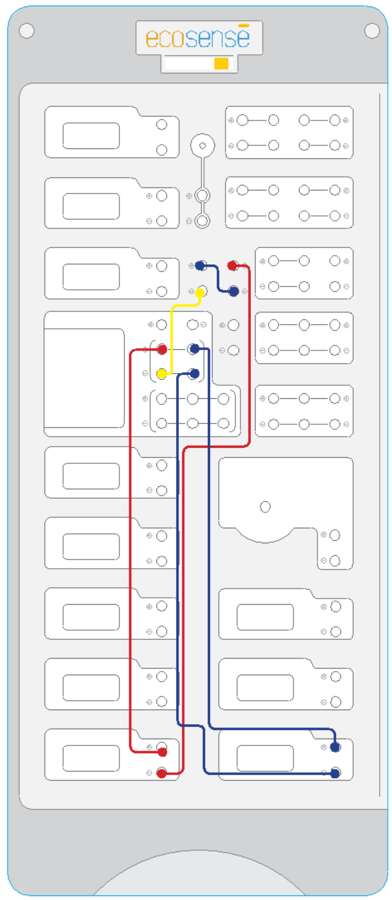


Fig.6.4 (a) Battery connections (Step I)

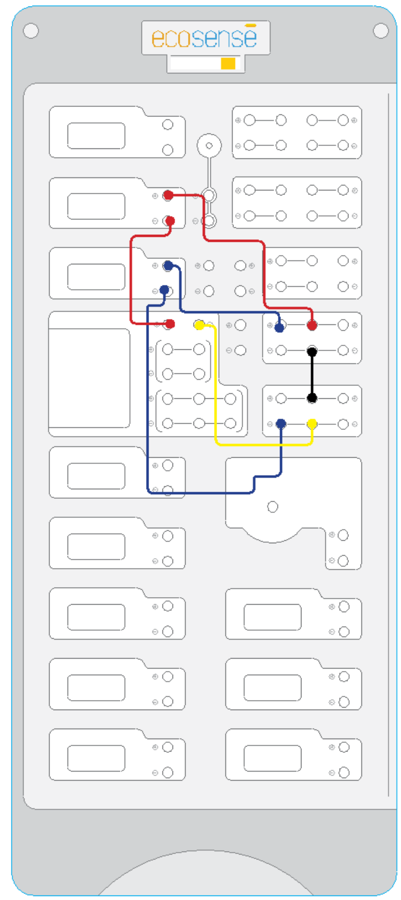


Fig.6.4 (c) Module connections (Step III)

Observation

The parameters to be observed are DC load current, DC load voltage, battery current and battery voltage with different series/parallel combinations of modules.

Tables for Stand-alone PV system calculation:

S.No.	Module Configuration	Array Current (A)	Array Voltage (V)	Array Power (Watt)	Load Current (A)	Load Voltage (V)	Battery Current (A)	Battery Voltage (V)	Battery Power (Watt)
1.	Single Module								
2.	Parallel Connected Module								
3.	Series Connected Module								

Calculations

Show the power balance by following formula:

Array power = load power + battery power + Power loss by charge controller

Note: Battery power will be with –ve sign if battery is discharging through load. Current consumption of Charge controller is 4mA.

Precautions

1. Readings should be taken carefully.

2. Always plug-in the module power lead at the input of charge controller, after connecting the battery terminals with charge controller output terminals.

3. Connections should be tight.

RESULT

Exp No		Power flow calculations of standalone PV system of AC load with battery
Date		

AIM:

Workout power flow calculations of standalone PV system of AC load with battery.

THEORY:

Stand alone PV system is the one which can be used for both AC and DC loads and installed near the location of load. These systems are easy to install and understand. These systems can be used without batteries also, but these systems perform best with battery bank. These systems are best suited for the locations where grid connectivity is not present and these systems fulfill the requirements of these locations. Stand alone PV system of AC type requires inverter to convert DC voltage available at the charge controller output to controlled AC voltage of required magnitude to supply AC type of load. This system consists of Modules, charge controller, battery and inverter. Charge controller regulates the module voltage to 12 volt and charge the battery and then this regulated DC power is converted to AC by means of inverter. Inverter efficiency is approximately 95%.

EXPERIMENTAL SET-UP

The demonstration of stand alone PV system with only AC load can be done in the following ways:

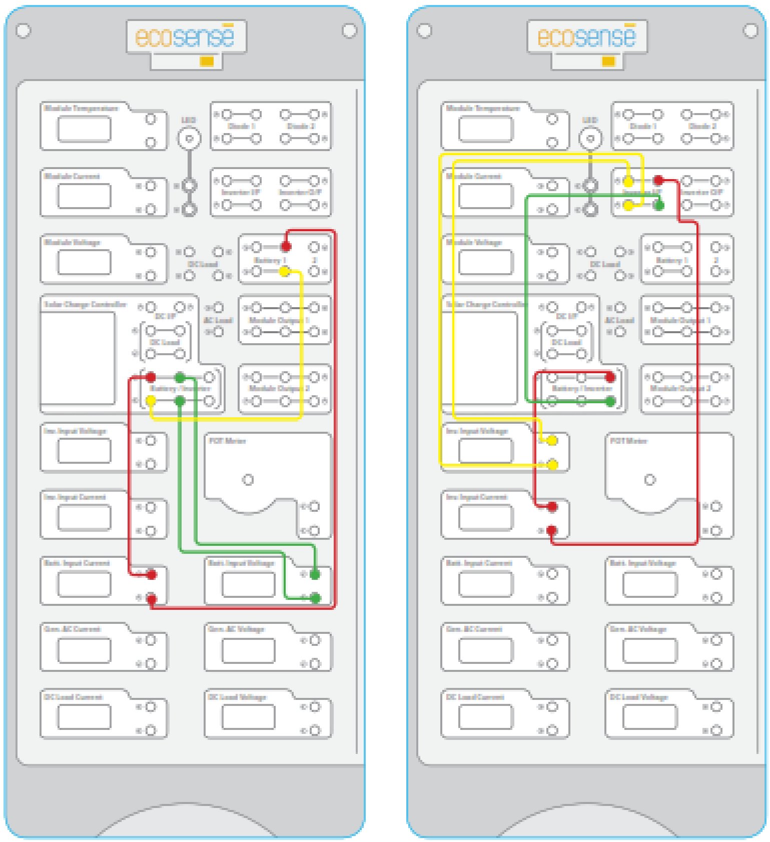
a) Using only single module

b) Using modules in parallel

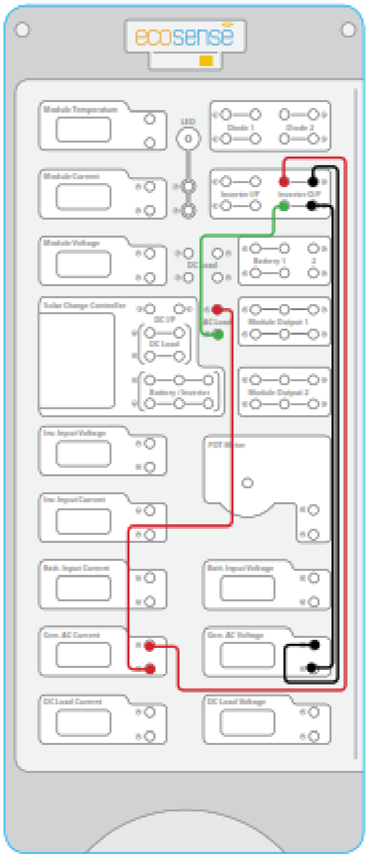
Controller connections

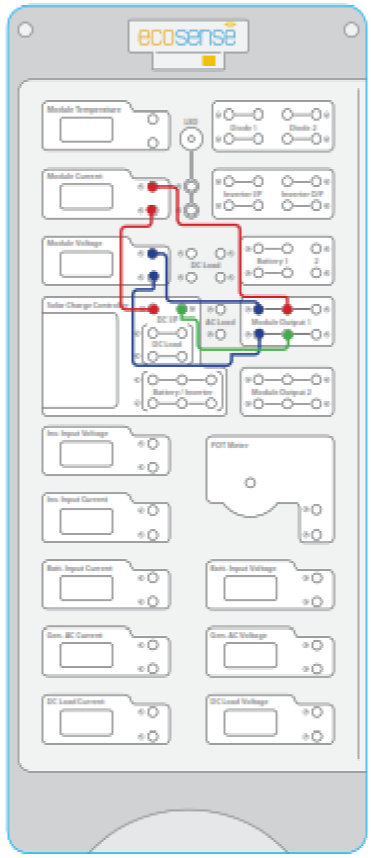
Demonstration of AC load with single module

(i) Battery Connection & (ii) Inverter Connection



(iii) AC load connection & (iv) Module connection

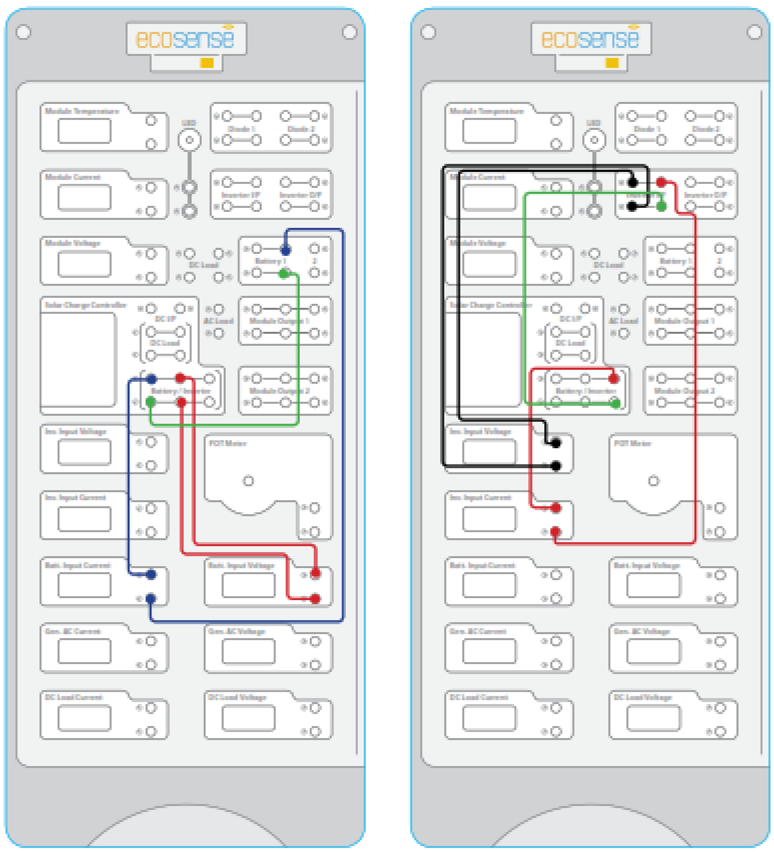




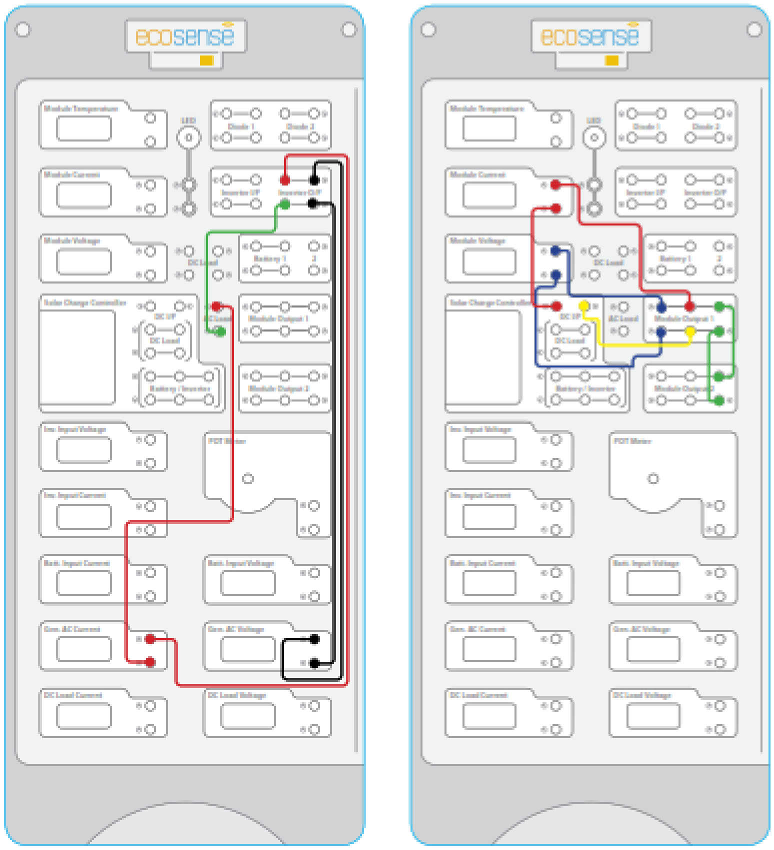
Controller connections

Demonstration of AC load with parallel connected modules

(i) Battery Connection & (ii) Inverter Connection



(iii) AC load connection & (iv) Module connection



Observations

The quantities to be observed are AC load current, AC load voltage, inverter input voltage, current, battery current and battery voltage with different parallel combinations of modules.

Tables for Stand-alone PV system calculation:

S.No.	Module Configuration	Array Current	Array Voltage	Array Power	Inverter I/P Current	Inverter I/P Voltage	Inverter I/P Power	Battery Current	Battery Voltage	Battery Power
		(A)	(V)	(W)	(A)	(V)	(W)	(A)	(V)	(W)
1	Single module									

2	Parallel connected modules									

Table for inverter efficiency:

S.No.	Module Configuration	Inverter I/P Current	Inverter I/P Voltage	Inverter I/P Power	Ac Load Current	Ac Load Voltage	Ac Load Power
		(A)	(V)	(W)	(A)	(V)	(VA)
1	Single module						
2	Parallel connected modules						

Results

Show the power balance in both the sets by following formulae:

1. Array power = Inverter i/p power + battery power + loss due to charge controller
2. Inverter efficiency = AC load power*100/Inverter input power (DC)

Precautions

1. Readings should be taken carefully.
2. Always plug-in the module power lead at the input of charge controller, after connecting the battery terminals with charge controller output terminals.

3.Connections should be tight.

Exp No	5	Power flow calculations of standalone PV system of DC and AC load with battery
Date		

AIM:

Workout power flow calculations of standalone PV system of DC and AC load with battery.

THEORY:

Stand alone system is the one which can be used for both AC and DC loads and installed near the location of load. These systems are easy to install and understand. These systems can be used without batteries also but these systems perform best with battery bank. These systems are best suited for the locations where grid connectivity is not present and these systems fulfill the requirements of these locations.This system use DC power to charge the battery and run the DC load but, use AC power to run the AC load. There are modules, charge controller, batteries, DC load, inverter and AC load in this system. This system runs the AC and DC load simultaneously and can fulfill the demand of the both types of loads.

EXPERIMENTAL SET-UP

The demonstration of stand alone PV system with DC and AC load can be done in the following ways:

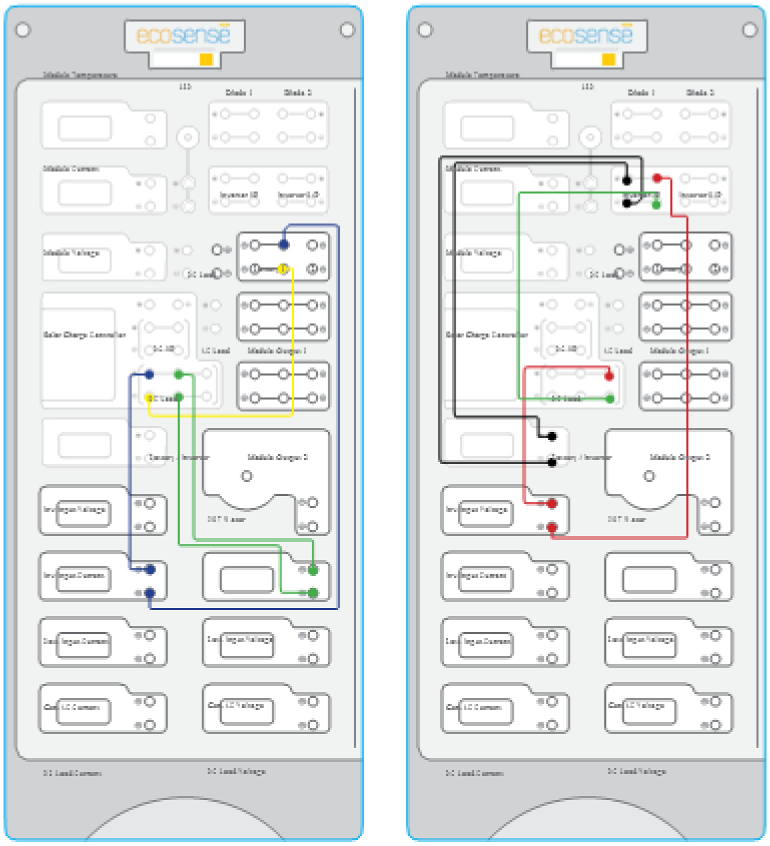
a) Using only single module

b) Using modules in parallel

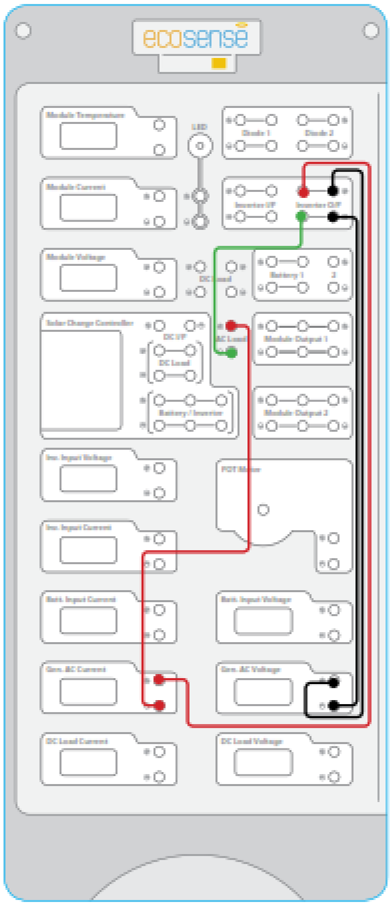
Controller connections

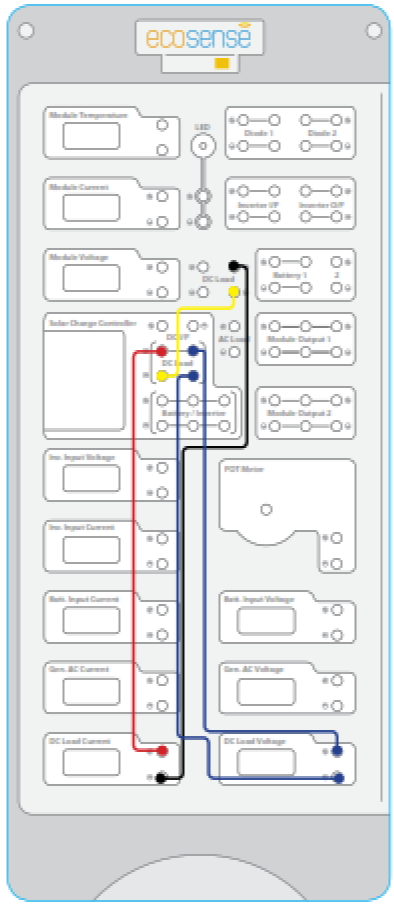
Demonstration of DC and AC load with single module

(i) Battery Connection & (ii) Inverter Connection

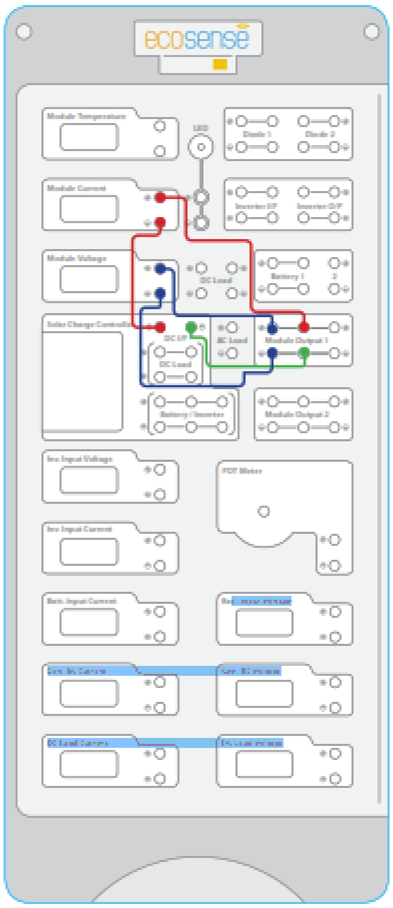


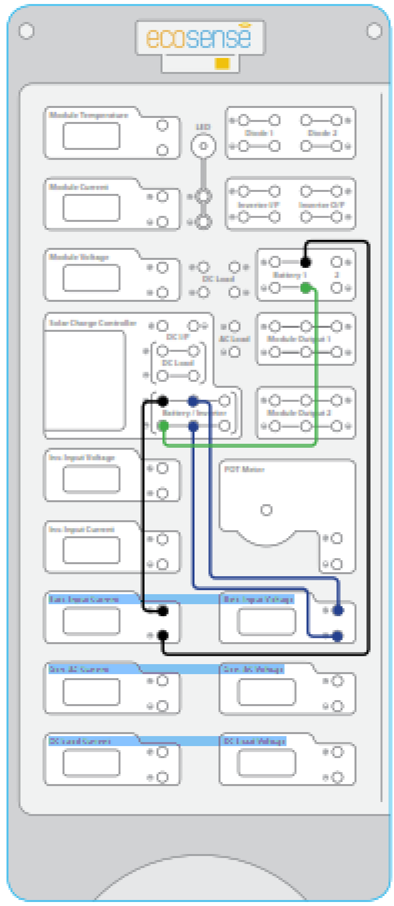
(iii) AC load connection & (iv) DC load connection



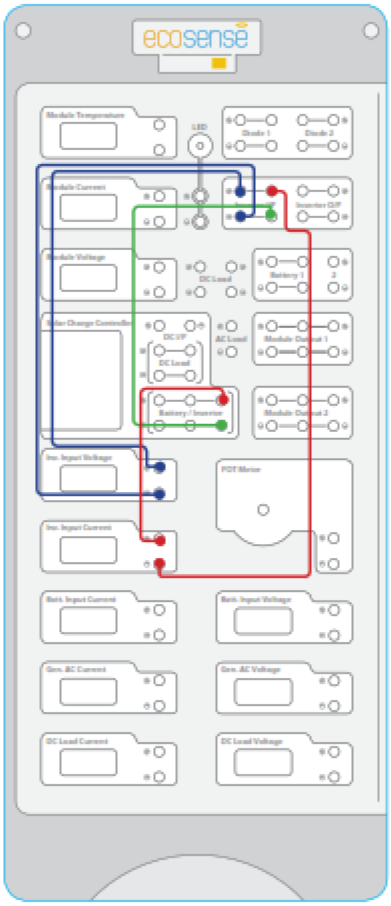


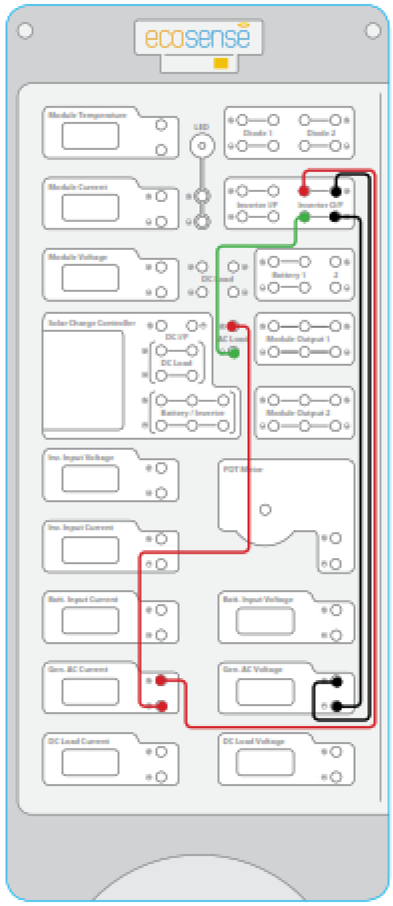
(iv) Module Connection & (v) Demonstration of AC and DC loads with parallel connected modules - Battery connection



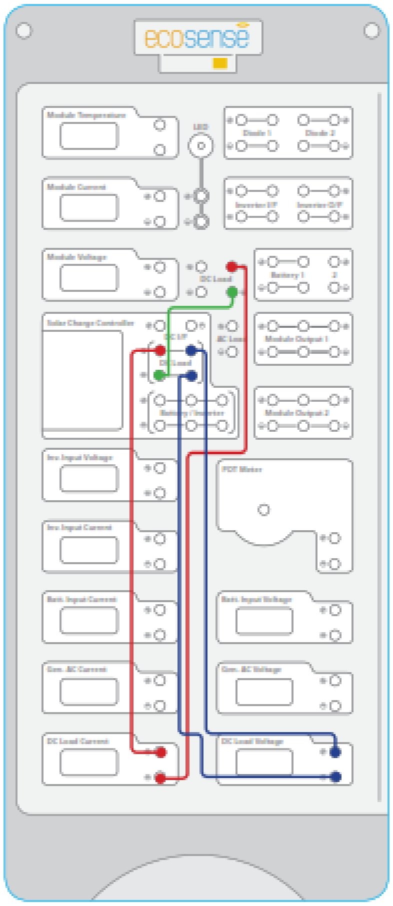


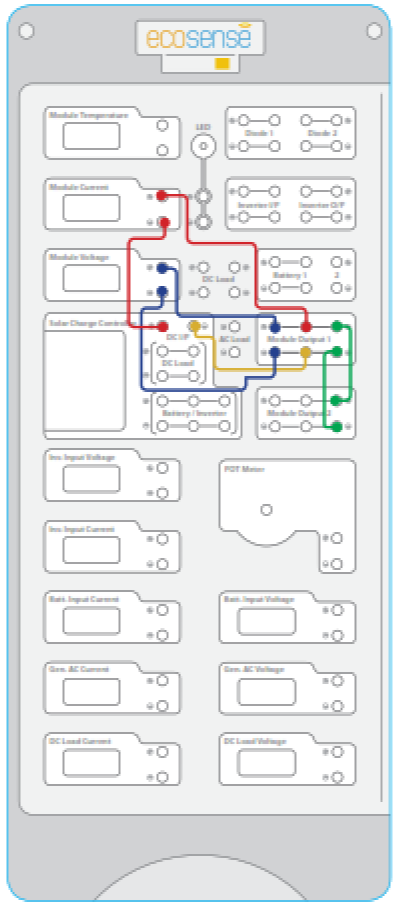
(i) Inverter Connections & (ii)AC load Connections





(i)DC Load Connections & Module Connections





Observations

Tables for Stand-alone PV system calculation:

S.No.	Module Configuration	Array Current	Array Voltage	Array Power	DC Load Current	DC Load Voltage	DC Load Power	Inverter I/P Current	Inverter I/P Voltage	Inverter I/P Power	Battery Current	Battery Voltage	Battery Power
		(A)	(V)	(W)	(A)	(V)	(W)	(A)	(V)	(W)	(A)	(V)	(W)
1	Single module												
2	Parallel connected												

Table for inverter efficiency:

S.No.	Module Configuration	Inverter I/P Current	Inverter I/P Voltage	Inverter I/P Power	Ac Load Current	Ac Load Voltage	Ac Load Power
		(A)	(V)	(W)	(A)	(V)	(VA)
1	Single module						
2	Parallel connected modules						

Results

Show the power balance in both the sets by following formulae:

1. Array power = DC load power +AC load power + battery power+ loss due to charge controller.
2. Inverter efficiency = AC load power*100/Inverter input power

Precautions

1. Readings should be taken carefully.
2. Always plug-in the module power lead at the input of charge controller, after connecting the battery terminals with charge controller output terminals.

3.Connections should be tight.

Exp No	6	Charging and discharging characteristics of battery
Date		

AIM:

To draw the charging and discharging characteristics of battery.

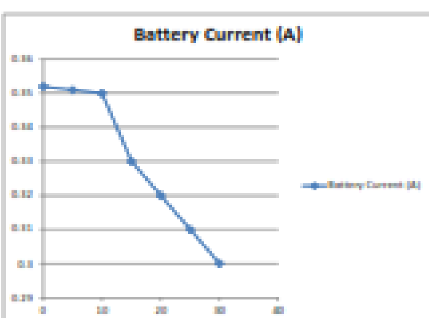
THEORY:

Battery discharging

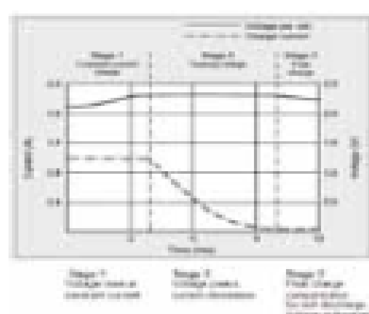
Battery discharging depends on magnitude of current drawn and the time for which this current is drawn. Rate of charge flowing determined the steepness of discharge characteristic. At higher current i.e. at higher rate of discharge, voltage variation becomes more steeper and battery discharge up to much low voltage. Similarly, at lower rate of discharging voltage variation becomes less steeper and battery discharge up to somewhat higher voltage. The typical 12V, 3Ah battery discharge characteristic is shown.

Battery charging

Starting current of charging is much higher because the voltage of the discharged battery is low. Initially battery draws almost constant charging current while battery voltage increases rapidly, as soon as battery voltage reaches rated voltage,charging current start reducing rapidly and battery voltage becomes constant. After fully charging, the battery charging current reduces to vary low value required to trickle charge the battery. The typical charge characteristic of 12V battery is shown.



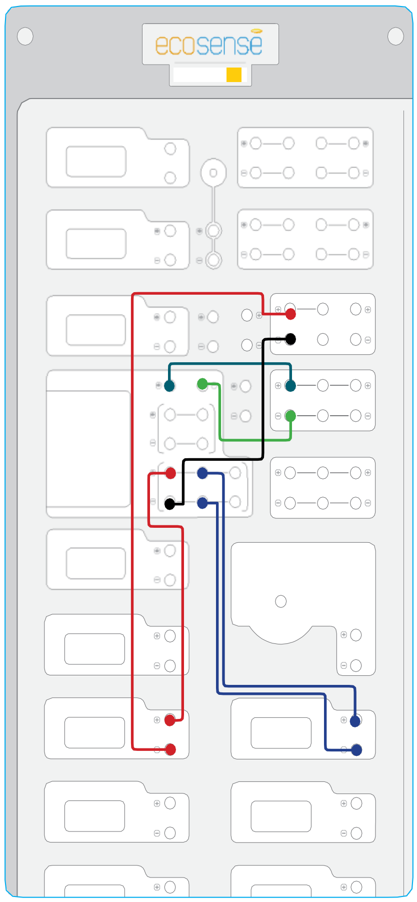
Battery Discharging

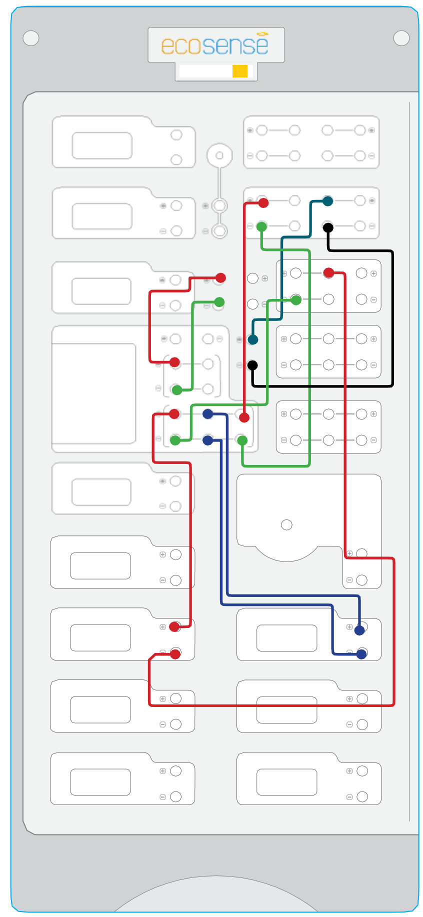


Battery Charging

Experimental set-up

To demonstrate charge and discharge characteristics of the battery connections, do the connections in control board as shown.





Battery Charging and Discharging

Observations

Discharging experiment can be done at different current values. This can be achieved by changing the load.

Table for discharging of battery:

Time	Voltage	Current

Table for charging of battery:

Time	Voltage	Current

Results

1. Draw charging and discharging curves by taking time (in hrs) on x-axis and voltage and current on y-axis..

Precautions

1. Connections of battery should be made carefully.

2. Always plug-in the module power lead at the input of charge controller, after connecting the battery terminals with charge controller output term

Exp No	8	Evaluation of Active, Reactive Power & Apparent Energy Flow between Grid-Tied Inverter, Grid & Load and Net Metering concept
Date		

AIM:

Evaluation of Active, Reactive Power & Apparent Energy Flow between Grid-Tied Inverter, Grid & Load and Net Metering concept

THEORY:

Just imagine of a house with roof top solar power plant. For the day times when solar irradiations are enough, electricity generated is usually more than the local load requirement of the house. If the solar plant is standalone type, the maximum power harnessed is limited to the load connected to the system (assuming batteries are fully charged). So this extra capacity of plant remains unutilized. However grid tied plant are beneficial in terms the excessive power can be sold to utility. Likewise for night time, loads can be supplied power by the utility grid as what usually happens. This scheme promotes more and more roof top grid tied solar plant installation as it provides opportunities for extra income or cutting in electricity bills, at the same time overcomes electricity shortage problem. However there should be a mechanism to govern the net amount to be received / paid by user with roof top installation. Net Metering Systems keep track of power drawn by user from grid and power fed to grid.

1. Instantaneous Power

Balance

As per Kirchoff's Law, net current at any electrical node is zero i.e. sum of currents entering in a node is equal to current leaving the node. Same way, active & reactive powers are individually balanced at any load. In this experimental system, Point of Common Coupling is any electrical node/junction of three lines. One line is connected to main or artificial grid; second one to grid tied solar PV inverter and third one to the local load.

At any instant of time, there should be individually net balance between active power, reactive power and apparent power. In terms of mathematical quantities it can be shown as below.

$$S_{GRID} + S_{PV} = S_{LOAD}$$

$$P_{GRID} + P_{PV} = P_{LOAD}$$

$$Q_{GRID} + Q_{PV} = Q_{LOAD}$$

For example, if grid tied solar inverter is supplying 200W of active power (P_{PV}), 10VAr of reactve power (Q_{PV}) and load isdrawing 300W active power (P_{LOAD}), 50Var of reactive power (Q_{LOAD}); then active power (P_{GRID}) supplied by grid is 100W and reactive power (Q_{GRID}) is 40VAr. Obviously there is balance is apparent power also known as the PCC.

Objective of this part of experiment is to calculate the power requirement of load. Also it tried to simulate the two real world scenarios, one represents the day time in which, power supplied by grid tied inverter is more than load connected. Hence extra power is fed to the grid. Second scenario represents night scenario, in which local load consumption is more than power generated & required extra power is now supplied by grid.

P_{PV}		Q_{PV}		S_{PV}		V_{LOAD}	
P_{GRID}		Q_{GRID}		S_{GRID}		I_{LOAD}	
P_{LOAD}		QL_{OAD}		S_{LOAD}		S_{LOAD}	
P_{PV}		Q_{PV}		S_{PV}		V_{LOAD}	
P_{GRID}		Q_{GRID}		SG_{RID}		I_{LOAD}	
P_{LOAD}		Q_{LOAD}		S_{LOAD}		S_{LOAD}	

Exp. No.	9	GRID SYNCHRONIZATION OF SOLAR PV INVERTER AND ITS PERFORMANCE ANALYSIS
Date		

AIM

Grid Synchronization of Solar PV Inverter and it Performance Analysis.

THEORY

Zero Crossing Detection (ZCD) is simplest way to obtain the frequency information. Zero crossing of voltage is sensed and ideally duration between two consecutive zero crossing equals to reciprocal of double of voltage frequency. However as it has been discussed that there are always harmonics present in the utility voltage and which can ultimately result in detection of zero crossing at the rate different than fundamental frequency. Also it is not possible to get instantaneous phase information.

Phased-Looked-Loop (PLL) based technique for grid synchronization is fast, efficient and most commonly adopted. With slight modifications, three phase PLL can be used for single phase system also. Operation for the same can be explained as below. For a three phase system, three voltage components Va, Vb and Vc are converted to two components system (d-q frame) by applying below mentioned mathematical operation

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

We can write this in complex notation as

$$V_{dq} = V_d + j * V_q$$

Vd and Vq are two sinusoidal quantities in which Vq lags the Vd by 90°.

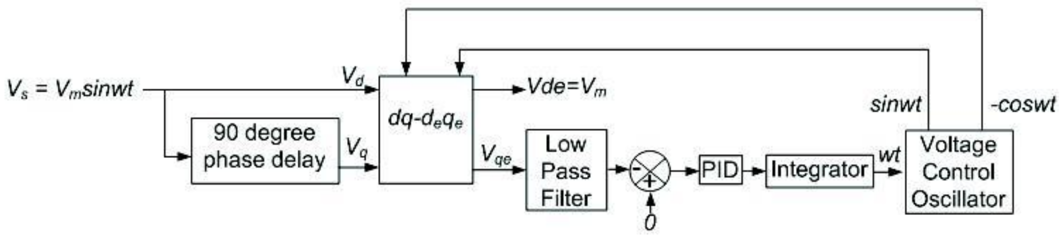
Since there is only one voltage component available for single phase unlike three for three phase system, so instead of using the abc - dq transformation matrix, single phase voltage (say Vs = Vm*sin(wt+Ø)) component itself is assume to be direct axis component (i.e. Vq =Vs = Vm*sin(wt+Ø)). Then 90° phase delayed component of single phase voltage is calculated and is assumed to be quadrature axis component (i.e. Vq = Vm*sin(wt+Ø -90) =- Vm*cos(wt+Ø)). If we draw Vdq phasor on d-q axis we will see a vector with magnitude equals to Vm rotating at speed equals to synchronous speed (w) or instantaneous phase equal to(wt+Ø).

Now suppose if this vector is observed from the frame rotating at the synchronous speed, it appears to be a stationary vector with a magnitude equal to Vm and a constant phase Ø.

Mathematically we can realize such observation by following transformation matrix (dq –deqe). Let us assume that this frame rotates at angular speed W0.

$$\begin{bmatrix} V_{de} \\ V_{qe} \end{bmatrix} = \begin{bmatrix} \sin w_0 t & -\cos w_0 t \\ \cos w_0 t & \sin w_0 t \end{bmatrix} \begin{bmatrix} V_d \\ V_q \end{bmatrix}$$

Both the vector will appear stationary with respect to each other only when speed of this frame equals to synchronous frame speed (i.e. w = w0) and even if phase is also matched the q –axis component becomes zero. Figure below shows the block diagram of PLL.



Performance of PLL is evaluated in terms of its ability to get synchronized to poor quality voltage, time elapsed to synchronize, response to rapidly changing frequency and up to what poor quality voltage it can stay synchronized.

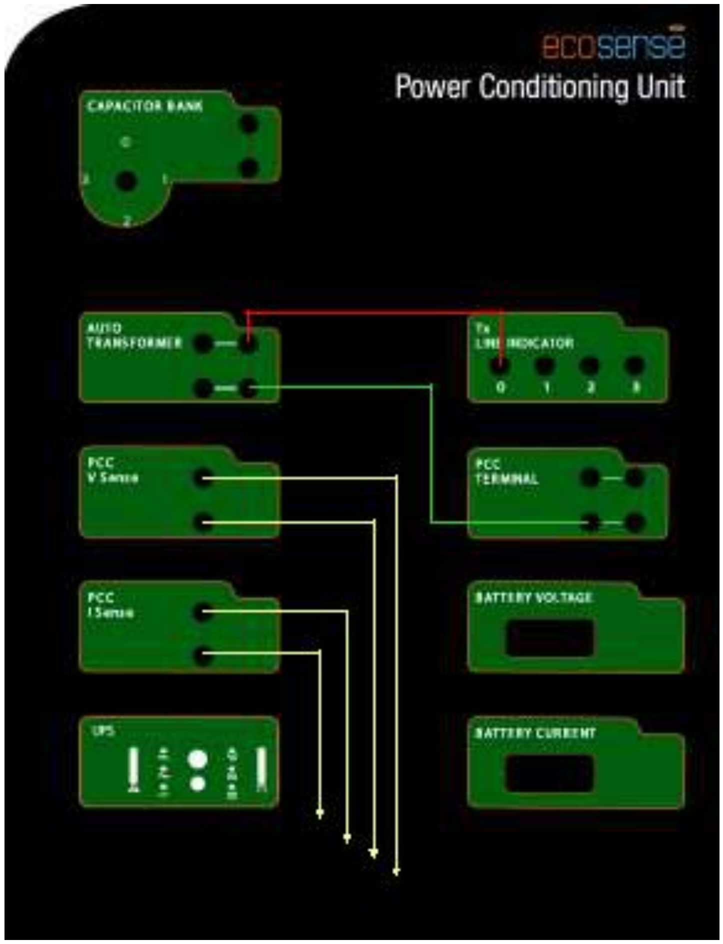
Objective of this experiment is a lab setup so as to make solar inverter synchronized to grid. Secondly, performance of inverter is evaluated in terms of time taken to synchronize the grid, how closely it is operating to MPPT, efficiency and finally its output power quality.

Experimental Setup

For this experiment, first connect the phase of autotransformer to 0 numbered terminal of Tx Line Impedance and autotransformer ground directly to the ground of PCC. This way inductance is by passed and there is a power analyzer 2 in the current path. Adjust the voltage of autotransformer at 210V. PV panels can be connected to the DC input of inverter by turning on the PV input MCB. Voltage of PV panel should be more than 45V for solar inverter to operate and inverter can generate rated output only if PV voltage is equal or more than 65V. In order to connect the grid to output of the inverter, turn on the AC output MCB. As soon inverter is supplied with DC voltage, it tries to synchronize. Now connect one channel of oscilloscope with VSENSE terminals and second with ISENSE terminals.

Data related to PV output (DC Voltage, DC Current and DC Power) can be monitor and stored on an intuitive GUI installed on computer. Just connect the USB cable from data logger and plotter box. Connect (CTRL+C) to the virtual port created by Serial to USB data converter cable and click on run button (F5). Time V/s Voltage, Current & Power curves can be monitored in real time.

CIRCUIT DIAGRAM



Procedure

1. Turn on the 'PV Panel MCB'. By doing so PV panels are now connected to the DC terminal of the solar grid tied inverter. Take the voltage reading of DC voltmeter. It is showing the reading of PV panel voltage. Now move the change over switch position towards the top. This way PV panel output is connected to DC input of grid tied inverter. Turn on the AC output MCB. Some current starts flowing from grid to inverter. As soon inverter gets synchronized, current starts flowing from inverter to grid. Note down the time taken for synchronization.

2. In order to judge the performance of inverter MPPT algorithm, take the reading of PV panel voltage and current from DC voltmeter and DC ammeter when inverter is synchronized. Multiply measured voltage and current to calculate the supplied power by PV panels. This experiment requires a rough estimation of maximum power that PV panels can produce with current solar insolation. Six panels are rated for net 450W at 1000W/m2. Usually at noon time, panels produce 60-70% of power for which it is rated i.e. from 350-300W. In this way we can judge the performance of solar inverter. For more precise results, PV panels can be connected to a variable

resistance and PV curve can be drawn by varying the resistance. From the curve, maximum power can be calculated for current solar insolation.

3. In this part, efficiency of solar grid tied inverter is calculated. Take down the reading of active power from power analyzer 1 and also calculate the power supplied by PV panels by multiplying the DC voltmeter and Ammeter reading. Efficiency can be calculated as below

Effeciency (n) = P (Inverter)/(Vdc*Idc)*100

4. Next, output power quality analysis is done. For this take the reading of inverter voltage THD, supplied current THD and also for the operating power factor. One thing that is worth watching is that THD in current supplied by inverter is higher for low current (i.e. when PV panels are supplying low power) and vice versa.

Readings for above 4 steps can give the idea of performance of grid tied solar inverter solar inverter. Ideally an inverter should have low grid synchronization time, should operate close to Maximum Power Point, higher efficiency, low current THD and unity power factor. Observe the voltage and current waveform on oscilloscope. This gives the clear idea about distortion in current supplied by the solar PV inverter.

Observation:

Time taken for synchronization	
Manually calculated maximum power of PV Panel	
Maximum power by MPPT algorithm	
Inverter operating efficiency	
Inverter operating Power Factor	
Inverter supplied current THD	

Precautions

1. Manually finding the maximum power of PV panel should be done carefully and under the guidance of experienced one.

2. Keep all the connections properly tightened**.**

RESULT