VINAYAKA MISSION'S RESEARCH FOUNDATION

AARUPADAI VEEDU INSTITUTE OF TECHNOLOGY

Vinayaka Nagar, Rajiv Gandhi Salai (OMR), Paiyanoor, Kanchipuram Dist., Chennai – 603 104

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

RESEARCH LAB MANUAL

SOLAR AND WIND ENERGY LABORATORY

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Professor & HOD

Testing Facilities

1. MPPT algorithm and Charge controller testing
2. MPPT algorithm testing for an stand alone system
3. Synchronization process for single phase solar Grid tied PV system
4. Evaluation of Cut in Speed of the Wind turbine
5. Evaluation of the efficiency of the charge Controller used in the wind energy training system
6. Evaluation of the tip speed ratio (tsr) at different wind speed.
7. Evaluation of turbine power versus wind speed curve.

Exp. No.	1	MPPT algorithm and Charge controller testing
Date		

AIM : To test the given controller for MPPT algorithm

Theory :

PV module is characterized by its I-V andP-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. The VI characteristics determines the peak operational point

Circuit Diagram :

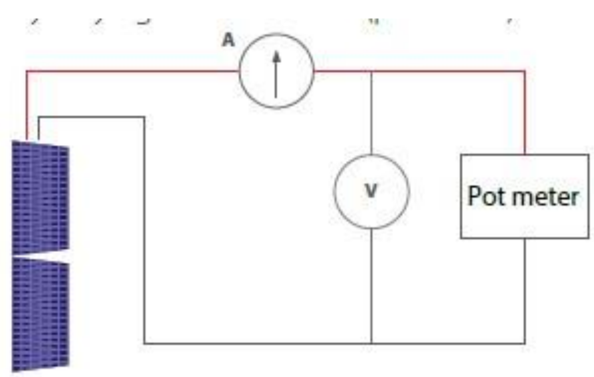


Fig. 1.1(a). Circuit diagram for evaluation of I-V and P-V characteristics of series connected module.

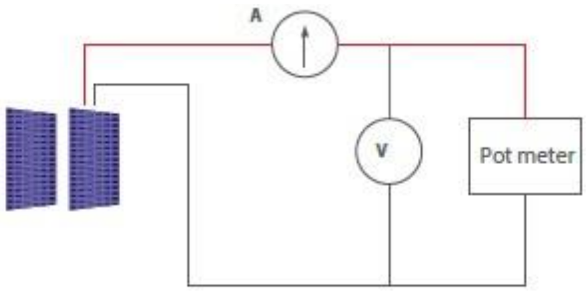
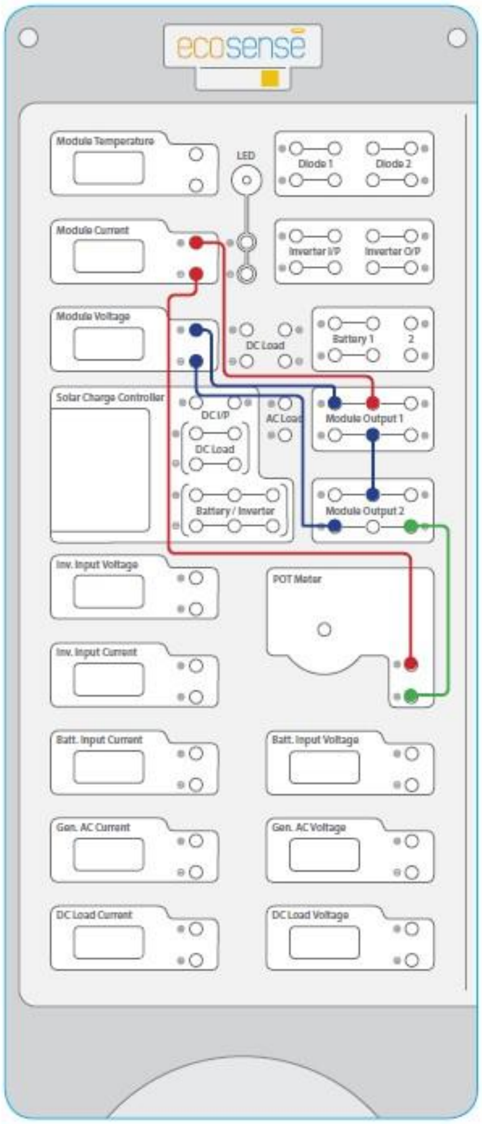


Fig. 1.2(b).Circuit diagram for evaluation of I-Vand P-V characteristics of parallel connected modules.

Connection Diagram :

Series connected modules Parallel connected modules



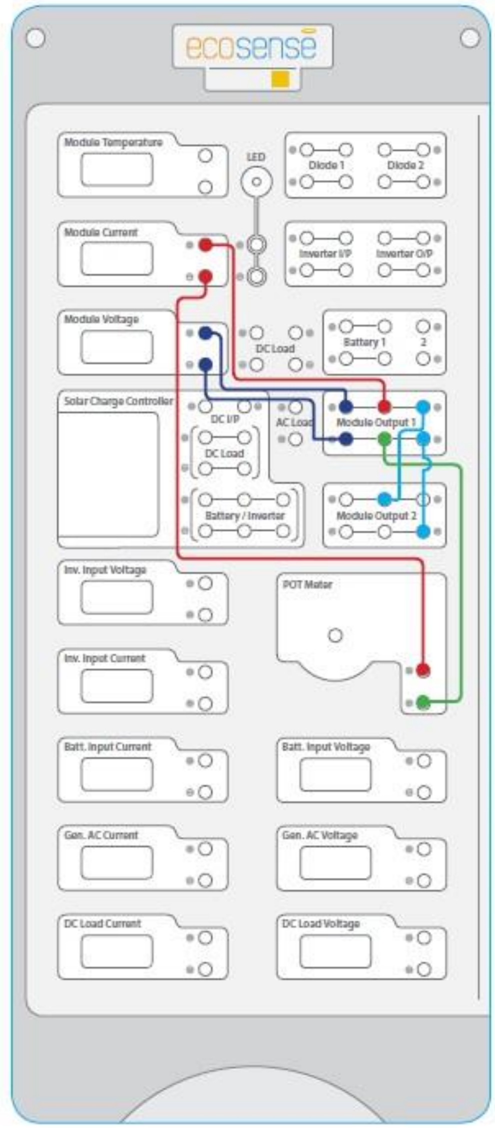
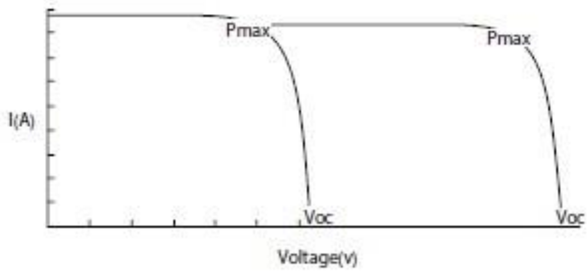


Fig. 1.3(a).Control board connections formodules connected in series.

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

Model Graph:



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TABULATION:

Series Connection

S.No.	**Voltage(V) (In Volts)**	**Current (I) (In Amps)**	**Power(P) (In Watts)**

Parallel Connections

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

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Exp. No.	2	**MPPT algorithm testing for an stand alone system**
Date		

AIM

To test the MPPT charger for an stand alone system

THEORY

The system test the MPPT algorithm for an stand alone system. 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.

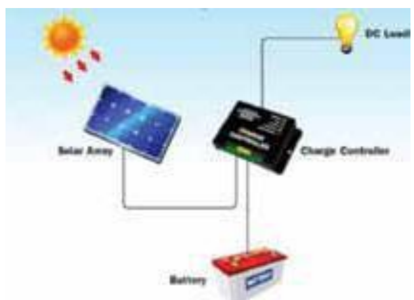


Fig. 6.1. Stand alone PV system

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.2.2a,b,c)

b) Using modules in parallel (Fig.2.3a,b,c)

c) Using modules in series (Fig.2.4a,b,

Controller connections

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

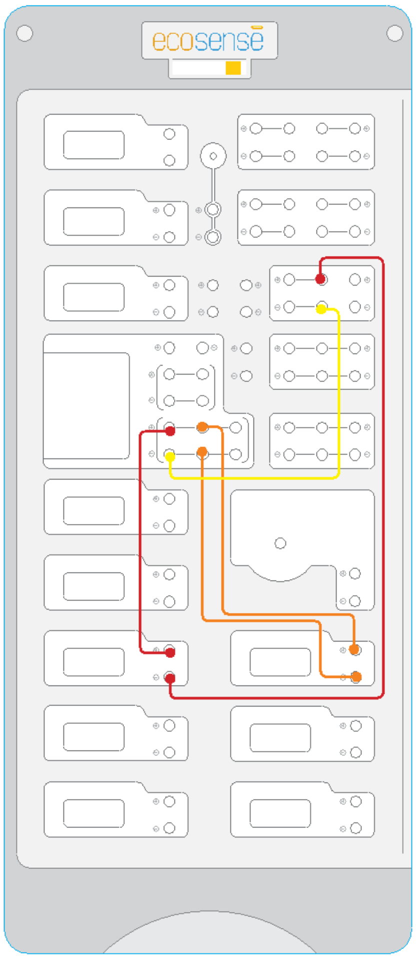


Fig.2.2 (a) Battery connections (Step I)

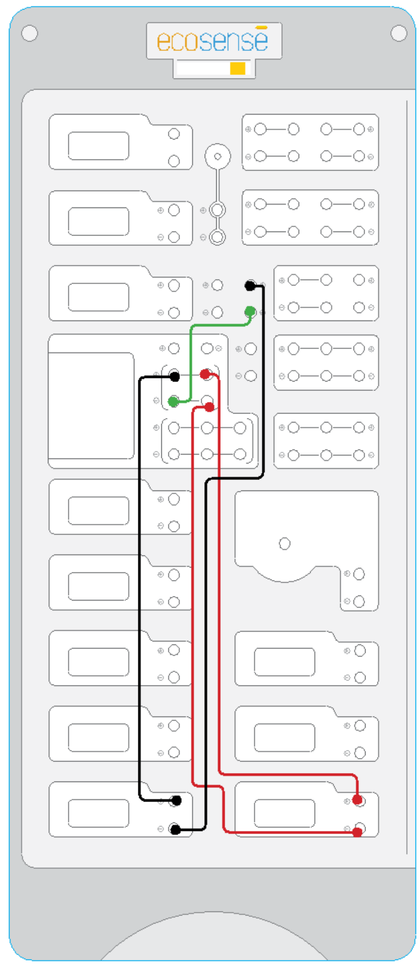


Fig.2.2 (b) DC load connections (Step II)

Controller connections

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

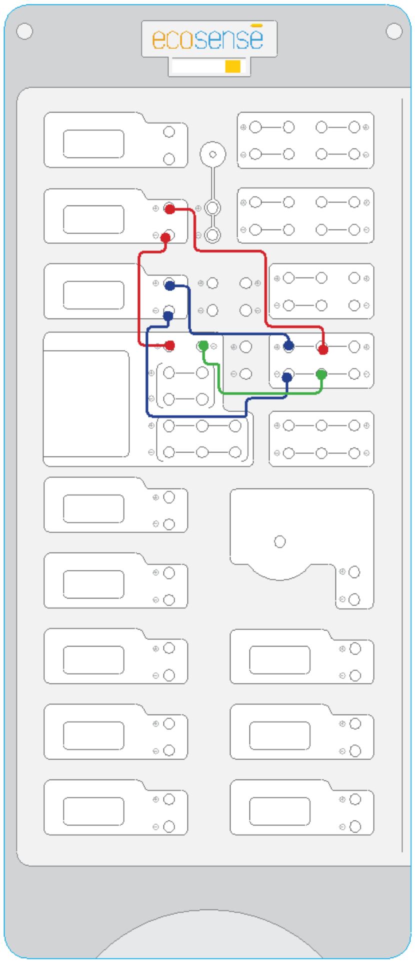


Fig.2.2 (c) Module connections (Step III)

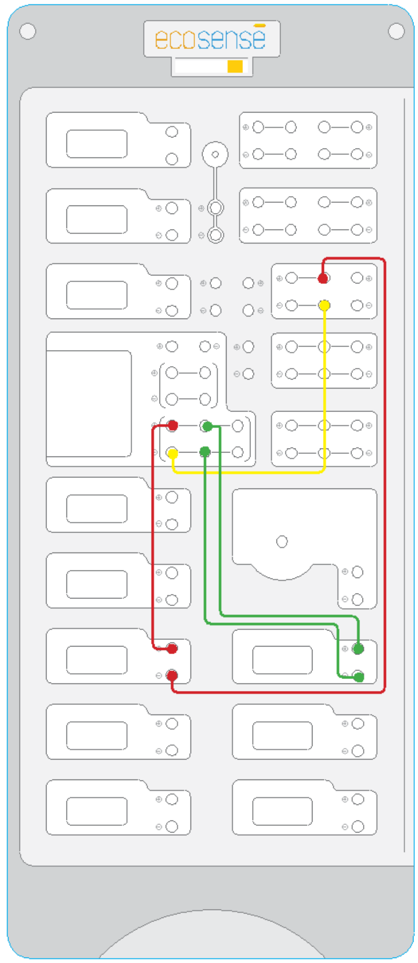


Fig.2.3 (a) Battery connections (Step I)

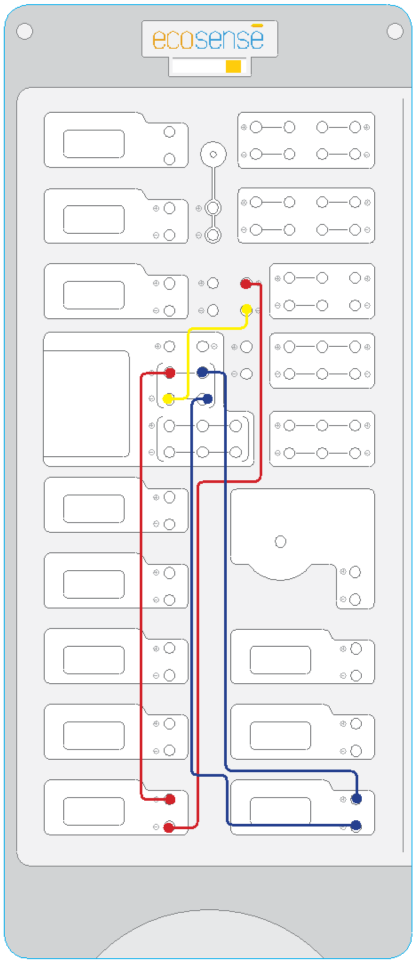


Fig.2.3 (b) DC load connections (Step II)

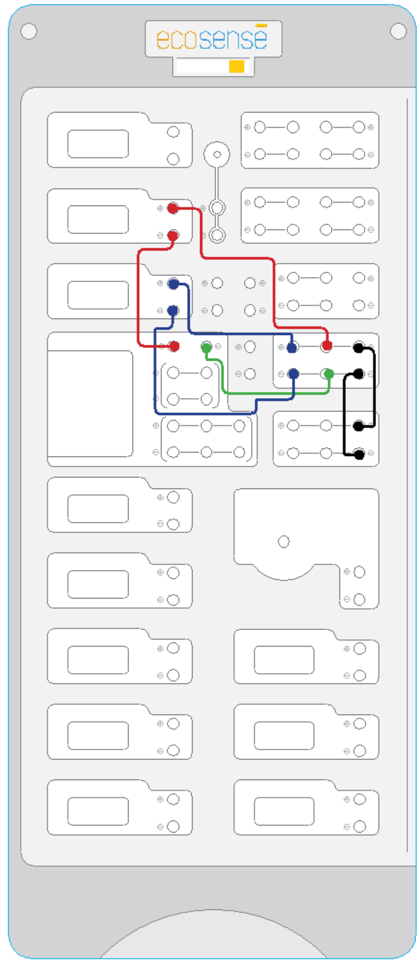


Fig.2.3(c) Module connections (Step III)

Controller connections

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

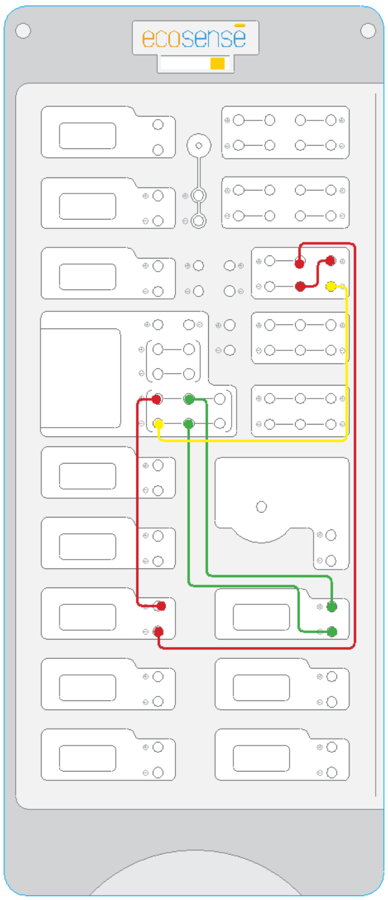


Fig.2.4 (a) Battery connections (Step I)

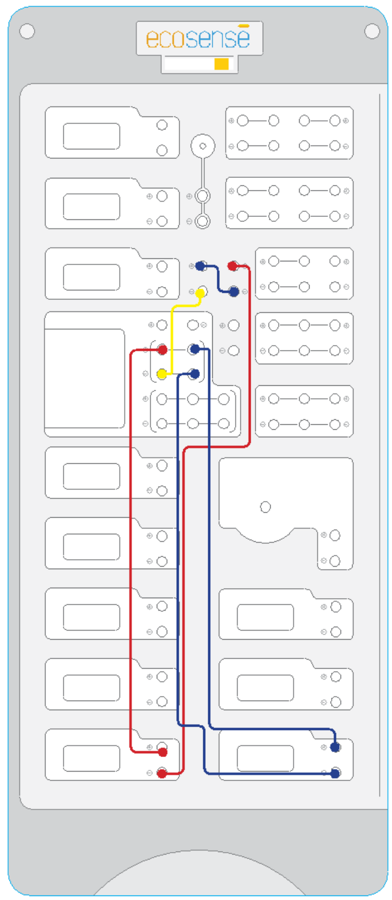


Fig.2.4 (a) Battery connections (Step I)

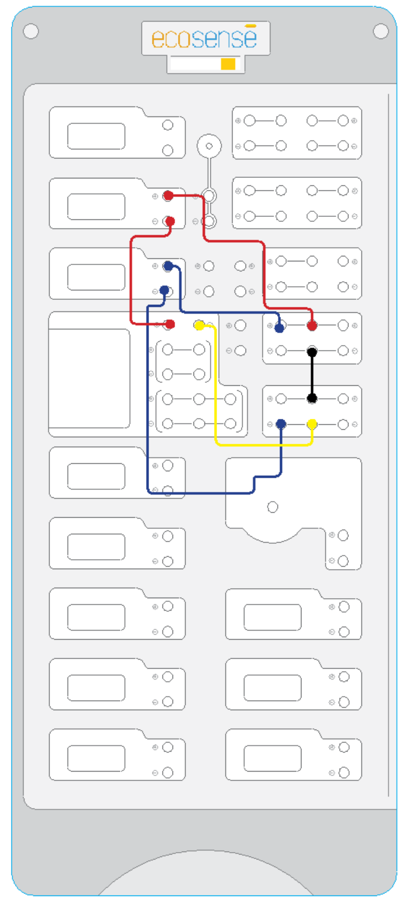


Fig.6.2 (c) Module connections (Step III)

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.	3	**Synchronization process for single phase solar Grid tied PV system**
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

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

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°.

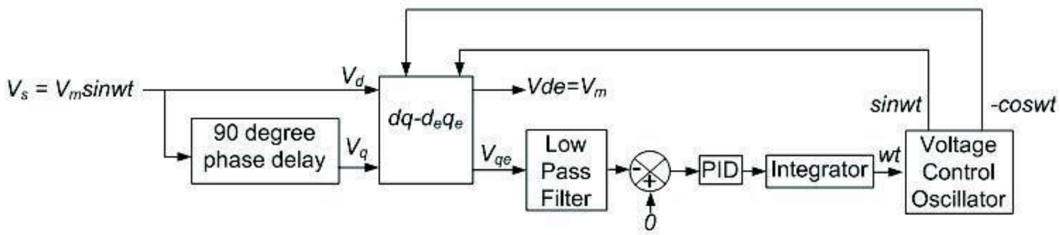
Since there is only one voltage component available for single phase unlike three for three phase system, so instead of using the abc - dq transformation matrix, single phase voltage (say Vs = Vm*sin(wt+Ø)) component itself is assume to be direct axis component (i.e. Vq =Vs = Vm*sin(wt+Ø)). Then 90° 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.

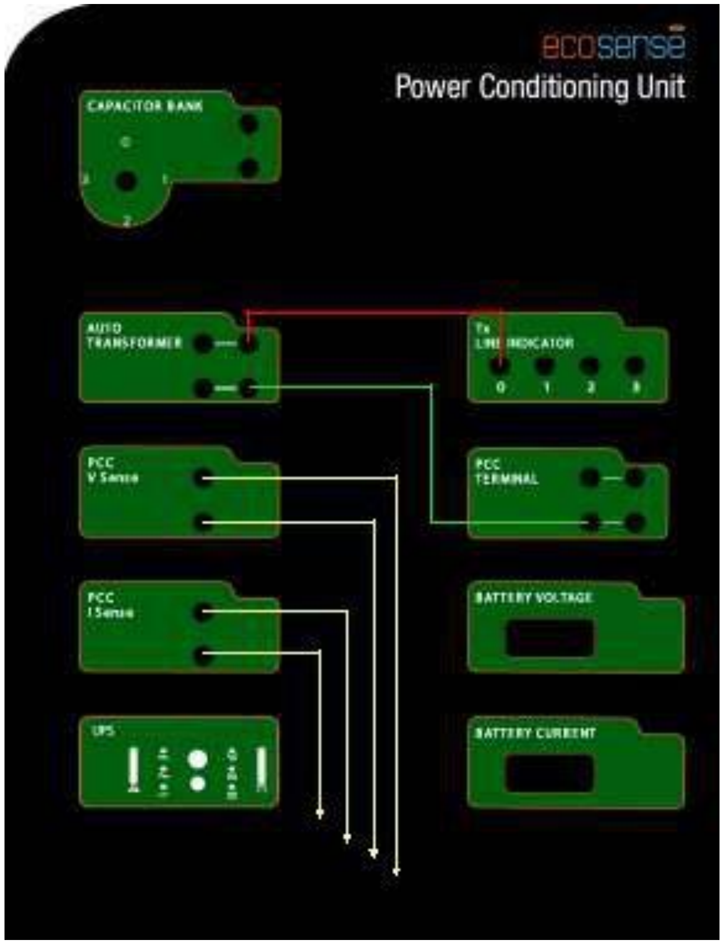
Objective of this experiment is a lab setup so as to make solar inverter synchronized to grid. Secondly, performance of inverter is evaluated in terms of time taken to synchronize the grid, how closely it is operating to MPPT, efficiency and finally its output power quality.

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

Exp. No.	4	**Evaluation of Cut in Speed of the Wind turbine**
Date		

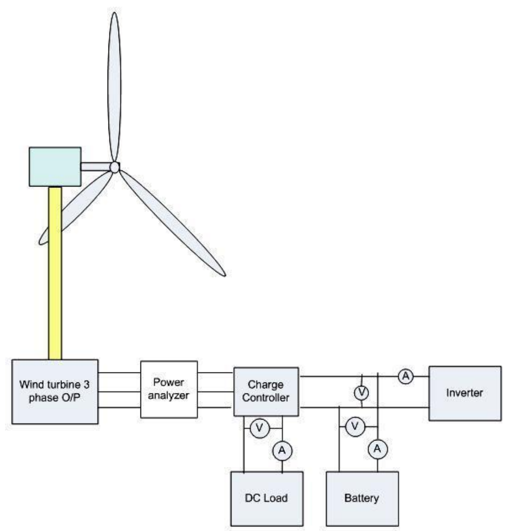
AIM

To evaluate the cut-in speed of wind.

THEORY

At very low wind speeds, there is insufficient torque exerted by the wind on the turbine blades to make them rotate. However, as the speed increases, the wind turbine will begin to rotate and generate electrical power. The speed at which the turbine first starts to rotate and generate power is called the cut-in speed. It is different with the start-up speed at which turbine starts to rotate, at cut-in speed turbine starts to generate some useful power. It is normally in the range of 3m/s - 4m/s.

CIRCUIT DIAGRAM



PROCEDURE

1. Fix the turbine in the setup and make the connections intact.
2. For this experiment, place the anemometer and tachometer at right position and readings will be noted down with these meters at different wind velocities.

3. Note the wind speed and shaft rpm corresponding to starting of turbine shaft rotation and power generation.

4.These wind velocities will be called start-up speed and cut-in speed.

5Test of the experimental set-up or system layout will remain the same.

OBSERVATION

S.No	Wind speed (m/s)	Rotational speed (RPM)	Battery Current (A)	Battery voltage (V)	DC load current (A)	DC load voltage (V)	Inverter i/p current (A)	Inverter i/p voltage (V)

Calculations

DC power at output of charge controller (DC power) = (DC load voltage*DC load current) + (battery voltage*battery current) OR

DC power at output of charge controller (DC power) = (inverter i/p current*inverter i/p voltage) + (battery voltage*battery current)

Generated power by wind turbine = DC power/charge controller efficiency

RESULTS

Start-up speed and Cut-in speed are found as follows:

Start-up speed =

Cut-in speed =

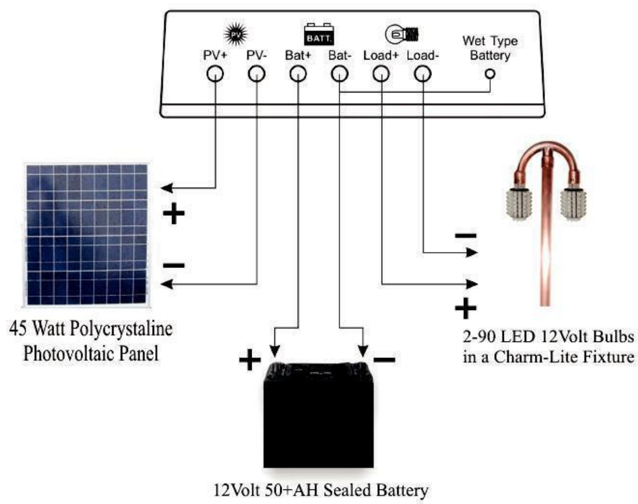
Exp. No.	5	Evaluation of the efficiency of the charge Controller used in the wind energy training system
Date		

AIM

To evaluate the efficiency of charge controller used in the Wind Energy Training System.

THEORY

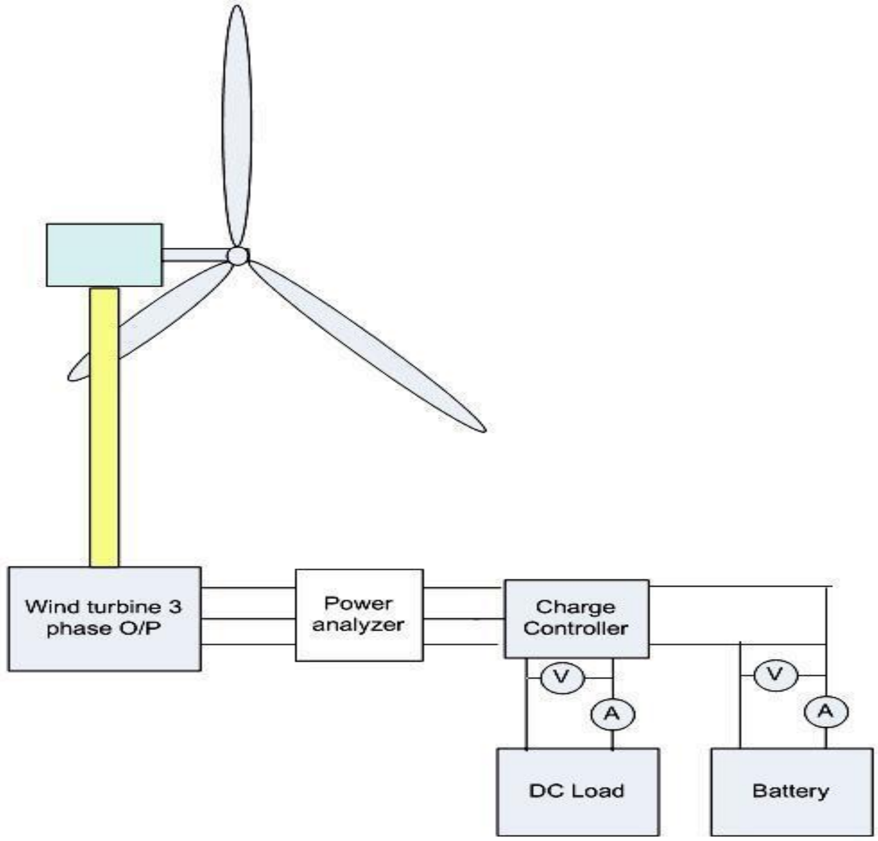
Charge controller is a electronic device which regulates the charging and discharging of battery and control the current and voltage in load. But this device has some efficiency of conversion which is more than 90%. It works on PWM control which open and close the switches at very high frequency. These provide a tapering charge by rapidly switching the full charging current on and off when the battery reaches the fully charged state. The length of the charging current pulse gradually decreases as battery voltage rises, reducing the average current into the battery.



Experimental Set-up

System layout for this experiment will be same as we discussed before (as shown in following figure) but the measurements will be made at the charge controller output. At this point, DC power is available for battery charging and DC load running. This Power calculation will be done by noting down voltage, current of battery and DC load. This experiment can be done in two ways:

1. Load running with battery only.
2. Load running with battery as well as turbine.



OBSERVATION

a. Load running with battery only

S.No.	Battery Current (A)	Battery voltage (V)	DC load current (A)	DC load voltage (V)

b. Load running with battery as well as turbine.

S.No.	Turbine current (A)	Power factor	Turbine voltage (V)	Battery Current (A)	Battery voltage (V)	DC load current (A)	DC load voltage (V)	Generated power (W)

Calculations

a. Battery power = battery current*battery voltage

b. Load power = load current*load voltage

c. Turbine power = √3*current*voltage*power factor

d. Charge controller efficiency with battery only = (load power/battery power)*100

e. Charge controller efficiency with battery as well as turbine = 100*(battery power + load power)/turbine power

RESULT

Exp. No.	**6**	**Evaluation of the tip speed ratio (tsr) at different wind speed**.
Date		

AIM

To evaluate the Tip Speed ratio (TSR) at different wind speeds.

THEORY

The relationship between the wind speed and the rate of rotation of the rotor is characterized by a non-dimensional factor, known as the tip speed ratio (TSR) or λ. The TSR for wind turbines is the ratio between the tangential speed of the tip of a blade and the actual velocity of the wind, . The tip-speed ratio is related to efficiency, with the maximum wind to electric power conversion efficiency occurring at a specific tip speed ratio for a given turbine under consideration. Higher tip speeds result in higher noise levels and require stronger blades due to large centrifugal forces. Lower tip speeds mean an under-utilization of the wind turbine to generate electricity. Thus it is generally desired to maintain the tip speed ratio at the optimal value to extract the most from the wind.

Tip speed ratio = Tip speed of blade/wind speed

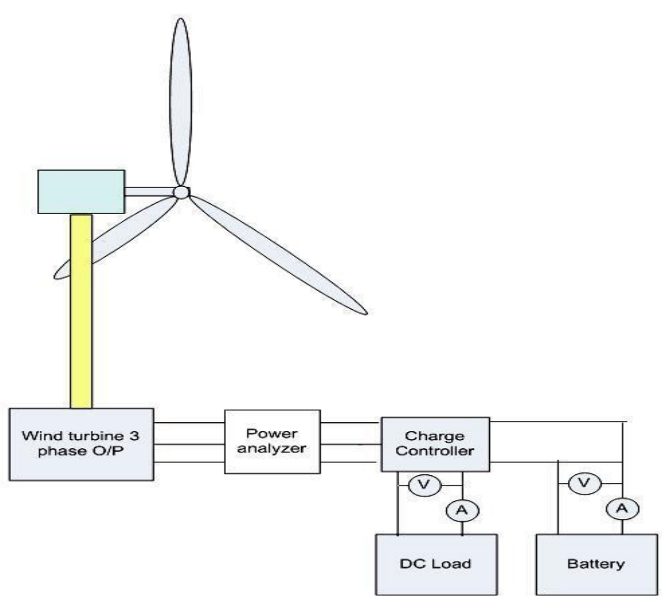
The tip speed of the blade can be calculated as ω times R, where ω is the rotor rotational speed in radians/second, and R is the rotor radius in meters. Therefore we can also write:

$$\lambda = \omega R/v$$

when wind speed is specified in meters/ second.

It should be constant for each wind velocity. Optimum TSR value for three blades wind turbine is 6-7.

CIRCUIT DIAGRAM



PROCEDURE

1. Make the circuit connections as in the diagram.

2. Place the anemometer and tachometer at right position and readings will be noted down with these meters at different wind velocities.

3.Vary the wind speed from cut in to maximum value and note the angular velocity of turbine blade and wind velocities.

4.Rest of the experimental set-up or system layout will remain the same.

OBSERVATIONS

1. Diameter of blades = 1.2m

2. Wind speed and angular velocity:

S.No.	Wind velocity (m/s)	Angular velocity (RPM)	TSR

Calculations

For performing this experiment, wind speed and angular velocity of turbine will be measured and TSR will be calculated by using following formula $\lambda = \omega R/v$

RESULT

TSR value at different wind velocities are as follows:

Exp. No.	7	To plot turbine power versus wind speed curve.
Date		

AIM

To draw the turbine power versus wind speed curve.

THEORY

Power curve of the wind turbine is the curve between the power output obtained from the wind turbine at different wind speeds. From the power curve one can assess the cut-in-speed, rated-speed, cut-out-speed of the turbine. These parameters are further defined as below.

1) Cut-in speed.

At very low wind speeds, there is insufficient torque exerted by the wind on the turbine blades to make them rotate. However, as the speed increases, the wind turbine will begin to rotate and generate electrical power. The speed at which the turbine first starts to rotate and generate power is called the cut-in speed.

2) Rated speed.

As the wind speed rises above the cut-in speed, the level of electrical output power rises rapidly as shown. However, at a certain wind speed the power output reaches the limit that the electrical generator is capable of. This limit to the generator output is called the rated power output and the wind speed at which it is reached is called the rated output wind speed. At higher wind speeds, the design of the turbine is arranged to limit the power to this maximum level (pitch controlled turbine) or the output power reduces (for a stall controlled turbine).

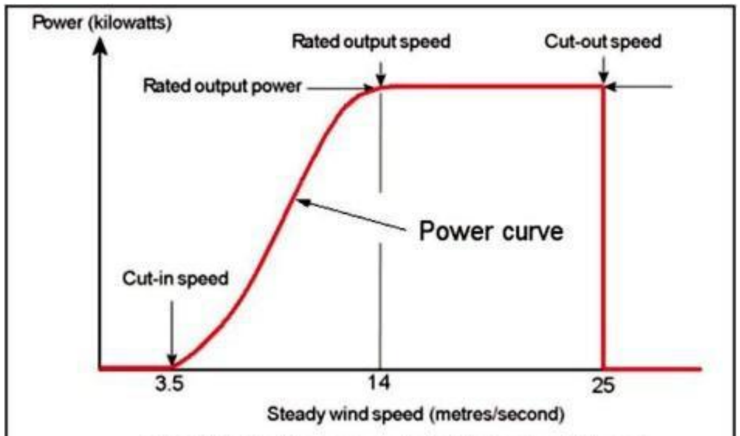
3) Cut-out speed.

As the speed increases above the rated output wind speed, the forces on the turbine structure continue to rise and, at some point, there is a risk of damage to the rotor. As a result, a braking system is employed to bring the rotor to a standstill. This is called the cut-out speed.

The power output of the wind turbine is given by,

$$P = 0.5\ \rho AV3Cp$$

where, ρ is the air density, A is the turbine swept area, V is the wind speed, Cp is the power coefficient of the wind turbine.



Typical wind turbine power output with steady wind speed.

Experimental Setup

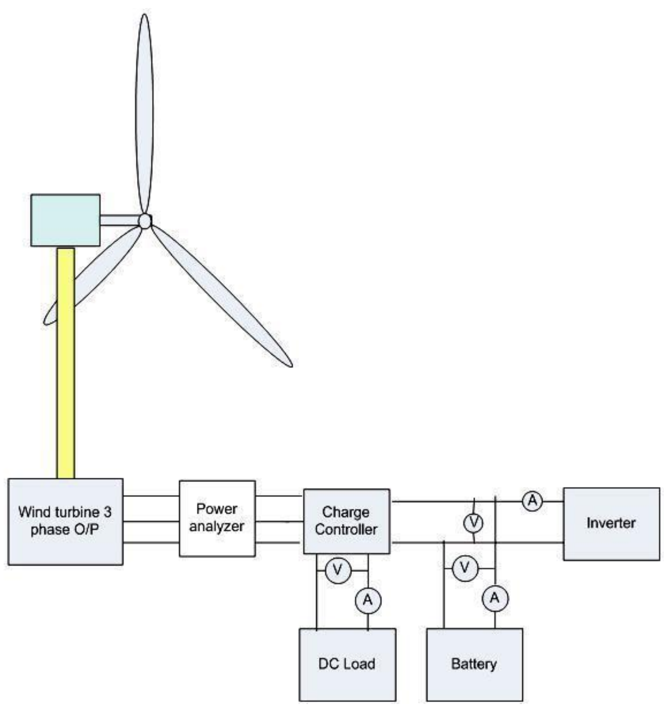
System layout for this experiment will be same as we discussed before (as shown in following figure) but the measurements will be made at charge controller output. At this point, variable frequency AC power of low voltage is available which is converted into DC power with the help of charge controller. Power calculation will be done by noting down voltage, current of battery and DC load. Then power can be calculated by

DC power at output of charge controller (DC power) = (DC load voltage*DC load current) - (battery voltage*battery current)

Generated power by wind turbine = DC power*charge controller efficiency

Power will be calculated at different wind speed and then a curve will be drawn by taking wind speed on x-axis and generated power on y-axis.

CIRCUIT DIAGRAM



OBSERVATION

Efficiency of charge controller =

S.No	Wind speed (m/s)	Battery Current (A)	Battery voltage (V)	DC load current (A)	DC load voltage (V)	Inverter i/p current (A)	Inverter i/p voltage (V)	Wind Power
1.								
2.								
3.								
4.								
5.								
6.								
7.								

Calculations

DC power at output of charge controller (DC power) = (DC load voltage*DC load current) + (battery voltage*battery current) OR

DC power at output of charge controller (DC power) = (inverter i/p current*inverter i/p voltage) + (battery voltage*battery current)

Generated power by wind turbine = DC power/charge controller efficiency

RESULT