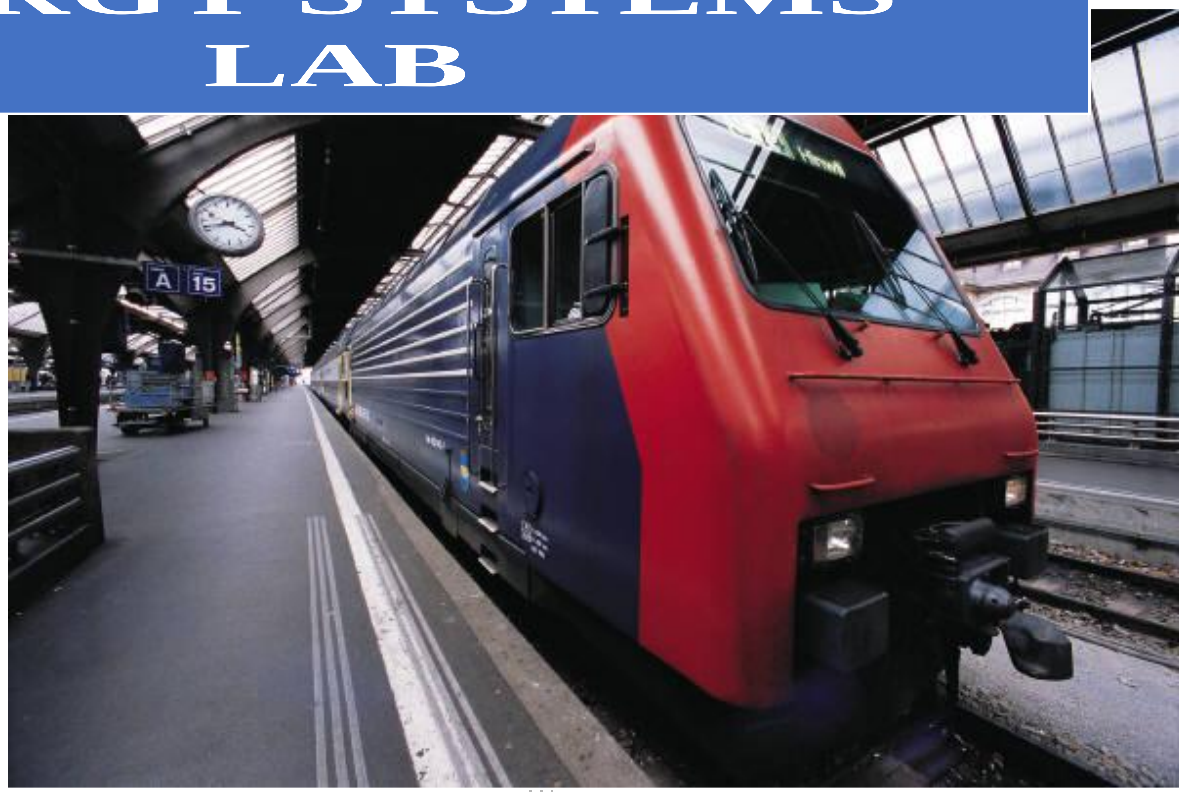
EE8712 RENEWABLE ENERGY SYSTEMS LAB



RENEWABLE ENERGY SYSTEMS LAB

Safety Information

This section contains safety information that must be observed at all times when working on or withthe product.

To prevent personal injury and property damage and to ensure long-term operation of the product,read this section carefully and observe all safety information at all times.

DANGER ⚠

Danger to life due to high voltages of the PV array when exposed to sunlight, the PV array generates dangerous DC voltage, which is present in the DC conductors and the live components of the inverter. Touching the DC conductors or the live components can lead to lethal electric shocks.

Prior to performing any work on the inverter, always disconnect the inverter from voltage sources on the AC and DC sides as described in the inverter manual. When doing so, note that even if the DC load-break is switched off, there will be dangerous direct voltage present in the DC conductors of the inverter

Notice

Damage to the inverter or product due to electrostatic discharge

- Touching electronic components can cause damage to or destroy the inverter or the product through electrostatic discharge
- Ground yourself before touching any component

RENEWABLE ENERGY SYSTEMS LAB

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RENEWABLE ENERGY SYSTEMS LAB

PART II

Experiment on Performance assessment of Micro Wind Energy Generator and Wind-Solar Hybrid system

RENEWABLE ENERGY SYSTEMS LAB

EE 8712 - **RENEWABLE ENERGY SYSTEMS LAB**

SYLLABUS

Course Objective:

- To train the students in Renewable Energy Sources and technologies.
- To provide adequate inputs on a variety of issues in harnessing Renewable Energy.
- To recognize current and possible future role of Renewable energy sources.

List of Experiments:

1. Simulation study on Solar PV Energy System.
2. Experiment on VI-Characteristics and Efficiency of 1kWpSolar PV System.
3. Experiment on Shadowing effect and diode based solution in1kWpSolar PV System.
4. Experiment on Performance assessment of Grid connected and Standalone 1kWp Solar Power System.
5. Simulation study on Wind Energy Generator.
6. Experiment on Performance assessment of micro Wind Energy Generator.
7. Simulation study on Hybrid (Solar-Wind) Power System.
8. Experiment on Performance Assessment of Hybrid (Solar-Wind) Power System.
9. Simulation study on Hydel Power.
10. Experiment on Performance Assessment of 100W Fuel Cell.
11. Simulation study on Intelligent Controllers for Hybrid Systems.

Course Outcome:

- Ability to understand and analyze Renewable energy systems.
- Ability to train the students in Renewable Energy Sources and technologies.
- Ability to provide adequate inputs on a variety of issues in harnessing Renewable Energy.
- Ability to simulate the various Renewable energy sources.
- Ability to recognize current and possible future role of Renewable energy sources.
- Ability to understand basics of Intelligent Controllers.

PART I

Experiments on Performance assessment of 1KW Solar PV Training Systems (Grid-Tied (On-Grid), Stand-Alone (Off-Grid)

General Specifications& Datasheets

Solar PV Module Used (250/260/265/270/275)/24V

SOLAR PV MODULE	At STC 1000W/m^2, Temp=25°C
Model	HST60F265P
Voc	38.39V
Isc	9.51A
Vpm	30.88V
Ipm	9.01A
Pmax	278.49W
FF	0.762
Rs	0.49Ohm
Rsh	207.95Ohm
ModEff	17.11%
Temp	25.0°C
Insol	1000W/m^2
Dimension	1650*987*40 mm

PV GRID TIED INVERTER(ON-GRID INVERTER)	
Model	Growatt 1000-S
$U_{DC\ max}$	450V
$I_{DC\ max}$	10A
$U_{DC\ range}$	70V-450V
$V_{AC\ norm}$	230V
$F_{AC\ norm}$	50Hz/60Hz
$S_{AC\ max}$	1000VA
$I_{AC\ norm}$	4.3A
PF	0.9leading-0.9lagging
Protection Degree	IP65
Operation Ambient Temperature	-25°C to 60°C

PV STAND ALONE INVERTER(PCU) (OFF-GRID INVERTER)	
Weight	15.8kg
Model No	ESP1450/24
Grid Charging Current High	16A/14A/16A/14A (TUB, FL, GEL, SMF)
Grid Charging Current Low	12A/10A/10A/10A (TUB, FL, GEL, SMF)
PCU	1450 VA
Boost Voltage	28.8 V/28.4 V/28.4 V/28.4 +/- 0.2 V (TUB, FL, GEL, SMF)
Float Voltage	27.6 V/27.2 V/27.6 V/27.6 +/- 0.2 V (TUB, FL, GEL, SMF)
Change Over Time Normal Mode	Less than 40 ms (Mains-PCU)
Change Over Time UPS Mode	Less than 10 ms (Mains-PCU/PCU-Mains)
Output Voltage Regulation AC from Min to Max Battery Voltage and No Load to Full Load	180 V-220 V
Nominal Input Battery Voltage DC	24 V
Battery Low Voltage Warning	21.6 V +/- 0.4 V
Mains AC High Cut UPS Mode	265 +/- 10 V
Battery Low Voltage Cut	21 V +/- 0.4 V
Load Reconnect Voltage	25.4 +/- 0.4 V
Short Circuit Protection	Provided
Maximum Input PV Voltage	45 V
Over Load Protection	6 Sec. (125%)
Over Temp Protection	Through Cooling Fan
Max Solar Panel Wattage	UP to 1500 Wp
Battery Charging Current Imax	20 Amp (From Solar+Grid)
Protection	Over Current, Battery Over Charge, PV Reverse Polarity, Reverse Current Flow
Display Type	LCD Display
Mains AC High Cut Recovery UPS Mode	255 +/- 10 V
Mains AC Low Cut UPS Mode	180 +/- 10 V
Mains AC Low Cut Recovery UPS Mode	190 +/- 10 V
Mains AC Low Cut Normal Mode	100 +/- 10 V
Mains AC Low Cut Recovery Normal Mode	110 +/- 10 V
Mains AC High Cut Normal Mode	280 +/- 10 V
Mains AC High Cut Recovery Normal Mode	270 +/- 10 V

EXPERIMENT NO: 2. Experiment on VI-Characteristics and Efficiency of 1kWpSolar PV System.

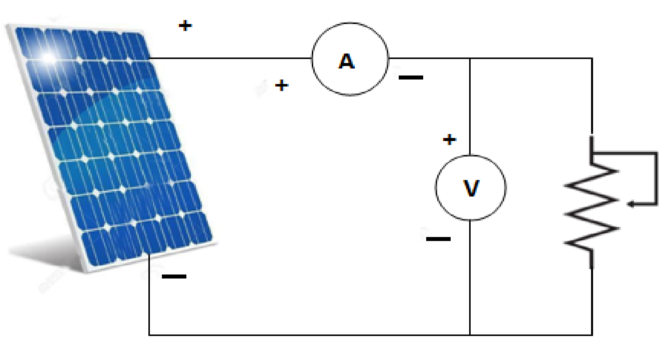
AIM:

To Conduct Experiment of P-V and V-I characteristics and Efficiency of Solar PV module

APPARATUS REQUIRED:

- ❖ Solar panels (1KW)
- ❖ LABTECH Solar PV training system.
- ❖ Resistive Load (100E/3A)
- ❖ Patch Chords.

CIRCUIT DIAGRAM:



PROCEDURE:

- Connect All panels in series and connect the meters and load as per diagram
- Switch ON the trainer.
- Output of solar panel is connected to the variable load (resistive load) through ammeter and voltmeter.
- Vary the load resistance and measure the voltage and current(slowly up **vary from 90% to 0%)**enough
- Tabulate the reading and plot the P-V and V-I graphs.

EXAMPLE PARAMETER SETTINGS:

No Of Panels Used: 4 no X 250/265/270W, 24V, (connected in series all 4 panels)

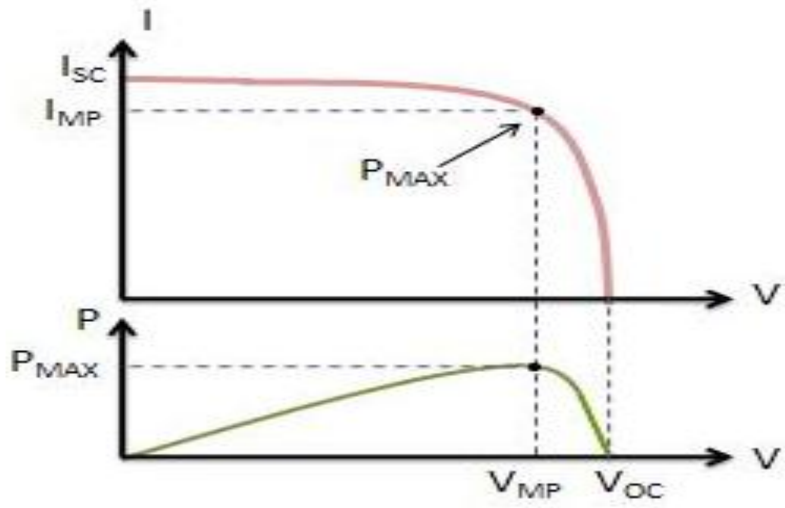
DC load = 100/3A, Rheostat (vary from 90% to 0%)

Panel Voltage: 120V (4 panels)

TABULATION:

SL.	Current	Voltage	Power
No	(A)	(V)	(W)
1	8	0	0
2	8	20	160
3	8	50	400
4	8	60	480
5	8	70	560
6	7.5	80	600
7	7	90	630
8	6.5	100	650
9	6	120	720
10	5	120	600
11	4	120	480
12	3	120	360
13	2	120	240
14	0	120	0

Model Graph



Result 1:

Thus the P-V and V-I characteristics of PV system was studied and the maximum power Pmax of 720W is delivered at the Voltage of 120V and Current 6A

<u>**Efficiency Calculations:**</u>

No of Panels Used: 4 no X 250/265/270W, 24V

Efficiency of the solar panel is given by the ratio of electrical power (kWp) of solar panel divided by the area of one panel.

Solar cell Efficiency (Maximum):-

$$\eta_{max} = \frac{P_{max}}{E * A_c} \times 100\ \%$$

P_{max} = Maximum Power Output (in W)

E = incident radiation flux (in W/m^2)

A_c = Area of Collector (in m^2)

Maximum power, Pmax for 1KW SPV is 720W, from the IV, PV Characteristics derived in last experiment

(Assumed Default)Incident Radiation Flux is (considered peak hours) 1000W/m^2

%Efficiency = (720/(1000* 6.192))*100

%Efficiency = 0.1163 *100 = **11.63%**

Result 2:

THUS THE EFFICIENCY OF 1KW SOLAR PV PANEL SYSTEM IS FOUND AS 11.63%

EXPERIMENT: 3: Experiment on Shadowing effect and diode based solution in1kWpSolar PV System

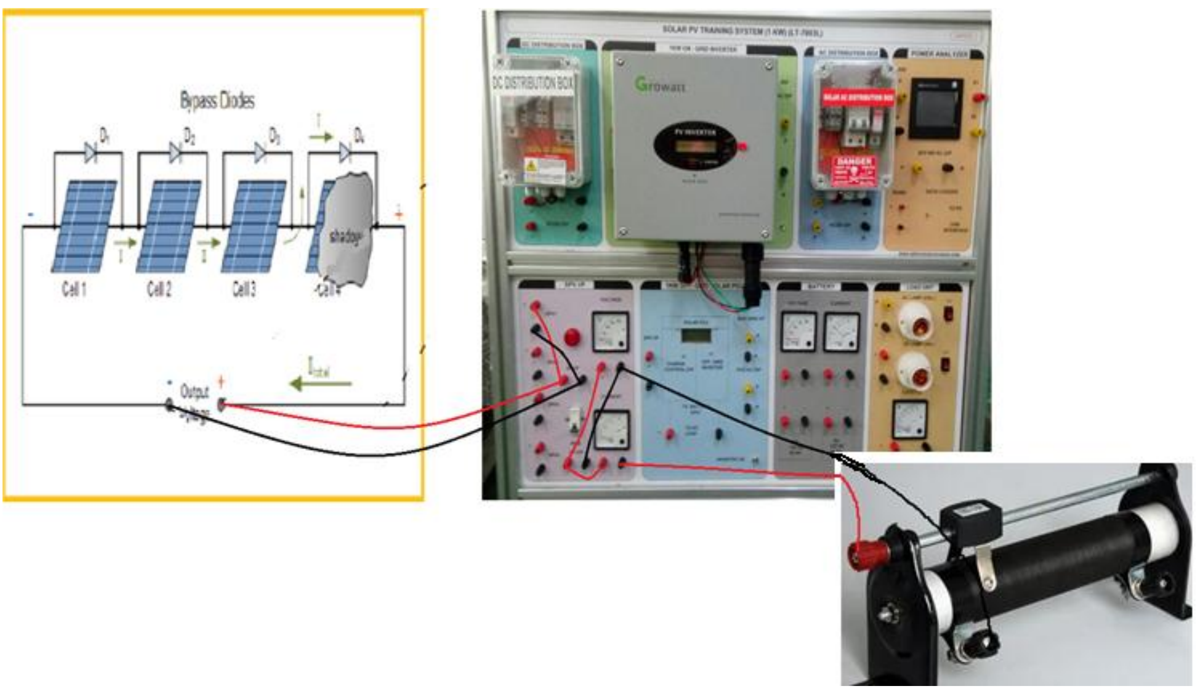
AIM:

To conduct the Experiment on **Shadowing effect and diode based solution in1kWpSolar PV System**

APPARATUS REQUIRED:

- ❖ Solar panels (1KW)
- ❖ LABTECH Solar PV training system.
- ❖ Resistive Load (100E/3A)
- ❖ Patch Chords.

CONNECTION DIAGRAM



PROCEDURE:

- ❖ Connect All panels in series and connect the meters and load as per diagram
- ❖ Switch ON the trainer.
- ❖ Output of solar panel is connected to the variable load (resistive load) through ammeter and voltmeter.
- ❖ Vary the load resistance and measure the voltage and current(slowly up **vary from 90% to 0%)**enough
- ❖ Tabulate the reading and plot the P-V and V-I graphs.

<u>**EXAMPLE PARAMETER SETTINGS:**</u>

No Of Panels Used: 4 no X 250/265/270W, 24V, (connected in series all 4 panels)

DC load = 100/3A, Rheostat (vary from 90% to 0%)

Panel Shadowing: Shadow one Panel as per diagram with any cardboard or dark cloth, Diode: By Pass Diode provided on back side of each panel

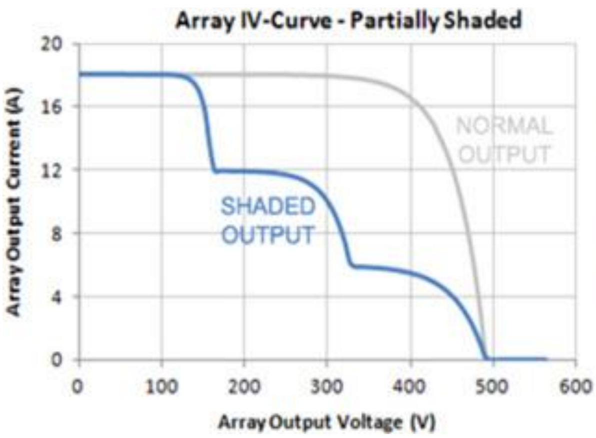
TABULATION:

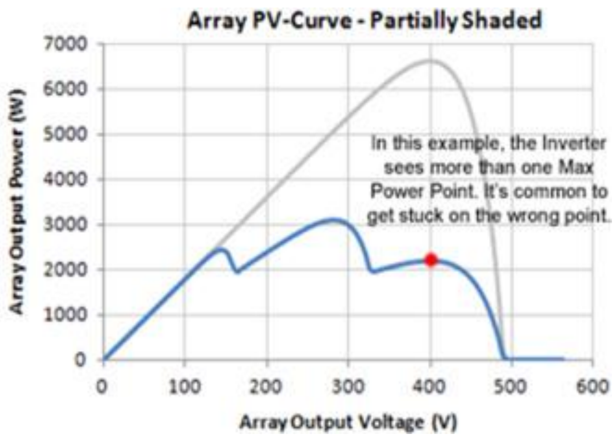
WITHOUT SHADOW EFFECT			
SL.	**Current**	**Voltage**	**Power**
No	**(A)**	**(V)**	**(W)**
1	8	0	0
2	8	20	160
3	8	50	400
4	8	60	480
5	8	70	560
6	7.5	80	600
7	7	90	630
8	6.5	100	650
9	6	120	720
10	5	120	600
11	4	120	480
12	3	120	360
13	2	120	240
14	0	120	0

WITH SHADOW EFFECT AND BYPASS DIODE

Current	Voltage	Power
(A)	**(V)**	**(W)**
8	0	0
8	20	160
8	30	240
8	40	320
8	50	400
6	60	360
5	70	350
4	80	320
3	90	270
2	95	190
0	95	0

MODEL GRAPH:





RESULT: Thus the Shadowing effect and diode based solution in1kWpSolar PV System is studied and found that the bypass diode closed the circuit without the last panel in series connection and we get the reduced voltage and current and power which is lesser than the power without shadowing effect.

EXPERIMENT: 4
Experiment on Performance assessment of Grid connected and Standalone 1kWp Solar Power System.
EXP.4.1

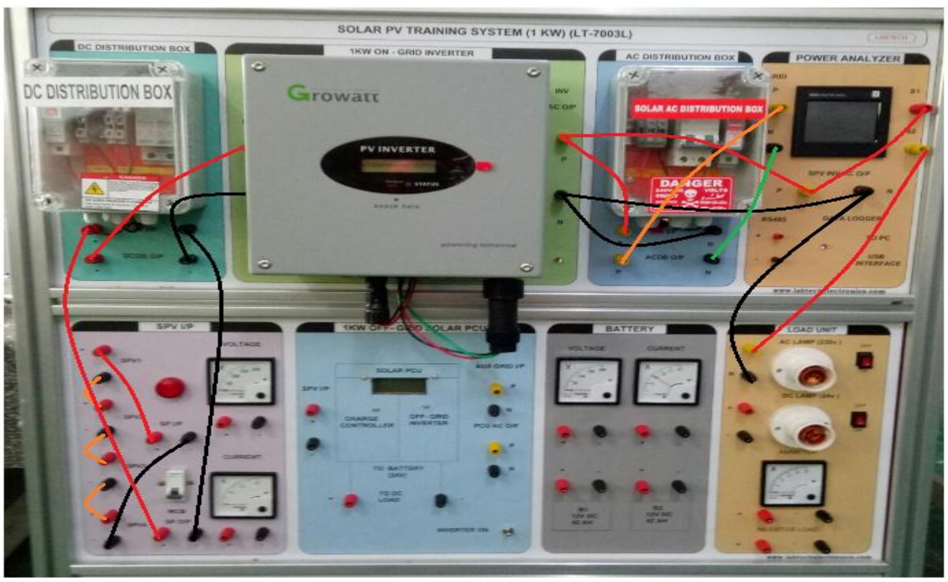
AIM:

To Conduct the Experiment on **Performance assessment of Grid connected 1kWp Solar Power System.**

APPARATUS REQUIRED:

- Solar panel
- Solar PV training system.
- Patch Chords
- Load Lamp

PATCHING DIAGRAM:



PROCEDURE:

- Connect All panels in series and connect the meters and load as per diagram
- Switch ON the trainer.
- Generate power from solar panel and transmit to the transmission line grid.
- Generated power can be monitored by LCD in the inverter and Load Power using multifunction meter.

Calculations

EXAMPLE PARAMETER SETTINGS:

No Of Panels Used: 4 no X 250/265/270W, 24V, (connected in series all 4 panels)

DC load = 100W/200W AC Lamp

1KW Grid-tied inverter considered with generated AC o/p of 680W for given 720W SPV Pmax

<u>Theoretical Power Output</u>

Note: VA to watts calculation

The real power P in watts (W) is equal to the apparent power S in volt-amps (VA), times the power factor PF:

$P_{(W)} = S_{(VA)} \times PF$

Eg. If the invert is 1000VA, and the power factor is 0.9(resistive load) then P(W) is 1000.9 = 900W, then efficiency of the inverter is 90%*

Eg. If the invert is 1400VA, and the power factor is 0.9(resistive load) then P(W) is 1400.9 =1260W, then efficiency of the inverter is 126% ,*

Hence please calculate the efficiency based on the inverter specifications in your kit

<u>To find Grid –tied Inverter efficiency (Actual power in the 1kw plant)</u>

The ratio of AC power generated by the inverter to the DC power generated by the PV array system is called inverter efficiency.

<u>AC power generated by the inverter:</u>

Connect all 4 Panels in series and Connect the Grid-tied inverter as given in the Patching diagram, Do the Grid Synchronization, then you will see the AC power Generated in the LCD Display of the Inverter

AC power generated by the inverter = 680W

<u>DC power generated by the PV array system</u> = 720W (Pamx from IV curve from 1st experiment)

Efficiency of the Grid-tied inverter is

$$\eta_{inv} = (P_{AC}/P_{DC})*100$$
$$= (680W/720W)*100$$
$$\mathbf{=90.23\%}$$

<u>To find On-grid System efficiency (with single panel 265W, 24V)</u>

The instantaneous daily system efficiency is given as solar photovoltaic module efficiency multiplied by inverter efficiency.

$$\eta_{sys,T} = \eta_{PV,T} * \eta_{inv,T}.$$
$$= (11.63 * 90.23)/100$$
$$= \mathbf{10.49\%}$$

<u>To find On-grid System efficiency (with Array of 4 panel of 1KW)</u>

The instantaneous daily system efficiency is given as solar photovoltaic module efficiency multiplied by inverter efficiency.

$$\eta_{sys,T} = \eta_{PV,T} * \eta_{inv,T}.$$
$$= (11.63 * 90.23*4)/100$$
$$\mathbf{= 41.97\%}$$

RESULT:

Thus the AC power Generated from the Grid-tied inverter is fund 680W, and Efficiency is found as 90.23% for the given Pmax of 720W, and the Overall System Efficiency is found as 41.97% and Performance is Analyzed.

OTHER REFERENCES IF REQUIRED

Array yield (Y_A):

The array yield is the ratio of daily, monthly, or yearly direct current (DC) energy output from a PV array to the rated PV array power and is given by I kWh/kWp.

$$Y_A = E_{DC}/P_{pv,rated}$$

Where, E_{DC}-Total DC energy output from the PV arrays (kWh)

$P_{pv,rated}$ -Rated output power of the PV system(kWp) at STC.

Final Yield (Y_F):

The final yield can be defined as the total AC energy during a given period divided by the rated PV array power, and is given by

$$Y_F = E_{AC}/ P_{pv,rated}$$

Where,

E_{AC} - Total AC energy output from the inverter generated by the PV power system for a specific period (kWh).

Reference Yield (Y_R):

The reference yield is the ratio of total in-plane solar radiation to the reference irradiance at standard test conditions (STC).It represents the total in-plane solar radiation or an equivalent number of hours at the reference irradiance.

$$Y_R = S_R/H_R$$

Where,

S_R-Total in-plane solar radiation (kWh/m2)

H_R-Array reference irradiance at STC (1 kW/m2).

Performance Ratio (PR):

The performance ratio (PR) is the ratio of the final energy yield of the PV system to the reference yield. It provides information about the overall losses incurred in converting DC to AC power. Therefore, it represents the percentage of energy actually available after deducting energy losses.

$$P_R = Y_F / Y_R$$

PV Module Efficiency (η_{PV}):

The PV module efficiency is,

$$\eta_{PV} = (E_{DC} / S_R A_{PV}) * 100\%$$

Where,

A_{PV} - PV module total area (m2).

PV System efficiency (η_S):

The overall PV system conversion efficiency is defined as the energy output from a PV array divided by the total in-plane solar isolation.

$$\eta_s = (E_{AC} / S_R A_{PV}) * 100\%.$$

Array Capture Loss (L_A):

The difference between reference yield and array yield is called Capture losses.

$$L_A = Y_R - Y_A$$

System Loss (Ls):

The difference between array field and final yield is called System losses.

$$L_S = Y_A - Y_F$$

Capacity Utilization Factor (CUF):

Capacity Utilization Factor (CUF) is defined as the ratio of actual energy output of the solar photovoltaic system to the energy output system that would generate if it works at rated power for 24 Hrs/day/month/year.

CUF = Energy measured (kWh)/(365 ∗ 24 ∗ installed capacity of the plant)

EXPERIMENT: 4

Experiment on Performance assessment of Grid connected and Standalone 1kWp Solar Power System.

EXP.4.2

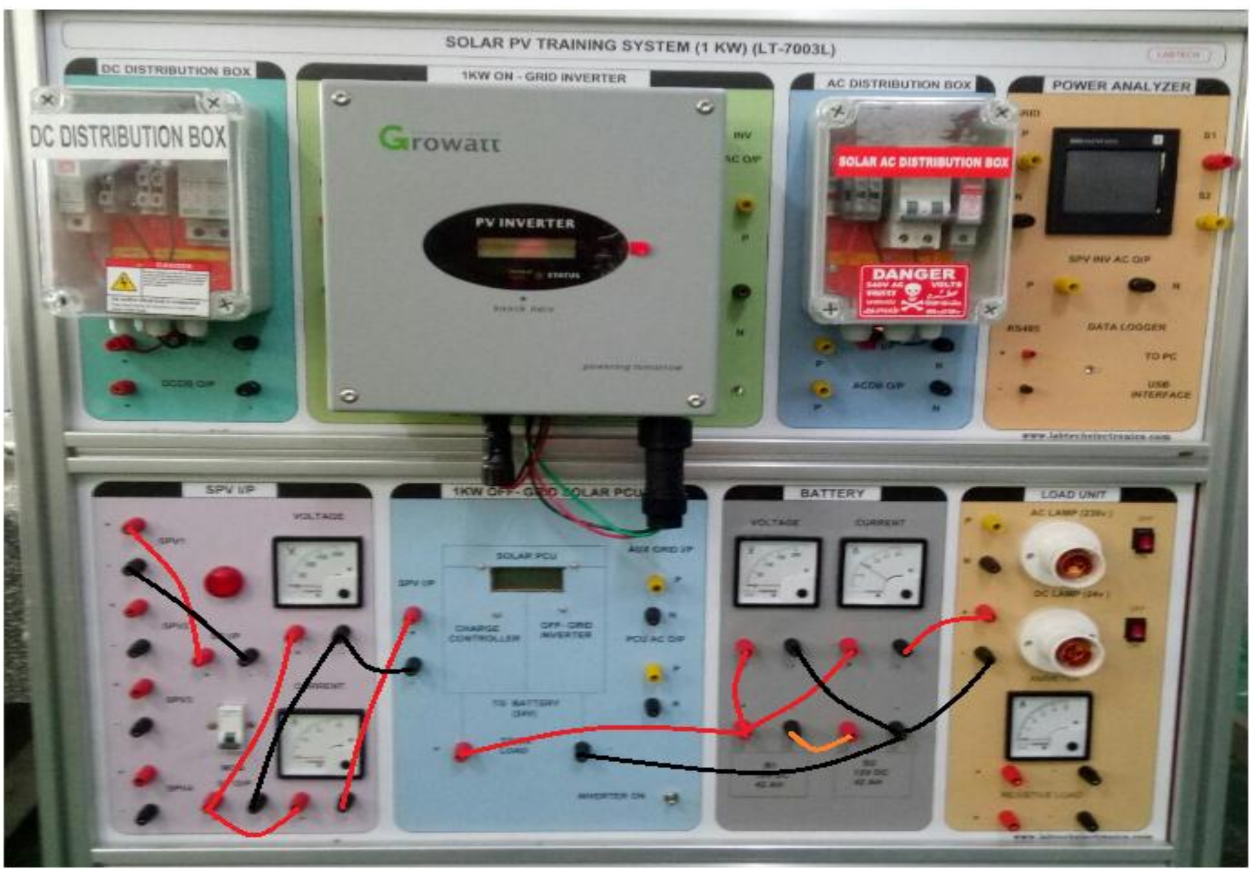
AIM:

To Conduct the experiment on **Performance assessment of Standalone 1kWp Solar Power System.**

APPARATUS REQUIRED:

- Solar panel (265/270W) – 2 nos
- LABTECH Solar PV training system.
- Patch Chords
- Load Lamp / Rheostat 150E/3A

PATCHING DIAGRAM:



PROCEDURE:

- Connect 2 batteries in Series and connect it to 1kw OFF-GRID SOLAR PCU block of TO BATTERY input.
- Make the connection as per patching diagram.
- Switch ON the trainer.
- Generated power can be monitored by giving it to DC Loads

<u>TO FIND THE LOSSES DUE TO CHARGE CONTROLLER</u>

<u>EXAMPLE PARAMETER SETTINGS:</u>

NO OF PANELS USED: 2 no X 250/265/270W, 24V, (connected in parallel)

No of Battery used: 2 nos X 12V, 42AH

DC load = 60W, 24V DC lamp

<u>POWER FLOW OF DC LOAD WITH BATTERY (Refer the connection Diagram)</u>

Array voltage (Spv i/p Volt meter)	**Array current (Spv i/p ammeter)**	**Array power (calculated)**	**Battery voltage (Battery section Voltmeter)**	**Battery current (Battery section ammeter)**	**Battery power (calculated)**	**Dc Load voltage (Battery section Voltmeter)**	**Dc Load current (Load Section Ammeter)**	**Dc Load power 60W DC blub**
35 V	4A	140W	26V	1.8A	46.8W	26V	2.6A	67.6W

Array power =Dc load power + Battery power+ Power loss in charge controller

Power loss in charge controller = Array power- (Dc load power + Battery power)

= 140-(67.6+46.8)

= 140-114.4

= 25.6W

POWER FLOW OF AC LOAD WITH BATTERY

Array voltage	Array current	Array power	Battery voltage	Battery current	Battery power	Inv i/p voltage To load	Inv i/p current	Inv i/p power
35 V	4A	140W	26V	1.8A	46.8W	26V	3.2A	83.2W

Array power = Inverter input power + Battery power + Loss due to charge controller

Loss due to charge controller = **Array power – (**Inverter input power + Battery power)

= 140-(83.2 + 46.8))

= 140-130 = **10W**

CALCULATION OF INVERTER EFFICIENCY

Inv i/p voltage	Inv i/p current	Inv i/p power	Ac Load voltage	Ac Load current	Ac Load power	Inv efficiency
26V	3.2A	83.2W	207	0.4A	82.8W	106%

Inverter efficiency = (AC load power* 100) / inverter input power

= (82.8*100)/83.2
= 99.5%

RESULT: Thus the performance assessment of standalone solar PV system was studied, The Loss due to charge controller is 25.6W for DC load and 10W for AC load, The Efficiency of the Stand-alone Inverter is found as 99.5%.

PART II

Experiment on Performance assessment of Micro Wind Energy Generator and Wind-Solar Hybrid system

THE GENERAL CHARACTERISTICS OF THE MICRO WIND TURBINE:

Features	**Value**
Rotor diameter	1.24 m
Rotor-swept area	1.207 m^2
Number of blades	3
Nominal power	177 W
Output voltage	10–35 V AC
Body structure	Aluminum
Weight	12 kg
Axis type VAWT-HAWT	HAWT
Wind direction adjustment mechanism (YAW)	Tail
Cut-in wind speed	2.7 m/s
Nominal wind speed	11 m/s
Cut-out wind speed	20 m/s
Braking	Electrical
Generator type	PMSG
Number of poles	12
Output phase (1/3)	3-phase
Annual energy production	384 kWh
Upwind-downwind	Upwind
Direction of rotation	Clockwise
Off/on-grid	Off-grid
Highest design wind speed	25 m/s
Highest temperature of the stator	90 ˚C
Design life	20 years
Maximum power (20 m/s)	524 W

Equations for Power Performance Analysis of Micro Wind Turbine (MWT)

Instantaneous wind power (P_w):

The energy of a MWT and continuously moves and rapidly changes in the atmosphere, has a certain mass and a kinetic energy. The instantaneous wind power of the MWT is expressed in,

$$P_w=1/2*(\rho*A*v^3)$$

Where,

P_w- Instantaneous wind power (W).

ρ - Air density (kg/m 3).

A - Cross-sectional area perpendicular to a wind stream (m^2).

v - Wind speed (m/s) that is wind velocity.

NOTE:

All of the instantaneous wind power is not converted into electrical energy in the MWT.

Generated Power (P_t):

The amount of power converted into electrical energy in the MWT is

$$P_t=1/2*(C_p*\rho*A*v^3)$$

Where,

P_t - Generated power of the MWT (W).

Cp - Power co-efficient.

A ($A=\pi.R^2$) - Swept area during the rotation of the rotor blades (m^2).

R - Maximum rotor radius (m) of the MWT.

Power coefficient (Cp):

The power coefficient of a MWT is varied by wind speed. For this reason, the efficiency of a MWT is expressed best by Cp – λ curves. If the electrical equipment and mechanical equipment losses are omitted, the power coefficient of the MWT is given,

$$Cp= P_t/ P_w$$

$$=I.V/(1/2*(\rho*A*v^3))$$

Where,

I and V are the current (A) and voltage (V) obtained from the MWT.

Tip speed ratio (λ):

The value of the power co-efficient is a function of the linear speed (u) of the turbine blades at the end point and the wind speed (v).

$$Cp = f(u/v).$$

The u/v ratio is called the TSR and is symbolized by λ. The power co-efficient of the MWT reaches the maximum value. The TSR is defined by,

$$\lambda= u/v = (\omega_t*R)/v = (2\pi*n(rpm)*R)/60*v$$

where,

ω_t R- Linear speed of the MWT blade tip (m/s).
ω_t - Mechanical angular speed of the MWT blades (rad/s).
The mechanical angular speed depends on frequency f (Hz, 1/s).It is defined by,

$$f = \omega_t /2\pi.$$

$$\omega_t = 2\pi*n/60$$

ω_t as a function of the rotational speed of the MWT.
Where,
n- Rotational speed of the MWT (rev/min).

$$n = 60*f \text{ (rev/s).}$$

Depending on the number of poles of the PMSG, the rotation is given by

$$n = 60*f/2P$$

where,
2P- number of pole pairs of the PMSG.

Kinetic energy (E_{kin}):
The air density is constant in the MWT's environment, the air stream has kinetic energy depending on the wind speed. If there is a constant wind speed, the kinetic energy is given by,

$$E_{kin}=v^2/2$$

Where,
E kin is the kinetic energy of wind (J).

Mass flow amount of the air (m):
The mass flow amount of air passing through the MWT rotor per unit time must be known to determine the wind power under the influence of the MWT.
The mass flow amount of the air m (kg/s) is defined by,

$$m = \rho*A*v = \rho*\pi*R^2*v$$

Where,
A*v - Volumetric flow rate of air (m^3/s)
ρ - Air density (kg/m^3).
The maximum instantaneous power obtained from the wind is then defined as,

$$Pw = m*E_{kin}$$

Experiment 6 Experiment on Performance assessment of micro Wind Energy Generator

Exp.6.1

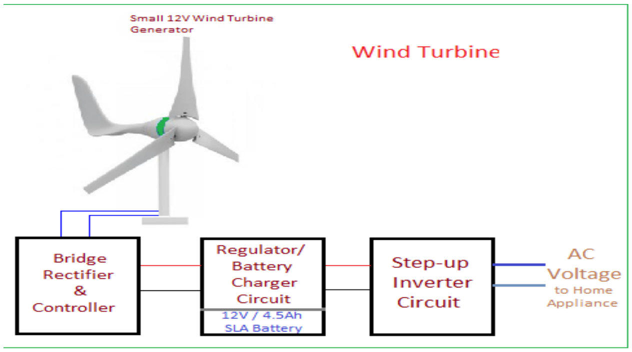
AIM

To Find the Performance Characteristics of Micro Wind Energy Generator and Plot the Power Curve - the relationship between the wind speed and the output power

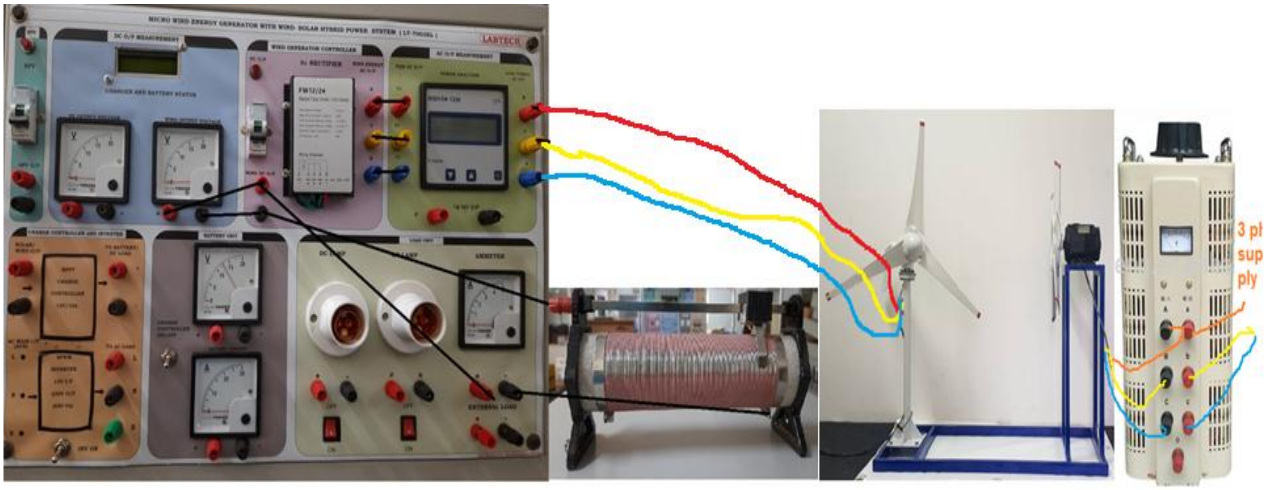
APPARATUS REQUIRED:

- LABTECH Wind energy training system
- LABTECH Wind Source and Wind Turbine generator
- Three phase supply with three phase autotransformer
- Connecting wires 15amps
- Single phase Loading Rheostat(100E/2.5A)
- Tachometer(non-contact type)
- Wind Anemometer

BLOCK DIAGRAM



CONNECTION DIAGRAM



PROCEDURE:

- Connect the circuit according to patching diagram.
- Connect the wind emulator Fan motor to the Three Phase auto Transformer RYB connections
- Connect R,Y,B,N output from the Wind turbine to Control Panel power analyzer and rectifier to observe the voltage/current/power generated output.
- Windmill output after rectifier to be connected to voltmeter and ammeter as per the connection diagram
- Connect the loading Rheostat 100E/2.5A to vary from 100W to 0W
- Switch on the mains supply. Then vary the speed of wind emulator motor through 3 phase auto transformer slowly from 0 to 30% (0r 0 to 50% from lower rating transformer)
- Measure the wind velocity of wind emulator with anemometer
- Measure speed of the Wind turbine with non-contact tachometer then calculate the wind turbine velocity with help of formula($v=2\pi 60 \cdot r \cdot N$, where : r = radius. N = number of revolutions per minute.
- Measure the voltage and current from the Power Meter for AC or DC voltmeter and ammeter for DC
- Tabulate the readings as below and draw the **POWER CURVE - Wind Speed Vs Wind Power**

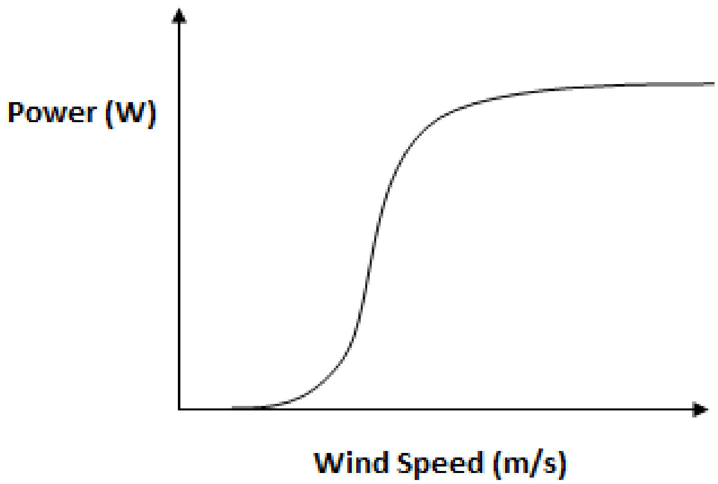
TABULATION:

Load resistance=100E/2.5A, (keep in 50% load)

Sl. No	Wind Turbine Rotor speed (RPM)	Wind speed V (m/s)	DC Output voltage(V)	Output current (I)	Output Power (W)
1	10	4.7	0	0	0
2	378	5	7.5	0.14	1.05
3	483	6	11	0.18	3.1
4	575	7.4	12	0.33	4.8
5	577	8	12	0.6	5.9
6	578	8.8	11	0.5	5.6
7	580	9.7	11	0.6	5.4
8	585	10.3	11	0.7	6.3
9	589	11.4	10	0.8	8
10	591	12.1	8.9	1.1	9.8

MODEL GRAPH:

POWER CURVE - Wind Speed Vs Wind Power



Result:

The relationship between the wind speed and the output power is plotted and the cut in speed is identified as 4.7m/s and Average Speed is 12.1m/s and the output power at the average speed is 9.1W for the given mechanical and electrical design.

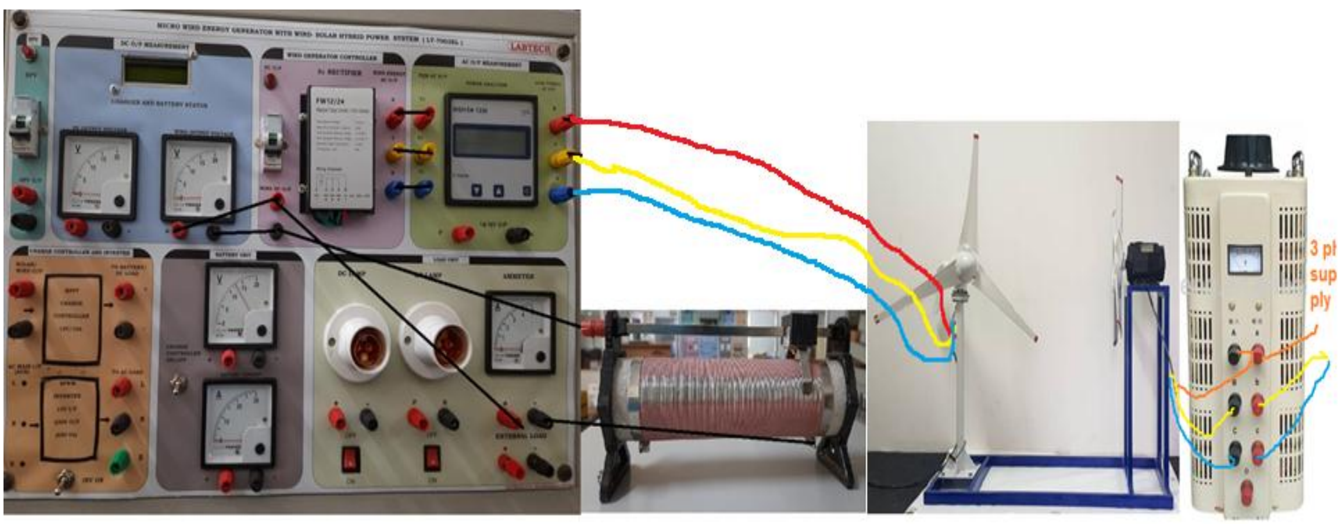
Exp.6.2

AIM : To Find the Performance Characteristics of Micro Wind Energy Generator and to study the relationship between the Tip Speed Ratio **(TSR)** and power coefficient **(Cp)** of the turbine at different wind speed and analysis of power performance using P_t and $P_{W.}$

APPARATUS REQUIRED:

- LABTECH Wind energy trainer system
- Wind Emulator and Wind Turbine generator
- Three phase supply with three phase autotransformer
- Connecting wires 15amps
- Load resistance (at least 100E/2.5A)
- Tachometer(non-contact type)
- Wind Anemometer

Patching Diagram:



PROCEDURE:

- Connect the circuit according to patching diagram.
- Connect the wind emulator Fan motor to the Three Phase auto Transformer RYB connections
- Connect R,Y,B,N output from the Wind turbine to Control Panel power analyzer and rectifier to observe the voltage/current/power generated output.
- Windmill output after rectifier to be connected to voltmeter and ammeter as per the connection diagram
- Connect the loading Rheostat 100E/2.5A to vary from 100W to 0W

- Switch on the mains supply. Then vary the speed of wind emulator motor through 3 phase auto transformer slowly from 0 to 30% (0r 0 to 50% from lower rating transformer)
- Measure the wind velocity of wind emulator with anemometer
- Measure speed of the Wind turbine with non-contact tachometer then calculate the wind turbine velocity with help of formula(v=2π60·r·N, where : r = radius. N = number of revolutions per minute.
- Measure the voltage and current from the Power Meter for AC or DC voltmeter and ammeter for DC
- Tabulate the readings as below and find the power coefficient and TSR and Pt and Pw

Formula:

$$\text{Blade Tip Speed} = \frac{(\text{Rotor Rotational Speed} * \pi * D)}{60}$$

$$\text{TSR} = \frac{\text{Speed of the tips of the turbine}}{\text{Wind Speed}}$$

$$\text{Power Coefficient } Cp = \frac{2P_t}{\rho A V^3}$$

Where,

P_t → Power from turbine, ρ → Air Density (1.23Kg/m^3)

A → Swept Area (A= πr^2) Where r – radius of blade

V → Wind Speed

<u>Model Calculation for 1st value from Tabulation:</u>

Power Coefficient Cp = $2P_t/\rho AV^3$.

P_t→ Power from turbine = 0 W

ρ → Air Density (1.23Kg/m^3)

A → Swept Area (A= πr^2) Where r – radius of blade = 0.62m

➔ A = 3.14*$(0.62)^2$ = 1.207

V → Wind Speed = 4.7 m/s

Cp = (2*0) / (1.23*1.207*$(4.7)^3$) = 0

Blade Tip Speed = (Rotor Rotational Speed *π*D) / 60 (Please refer the Equations section)

Rotor Rotational Speed = 10 rpm, D = 1.24.

D -> Diameter of the wind Turbine blade

Blade Tip Speed = (10* 3.14 * 1.24) / 60 = 0.64893

TSR = Blade Tip Speed / Wind Speed.

Blade Tip Speed = 0.64893

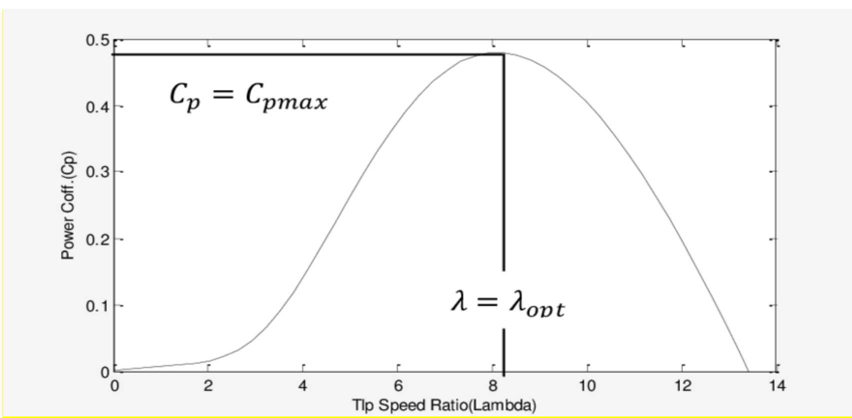
Wind Speed = 4.7 m/s.

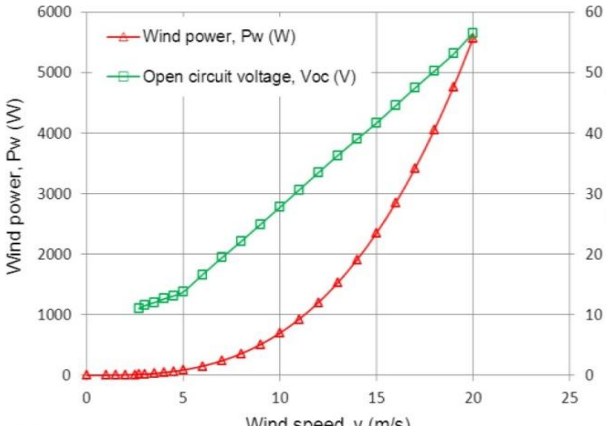
TSR (λ) = 0.64893/ 4.7 = 0.13807

Tabulation

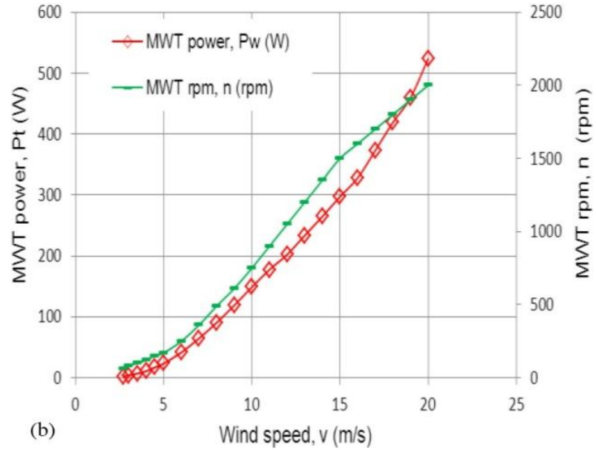
S. No	Turbine rotor speed (rpm)	Wind velocity V (m/s)	Power W P_t	Blade Tip Speed	Tip Speed Ratio (λ)	Power Coefficient (Cp)
1	10	4.7	0	**0.64893**	**0.13807**	**0**
2	378	5	1.05	**24.52968**	**4.90594**	**0.01751**
3	483	6	3.1	**31.34348**	**5.22391**	**0.02992**
4	575	7.4	4.8	**37.31367**	**5.04239**	**0.02469**
5	577	8	5.9	**37.44345**	**4.68043**	**0.02402**
6	578	8.8	5.6	**37.50835**	**4.26231**	**0.01713**
7	580	9.7	5.4	**37.63813**	**3.88022**	**0.01233**
8	585	10.3	6.3	**37.96260**	**3.68569**	**0.01202**
9	589	11.4	8	**38.22217**	**3.35282**	**0.01126**
10	591	12.1	9.8	**38.35196**	**3.16958**	**0.01153**

Model Graph

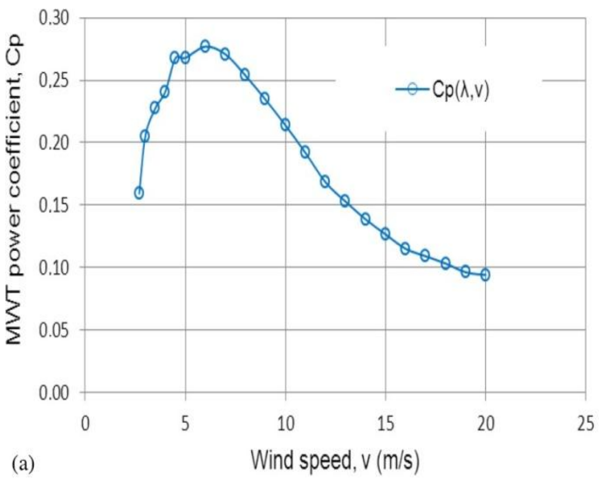




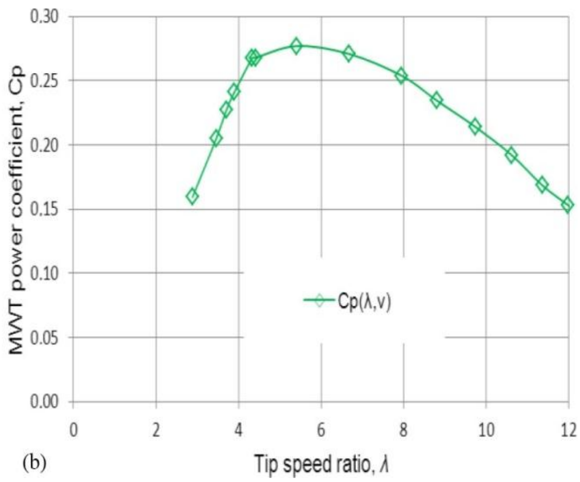
(a)



(b)



(a)



(b)

Instantaneous wind power (P_w):

The Instantaneous wind power (P_w) available to the wind turbine in the given wind speed in the swept area at the maximum wind speed of 12.1m/s is calculated as:

ρ=1.23kg/m³, A=1.207 as r=0.62m², Wind speed= v= 12.1m/s, Power=9.8W, Turbine rotor rotational Speed=591rpm.

P_w=1/2* (ρ *A*v^3) = 1/2*(1.23*1.207*(12.1)³) = 1315W

<u>RESULT:</u> Thus the performance assessment of micro wind generator was analyzed with Load Rheostat=100E/2.5A at 50% the maximum Power from the turbine P_t is 9.8W, the Tip Speed Ratio is 3.16, the Power coefficient is 0.01153 at maximum power output , The Instantaneous wind power (P_w) available to the Turbine is 1315W for the maximum wind speed of 12.1m/s.

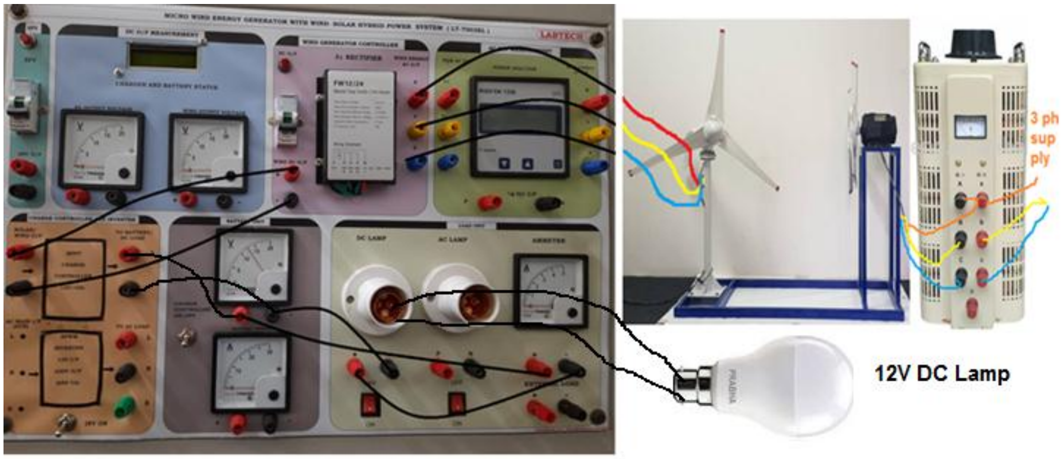
EXP: 6.3

AIM: Design of Wind Energy based Renewable Energy system with Charge controller and Battery for a DC load (12V DC Lamp)

APPARATUS REQUIRED:

- LABTECH Wind energy trainer system
- Wind Emulator and Wind Turbine generator
- Three phase supply with three phase autotransformer(Min 10A)
- Connecting wires 15amps
- 12V , 9W DC LED lamp load
- Tachometer(non-contact type)
- Wind Anemometer

Patching Diagram:



PROCEDURE:

- Connect the circuit according to patching diagram.
- Connect the wind emulator Fan motor to the Three Phase auto Transformer RYB connections
- Connect R,Y,B,N output from the Wind turbine to Control Panel power analyzer and rectifier to observe the voltage/current/power generated output.
- **Keep the wind Turbine at the Maximum Velocity of 12 m/s (find from the last experiment)**
- Switch on the mains supply. Then vary the speed of wind emulator motor through 3 phase auto transformer slowly from 0 to 30% and Keep the wind turbine speed at maximum speed of 500 RPM
- Connect the DC Lamp to the Charge controller and Battery and observe the charging and discharging currents

<u>Result :</u> Thus the wind Energy generator with DC load is connected and 12V DC lamp is discharging the battery of about 9W and the battery is charged simultaneously from the wind Turbine Power and increased and system is studied.

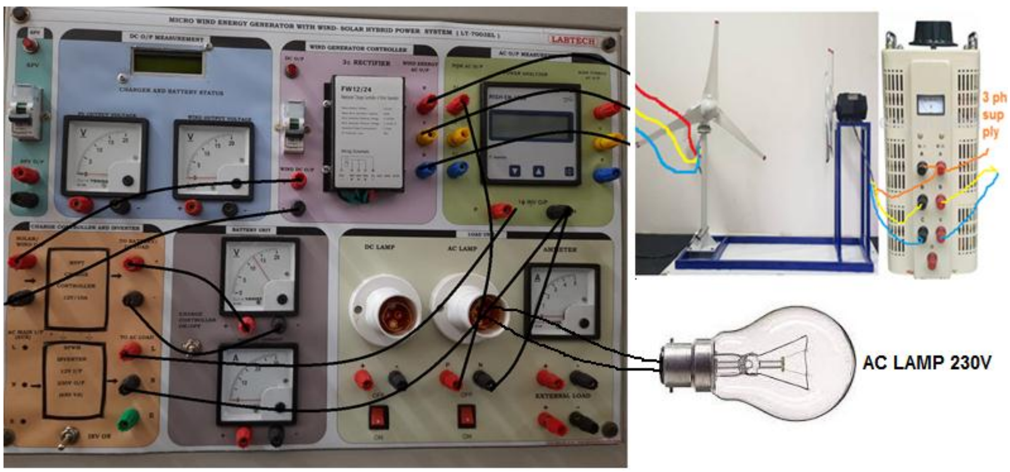
EXP: 6.4

AIM: Design of Wind Energy based Renewable Energy system with Charge controller, Battery and Single Phase Inverter for a Single Phase AC load (230V AC)

APPARATUS REQUIRED:

- ❖ LABTECH Wind energy trainer system
- ❖ Wind Emulator and Wind Turbine generator
- ❖ Three phase supply with three phase autotransformer(Min 10A)
- ❖ Connecting wires 15amps
- ❖ 230V , 100W AC lamp load
- ❖ Tachometer(non-contact type)
- ❖ Wind Anemometer

Patching Diagram:



PROCEDURE:

- Connect the circuit according to patching diagram.
- Connect the wind emulator Fan motor to the Three Phase auto Transformer RYB connections
- Connect R,Y,B,N output from the Wind turbine to Control Panel power analyzer and rectifier to observe the voltage/current/power generated output.
- **Keep the wind Turbine at the Maximum Velocity of 12 m/s (find from the last experiment)**
- Switch on the mains supply. Then vary the speed of wind emulator motor through 3 phase auto transformer slowly from 0 to 30% and Keep the wind turbine speed at maximum speed of 500 RPM
- Connect the DC Lamp to the Charge controller and Battery and observe the charging and discharging currents

<u>Result:</u> Thus the wind Energy generator with DC load is connected and 12V DC lamp is discharging the battery of about 9W and the battery is charged simultaneously from the wind Turbine Power and increased and system is studied.

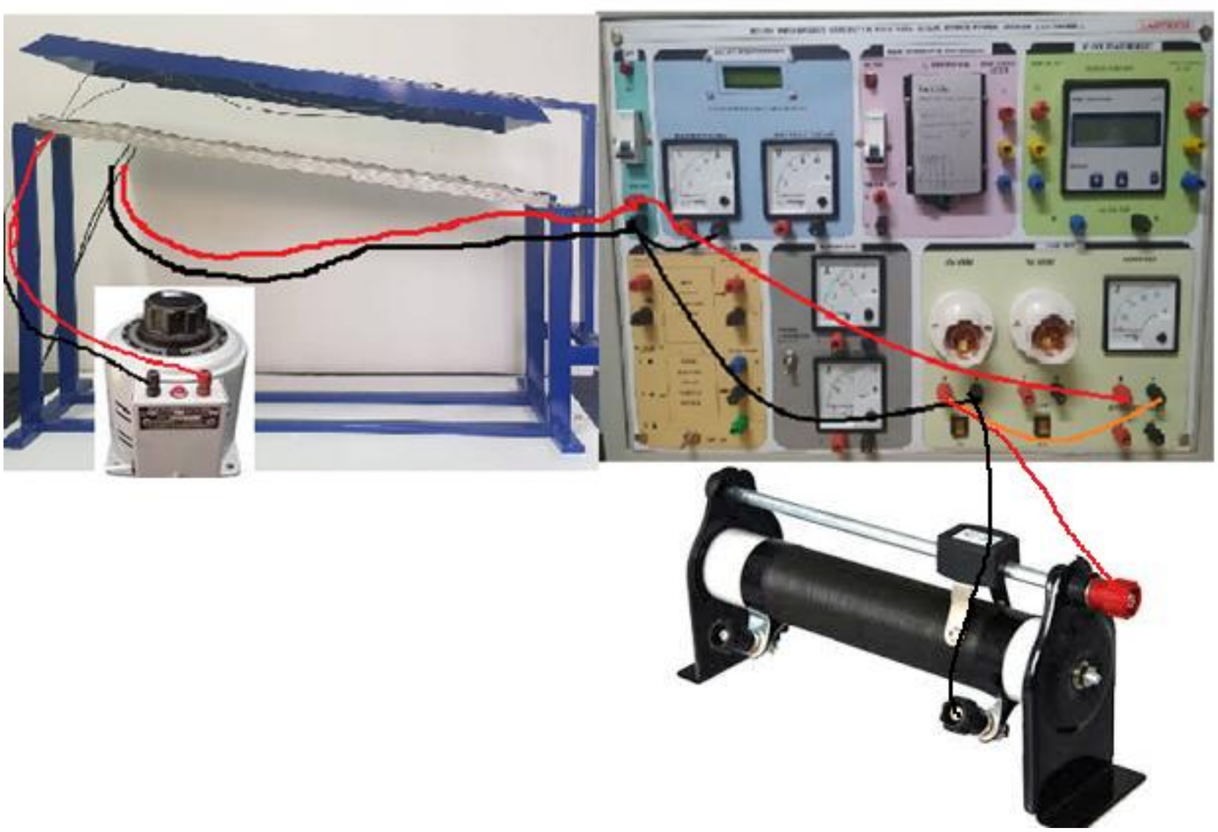
EXP: 6.5

AIM: To study the IV and PV characteristics of a 100W solar Panel, going to be used for Wind-solar Hybrid system design

APPARATUS REQUIRED:

- LABTECH Wind energy trainer system
- 100W solar Panel
- LABTECH Artificial Solar Emulator (Halogen Lamp setup 1000W)
- Single Phase Autotransformer minimum 4A
- Connecting wires 15amps
- 100E/2A Rheostat
- Tachometer(non-contact type)
- Wind Anemometer

Patching Diagram:



PROCEDURE:

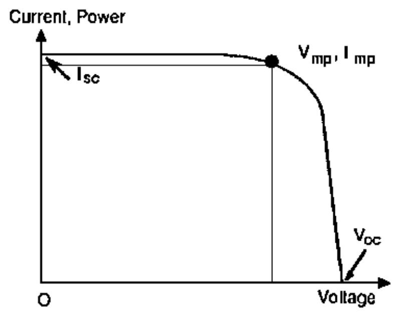
- Solar panel output has connected to SPV o/p of + & - respectively.
- Halogen lamp has connected to single phase auto transformer
- Patch the wire as mentioned in the diagram

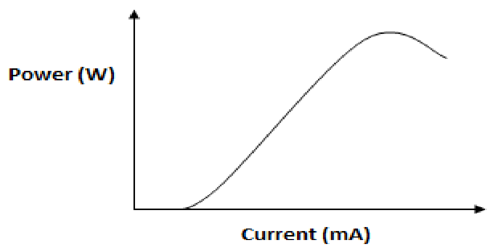
- Switch on the kit
- Switch on the solar panel MCB for output to kit
- Switch on the auto transformer
- Vary the auto transformer to get the power variation
- Keep the halogen lamp to the maximum power and now connect the load rheostat
- Connect the rheostat and vary from 50% to 0%
- Note down the voltage and current and tabulate

TABULATION

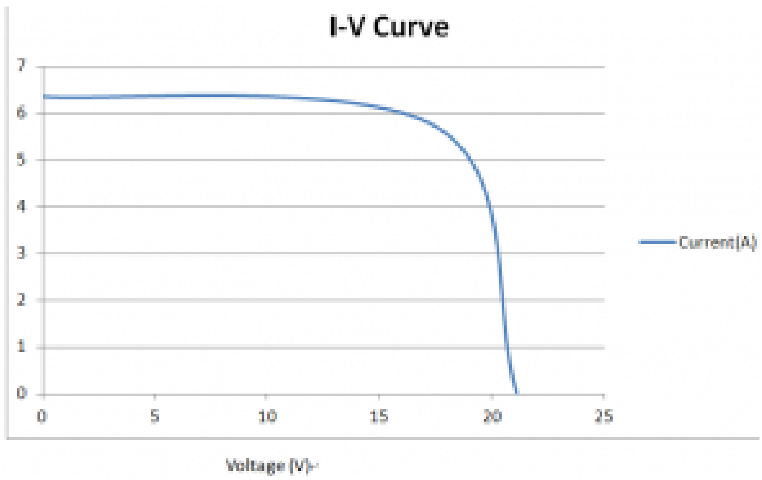
S.No	VOLTAGE(V)	CURRENT(A)
1	16	0.5
2	17	0.5
3	18	0.4
4	19	0.3
5	21	0.1

MODEL GRAPH: (for indoore Light setup)





MODEL GRAPH: (if it kept at outdoor sunlight)



<u>Result :</u> Thus the 100W solar Panel IV characteristics is studied and maximum voltage of 17V and Max Current of 500mA from Indoor Halogen Light, Max Voltage of 15V and Isc of 6.5A in the Outdoor Sunlight is observed. The IV and P_{max} of 97.5W is obtained.

Experiment 8 :

Experiment on Performance Assessment of Hybrid (Solar-Wind) Power System.

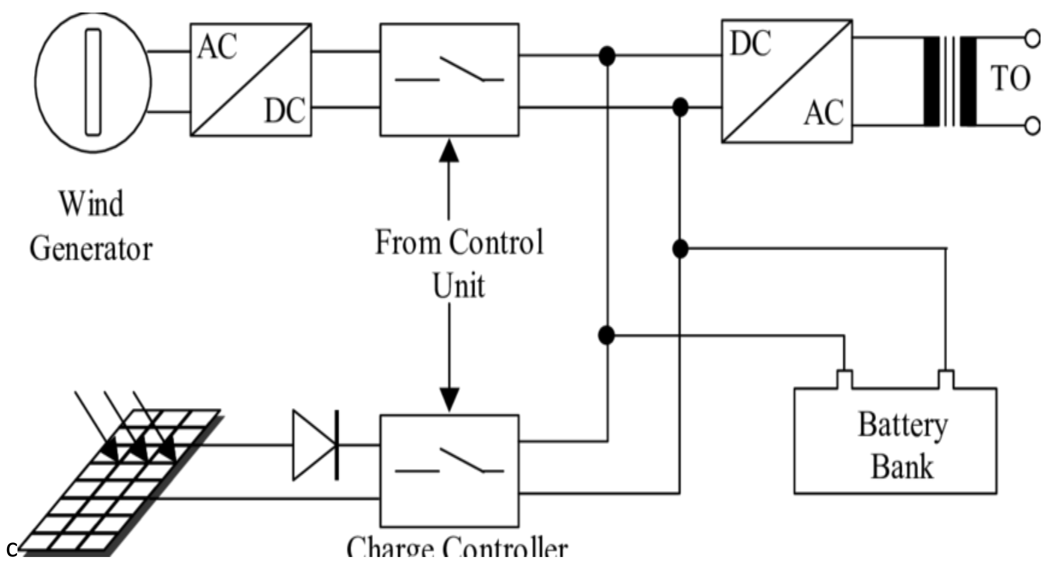
Exp 8.1

AIM: Conduct the Experiment to find the Performance Hybrid (Solar-Wind) Power System and to find the charging and discharging pattern of the Battery from the maximum current source (Solar/wind) for the given load with Help of the Hybrid MPPT charge Controller

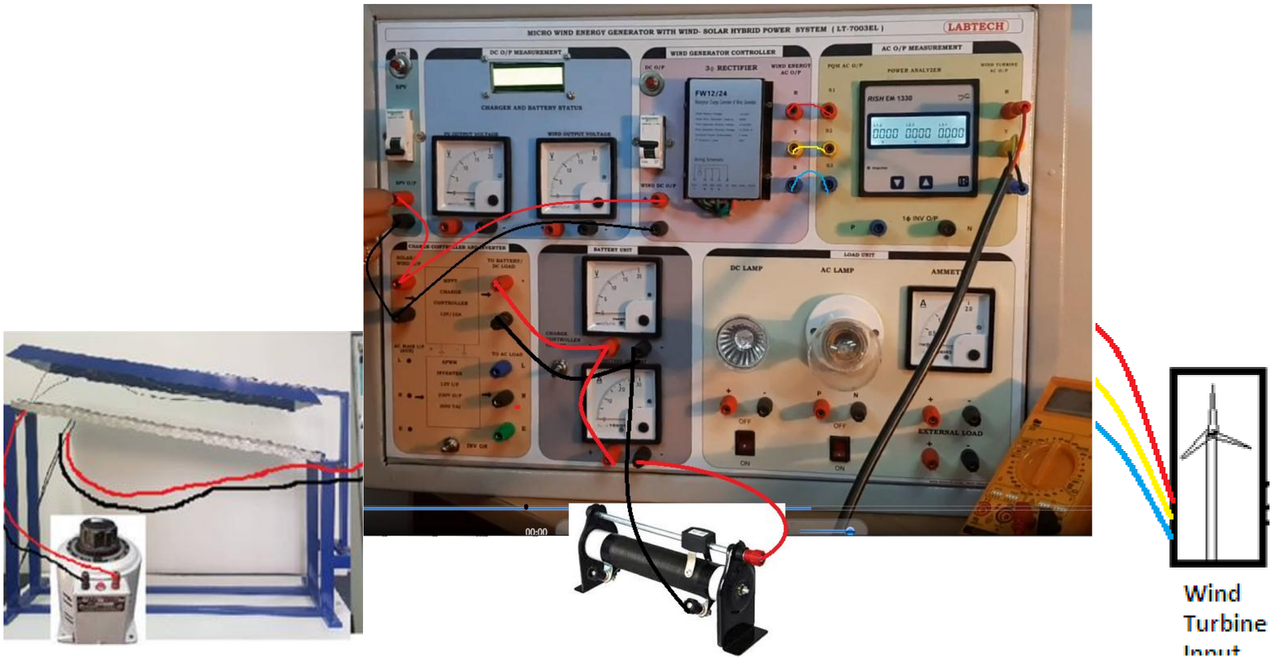
APPARATUS REQUIRED:

- LABTECH Hybrid energy trainer system
- single phase auto transformer
- three phase auto transformer
- Fan motor Artificial wind generator and Artificial solar energy generator setup
- Wind Turbine generator(200W)
- Solar panel(100W)
- Connecting wires 15amps
- Load Rheostat 100E/2A

System connection



Patching Diagram:



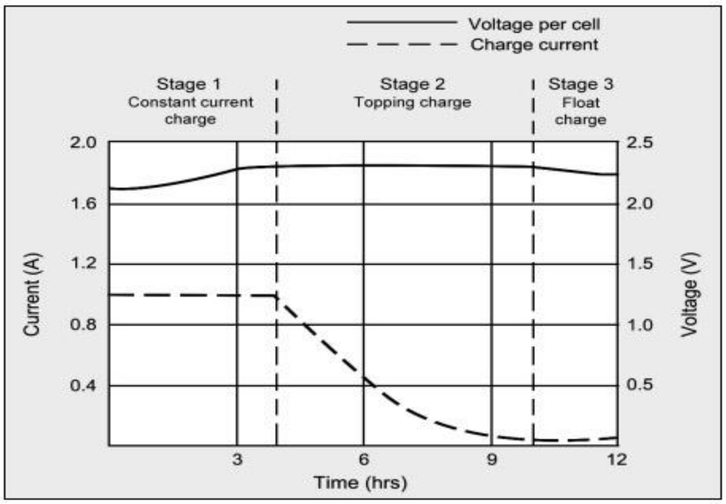
PROCEDURE:

- ❖ Solar panel output has connected to SPV o/p of + & - respectively.
- ❖ Halogen lamp has connected to single phase auto transformer
- ❖ Wind Emulator Fan motor connected to three phase auto transformer
- ❖ Wind Turbine generator has to be connected to trainer kit
- ❖ Patch the wire as mentioned in the diagram connect both sources parallel to MPPT charge controller and Switch on the trainer kit
- ❖ Switch on the solar panel MCB and wind generator MCB for output to kit
- ❖ Vary the single auto transformer to get the power variation by seeing the lamp load brightness
- ❖ Similarly vary the three phase auto transformer to vary the wind turbine speed from 0 to 25%
- ❖ Fix the wind and solar sources to the maximum output
- ❖ Vary the Rheostat from minimum to maximum 0 to 3A, after each reading wait for some time for charging the battery from the maximum source of wind or solar
- ❖ Take down the readings of voltage and current in the Battery section voltmeter and Ammeter
- ❖ Take down the reading of Battery Charging and discharging % from the MMPT LCD display

TABULATION

S.No	VOLTAGE(v)	CURRENT(A)	Battery %
1	12	0.5	45
2	12	1	45
3	12	2	38
4	11.8	3	36
5	11.5	3.2	35

MODEL GRAPH:

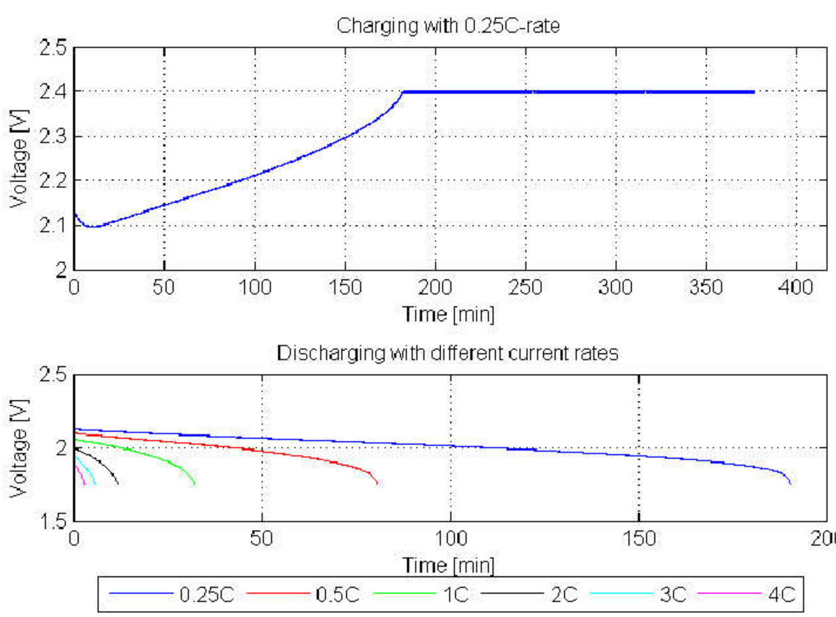


Stage 1: Voltage rises at constant current to V-peak.

Stage 2: Current drops; full charge is reached when current levels off

Stage 3: Voltage is lowered to float charge level

Discharging and charging pattern of the battery for the given load



<u>**Result:**</u> **The wind solar Hybrid System is studied and found the MPPT Charger is switching the Battery charging from the maximum power either from the wind or solar power source automatically in parallel to the discharging by the load and the charging and discharging current pattern is studied.**

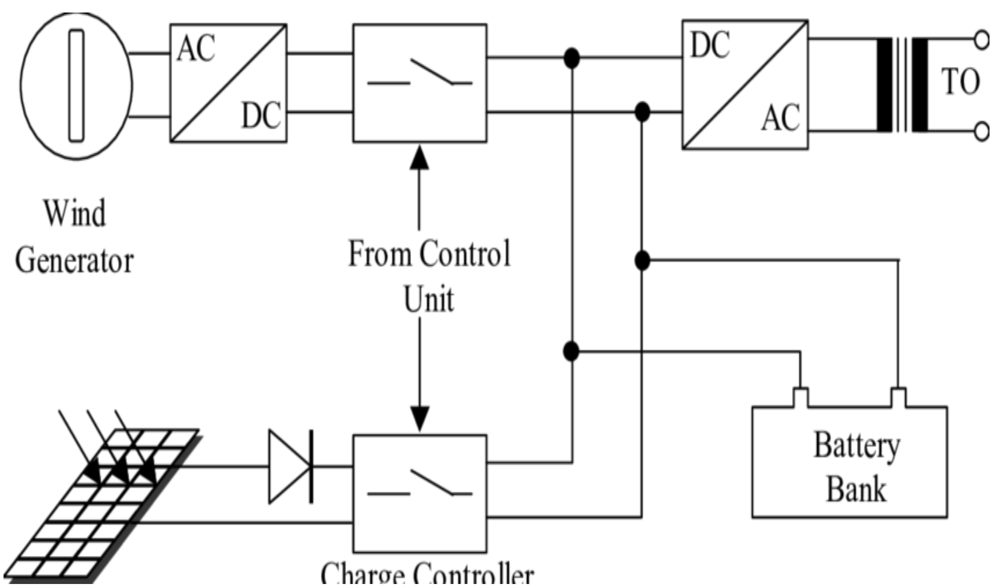
Exp 8.2

AIM: Design of a Hybrid (Solar-Wind) Power System with MPPT charge controller, Single Phase inverter for an AC and DC lamp loads and to study the Performance

APPARATUS REQUIRED:

- ❖ LABTECH Hybrid energy trainer system
- ❖ single phase auto transformer
- ❖ three phase auto transformer
- ❖ Fan motor Artificial wind generator and Artificial solar energy generator setup
- ❖ Wind Turbine generator(200W)
- ❖ Solar panel(100W)
- ❖ Connecting wires 15amps
- ❖ Load Rheostat 100E/2A

System connection



Patching diagram

PROCEDURE:

- ❖ Solar panel output has connected to SPV o/p of + & - respectively.
- ❖ Halogen lamp has connected to single phase auto transformer
- ❖ Wind Emulator Fan motor connected to three phase auto transformer
- ❖ Wind Turbine generator has to be connected to trainer kit
- ❖ Patch the wire as mentioned in the diagram connect both sources parallel to MPPT charge controller and Switch on the trainer kit
- ❖ Switch on the solar panel MCB and wind generator MCB for output to kit
- ❖ Vary the single auto transformer to get the power variation by seeing the lamp load brightness
- ❖ Similarly vary the three phase auto transformer to vary the wind turbine speed from 0 to 25%
- ❖ Fix the wind and solar sources to the maximum output
- ❖ Connect the Inverter output to the Power meter series via AC lamp load
- ❖ Then turn on the inverter switch on .After that we can see at ac load the bulb is glowing.
- ❖ Take down the readings of voltage and current in the Battery section voltmeter and Ammeter and AC voltage and current in the Power meter.
- ❖ Take down the reading of Battery Charging and discharging % from the MMPT LCD display

TABULATION

POWER(w)	VOLTAGE(v)	CURRENT(A)
100	230 AC	0.4
50	12 DC	4

<u>**Result:**</u> **The Wind-Solar hybrid power system is connected to the AC load using MPPT charge controller and with Help of the single phase inverter. The output voltage and current are found 230V AC 0.4A for the given load of AC 100W/230V Lamp, and 12V 4A for the DC lamp.**

PART III

Experiment on Performance Assessment of 100W Fuel Cell

EXPERIMENT NO: 10 (Fuel Cell System Experiments)

EXPERIMENT: 10.1

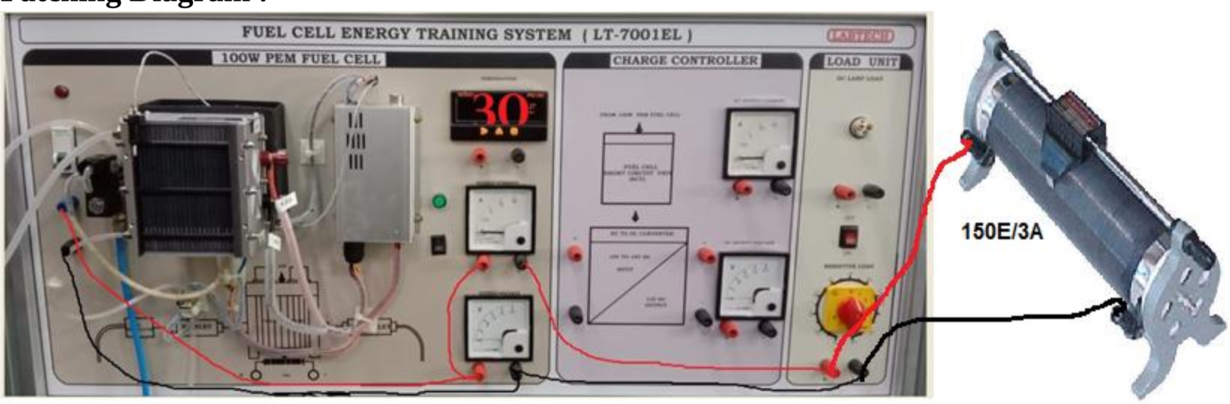
AIM:

To study the performance assessment of Fuel Cell generator directly from load characteristics .

APPARATUS REQUIRED:

- Fuel Cell Trainer
- Variable resistive load
- Patch Cards
- Hydrogen Cylinder with Air Regulator

Patching Diagram :



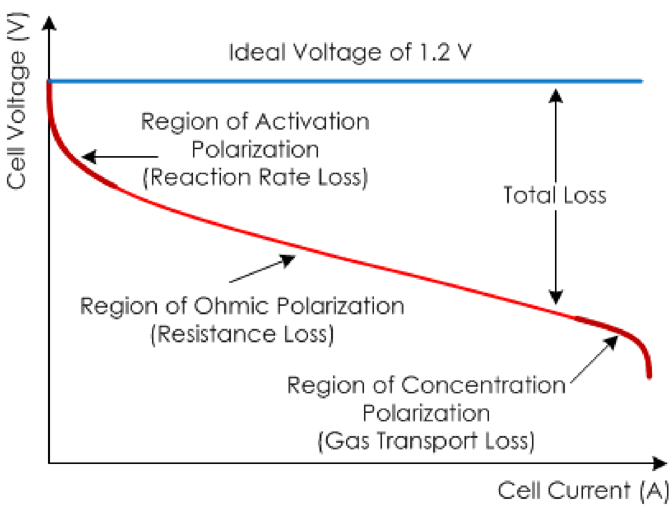
Procedure :

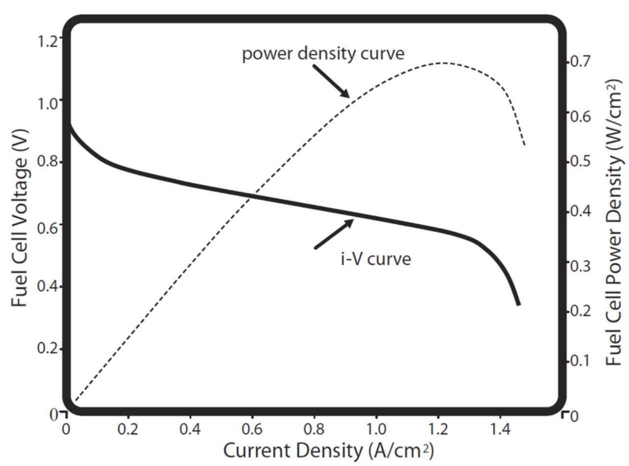
- Connect the patching wires as mentioned in the picture
- Connect the tube to hydrogen cylinder
- Power on the panel on backside connection provision given
- Switch on the charge controller block.
- A green push button for on/off the fuel cell by long press for 5 sec
  NOTE: **BEFORE OFF THE FUEL CELL MAKE SURE THAT CYLIDER VALVE IS CLOSED FULLY AND THERE IS NO PRESSURE INDICATION IN THE GUAGE IN CYLINDER**
- Open the cylinder by small pressure with using key
- Then open the output air regulator knob to give the pressure to fuel cell of constant 0.45 bar
- Then switch on the MCB for the fuel cell output
- Note the temperature
- Note down the voltage and current
- After finish the experiment first close the cylinder valve using key
- The gas in the hose has to be used by fuel cell even after close the valve
- When there is no gas in the hose fuel cell give beep sound then you have to close the air regulator knob
- Finally long press the green push button for switch off the cell

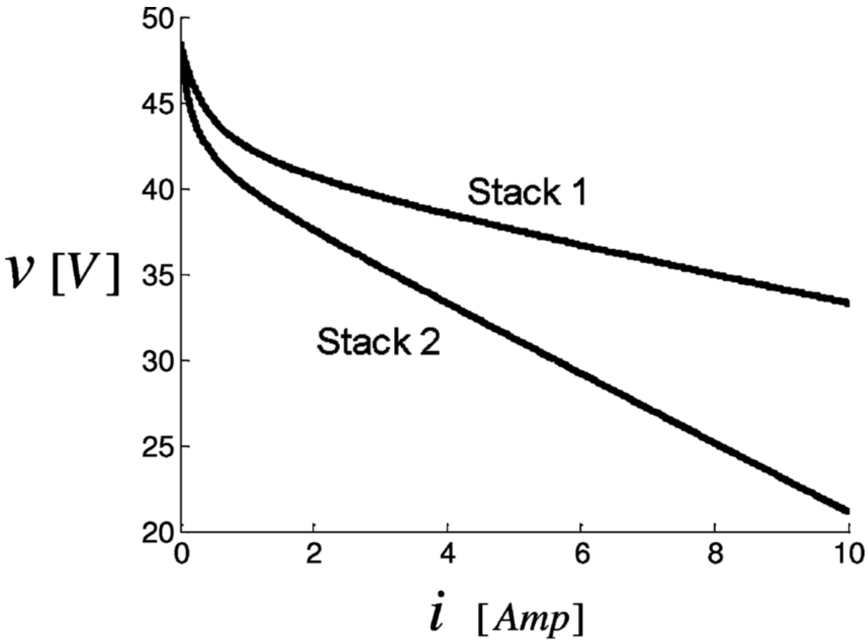
Tabulation :

Pressure = 0.45bar. **Temperature = ____________**

S. No	Voltage (v)	Current (I)
1	18	1.5
2	17	2
3	16	2.5
4	16	4
5	16	4.5
6	15	5
7	15	6
8	14.5	6

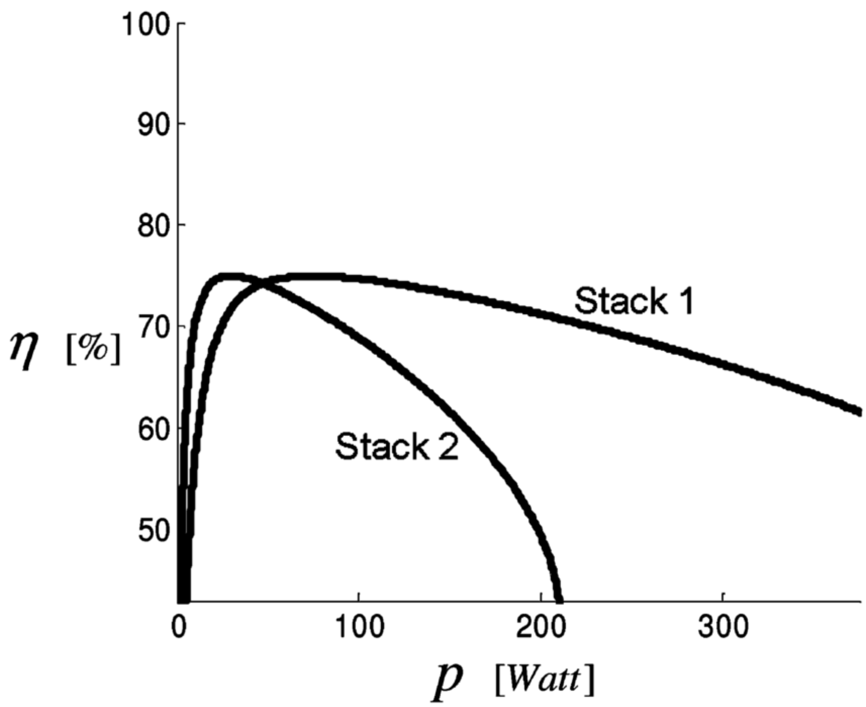






50
45
40
35
30
25
20
v [V]
Stack 1
Stack 2
0
2
4
6
8
10
i [Amp]

(a)



100
90
80
70
60
50
η [%]
Stack 1
Stack 2
0
100
200
300
p [Watt]

(b)

EXPERIMENT 10.2

Study the performance assessment of Fuel Cell generator with charge controller and Battery

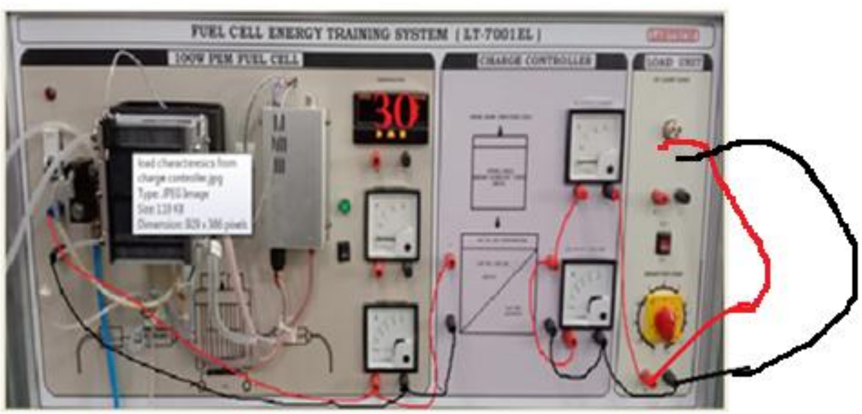
AIM:

To Study the Working of Fuel Cell with Charge Controller.

APPARATUS REQUIRED:

- FuelCell training system.
- Patch Chords.
- Hydrogen Cylinder with Air Regulator

Patching Diagram:



Procedure :

- Connect the patching wires as mentioned in the picture
- Connect the DC Bulb load to the charge controller output of 12V
- Connect the tube to hydrogen cylinder
- Power on the panel on backside connection provision given
- Switch on the charge controller provision on backside
- A green push button for on/off the fuel cell by long press for 5 sec
  NOTE: **BEFORE OFF THE FUEL CELL MAKE SURE THAT CYLIDER VALVE IS CLOSED FULLY AND THERE IS NO PRESSURE INDICATION IN THE GUAGE IN CYLINDER**
- Open the cylinder by small pressure with using key
- Then open the output air regulator knob to give the pressure to fuel cell of constant 0.45 bar
- Then switch on the MCB for the fuel cell output
- Note the temperature

- Note down the voltage and current based on the load current of the traffic light
- After finish the experiment first close the cylinder valve using key
- The gas in the hose has to be used by fuel cell even after close the valve
- When there is no gas in the hose fuel cell give beep sound then you have to close the air regulator knob
- Finally long press the green push button for switch off the cell

Tabulation :

Pressure = 0.45bar. **Temperature = ____________**

TABULATION

POWER(w)	VOLTAGE(v)	CURRENT(A)
	12	

RESULT:

The performance of the 100W PEM Fuelcell with charge controller and battery for DC lamp load is studied

EXPERIMENT 10.3

Power Performance Analysis of Fuel Cell :

Fuel cells are a promising alternative energy conversion technology. Most fuel cells use hydrogen as a fuel which reacts with oxygen to produce electricity. Different types of fuel cells are distinguished by the nature of the electrolyte. For example, a proton exchange membrane fuel cell (PEMFC) contains a polymer electrolyte that transports protons as shown in Figure 1.

The PEMFC reactions are: Anode: $H_2 \rightarrow 2H^+ + 2e^-$

Cathode: $\frac{1}{2} O_2 + 2H^+ + 2e^- \rightarrow H_2O$

Overall: $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

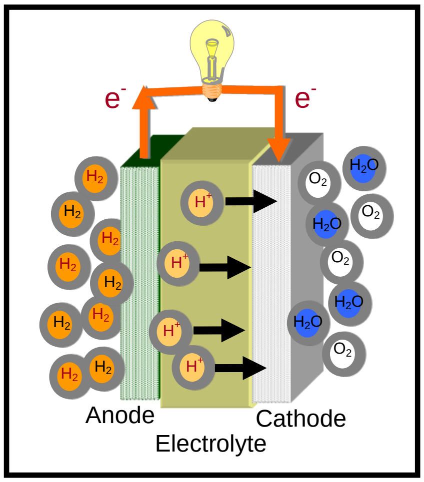


Figure 1. Reactions with PEMFC

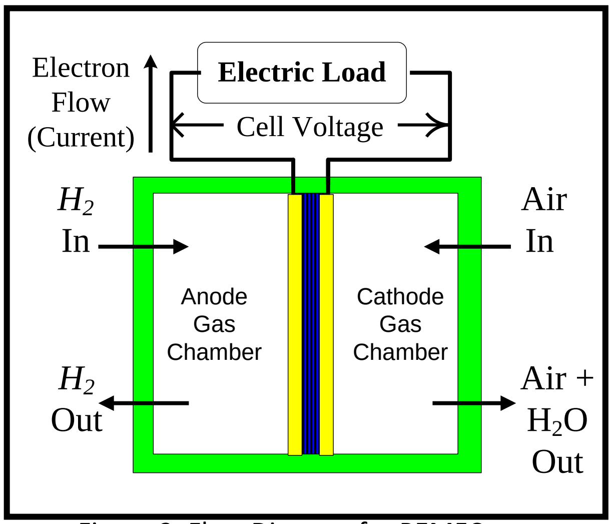


Figure 2. Flow Diagram for PEMFC

For each mole of hydrogen consumed, two moles of electrons are passed through the electric load. Faraday's constant is commonly used to relate number of electrons and charge ($F = 96{,}485$ coulombs/mole of electrons). The objective of a fuel cell is to deliver power to the load:

$$P = E \cdot I$$

$$\text{Power} = \text{Voltage} \cdot \text{Current}$$

$$watt = \frac{joule}{s} = volt \cdot \frac{coulomb}{s}$$

Clearly the voltage of a fuel cell directly affects power output. The maximum voltage, E, of a fuel cell is calculated with Gibbs Free Energy.

$$E = -\frac{\Delta G}{nF}$$

Here n is the moles of electrons released for every mole of hydrogen reacted (2 mol e^-/ 1 mol H_2).

One of the major advantages of fuel cell technology is the potential for very high efficiencies. In this module, we will calculate Gibbs free energy with heat capacity integrals, show how Gibbs free energy can be used to calculate the maximum efficiency of a fuel cell, and investigate how maximum efficiency is affected by fuel cell operating temperature.

Problem Information

The Gibbs free energy of reaction, ΔG°_{rxn}, at standard pressure and fuel cell operating temperature can be calculated as follows.

$$\Delta G^{\circ}{}_{rxn,T} = \Delta H^{\circ}{}_{rxn,T} - T \cdot \Delta S^{\circ}{}_{rxn,T}$$

The stoichiometry of the reaction must be taken into account when calculating enthalpy and entropy of formation.

$$H_2 + \tfrac{1}{2} O_2 \rightarrow H_2O$$

$$\Delta H^{\circ}{}_{rxn,T} = \Delta H^{\circ}{}_{f\ H_2O,T} - \Delta H^{\circ}{}_{f\ H_2,T} - \frac{1}{2}\Delta H^{\circ}{}_{f\ O_2,T}$$

$$\Delta S^{\circ}{}_{rxn,T} = \Delta S^{\circ}{}_{f\ H_2O,T} - \Delta S^{\circ}{}_{f\ H_2,T} - \frac{1}{2}\Delta S^{\circ}{}_{f\ O_2,T}$$

The enthalpy and entropy at standard pressure and temperature, 1 atm and 298K, can easily be found in thermodynamic tables; however, heat capacities are often used to determine enthalpy and entropy at other temperatures.

$$\Delta H^\circ{}_{f\,T} = \Delta H^\circ{}_{f\,298} + \int_{298}^{T} C_p dT \qquad \text{Smith, Van Ness, Abbott: Eqn 4.2}$$

$$\Delta S^\circ{}_{f\,T} = \Delta S^\circ{}_{f\,298} + \int_{298}^{T} \frac{C_p}{T} dT \qquad \text{Smith, Van Ness, Abbott: Eqn 5.14}$$

Heat capacity is a function of temperature and is typically calculated with an empirical expression. For ideal gases:

$$\frac{C_p}{R} = \mathrm{A} + \mathrm{BT} + \mathrm{CT}^2 + \mathrm{DT}^{-2} \qquad \text{Appendix C Smith, Van Ness, Abbott}$$

For liquids:

$$\frac{C_p}{R} = \mathrm{A} + \mathrm{BT} + \mathrm{CT}^2 \qquad \text{Appendix C Smith, Van Ness, Abbott}$$

The maximum efficiency limit of a fuel cell, often referred to as the thermodynamic efficiency, is calculated as follows.

$$\text{Maximum Efficiency} = \eta_{\max} = \frac{\Delta G^\circ{}_{rxn,T}}{\Delta H^\circ{}_{rxn,298}} \times 100$$

The Gibbs Free Energy of reaction is calculated at the operating temperature of a fuel cell since this is the temperature the reaction takes place. However, the enthalpy of reaction is typically calculated at standard temperature, 298 K, and for water in the liquid phase. This allows us to take into account recoverable heat from cooling the water product to 298 K and condensing the water.

At 298k constant Enthalpy, Entropy Ranges are mentioned below,

Note : R(Gas Constant) = 8.314 J/(mol.K)

Chemical Species	**State**	**$\Delta H^o_{f,\,298}$ / J mol^{-1}**	**$\Delta G^o_{f,\,298}$ / J mol^{-1}**
H_2	Gas	0	0
O_2	Gas	0	0

H_2O	Liquid	-285830	-237129

From Table C.1 and C.3 of Smith, Van Ness, and Abbott

Chemical Species	State	A	10^3 B	10^6 C	10^{-5} D
H_2	Gas	3.249	0.422	0	0.083
O_2	Gas	3.639	0.506	0	-0.227
H_2O	Liquid	8.712	1.25	-0.18	

Measured temp :30 deg C i.e 298K

Part a)

Step 1) First, we should calculate the $\Delta S^o_{f,\,298}$ of liquid water. The $\Delta S^o_{f,\,298}$ of H_2 and O_2 is referenced as zero since they are elemental.

$$\Delta G^\circ{}_{f\ H_2O,298} = \Delta H^\circ{}_{f\ H_2O,298} - T \cdot \Delta S^\circ{}_{f\ H_2O,298}$$

Rearranging,

$$\Delta S^\circ{}_{f\ H_2O,298} = -\left(\frac{\Delta G^\circ{}_{f\ H_2O,298} - \Delta H^\circ{}_{f\ H_2O,298}}{T}\right)$$

$$= -\left(\frac{\left(-237129\frac{J}{mol}\right) - \left(-285830\frac{J}{mol}\right)}{298K}\right)$$

$$= -163.43\frac{J}{mol \cdot K}$$

Step 2) The enthalpy of formation should calculated for PEMFC operation at 30ºC.

$$\Delta H^\circ{}_{f\,H_2O,303} = \Delta H^\circ{}_{f\,H_2O,298} + \int_{298}^{303} C_p\,dT$$

$$= \Delta H^\circ{}_{f\,H_2O,298} + R\int_{298}^{303} (A + BT + CT^2 + DT^{-2})\,dT$$

$$= \Delta H^\circ{}_{f\,H_2O,298} + R\left[AT + \frac{B}{2}T^2 + \frac{C}{3}T^3 - \frac{D}{T} \right]_{298}^{303}$$

$$= -285830\,\frac{J}{mol} + 8.314\,\frac{J}{mol\cdot K}\left[\begin{array}{c} 8.712\cdot(303-298) + \dfrac{1.25x10^{-3}}{2}\cdot\left(303^2 - 298^2\right) \\ + \dfrac{-0.18x10^{-6}}{3}\cdot\left(303^3 - 298^3\right) + 0 \end{array}\right]K$$

$$= -285830\,\frac{J}{mol} + 377\,\frac{J}{mol} = -285453\,\frac{J}{mol}$$

From similar calculations for H_2 and O_2 we get

$$\Delta H^\circ{}_{f\,H_2,303} = 144\,\frac{J}{mol}$$

$$\Delta H^\circ{}_{f\,O_2,303} = 147\,\frac{J}{mol}$$

Step 3) The entropy of formation should calculated for PEMFC operation at 30ºC.

$$\Delta S^\circ{}_{f\ H_2O,303} = \Delta S^\circ{}_{f\ H_2O,298} + \int_{298}^{303} \frac{C_p}{T}\, dT$$

$$= \Delta S^\circ{}_{f\ H_2O,298} + R\int_{298}^{303}\left(\frac{A}{T} + B + CT + DT^{-3}\right)dT$$

$$= \Delta S^\circ{}_{f\ H_2O,298} + R\left[A\ln(T) + BT + \frac{C}{2}T^2 - \frac{D}{2}T^{-2}\right]_{298}^{303}$$

$$= -163.43\frac{J}{mol} + 8.314\frac{J}{mol\cdot K}\left[\begin{array}{c} 8.712\cdot(\ln(303)-\ln(298)) + 1.25x10^{-3}\cdot(303-298) + \\ \frac{-0.18x10^{-6}}{2}\cdot\left(303^2 - 298^2\right) + 0 \end{array}\right]$$

$$= -163.43\frac{J}{mol\cdot K} + 1.25\frac{J}{mol\cdot K} = -162.18\frac{J}{mol\cdot K}$$

From similar calculations for H_2 and O_2 we get

$$\Delta S^\circ{}_{f\ H_2,303} = 0.48\frac{J}{mol\cdot K}$$

$$\Delta S^\circ{}_{f\ O_2,303} = 0.49\frac{J}{mol\cdot K}$$

The following table summarizes the calculated enthalpies and entropies at 303K.

Chemical Species	**State**	**$\Delta H^o_{f,\ 303}$ / J mol^{-1}**	**$\Delta S^o_{f,\ 303}$ / J mol^{-1}**
H_2	Gas	144	0.48
O_2	Gas	147	0.49
H_2O	Liquid	-285453	-162.18

Step 4) We can now calculate $\Delta H^o_{rxn,303K}$, $\Delta S^o_{rxn,303K}$, and $\Delta G^o_{rxn,303K}$.

$$\Delta H^\circ_{rxn,303} = H^\circ_{H_2O,303} - H^\circ_{H_2,303} - \frac{1}{2}H^\circ_{O_2,303}$$

$$= -285453\frac{J}{mol} - 144\frac{J}{mol} - \frac{1}{2}\left(147\frac{J}{mol}\right)$$

$$= -285671\frac{J}{mol}$$

$$\Delta S^\circ_{rxn,303} = S^\circ_{H_2O,303} - S^\circ_{H_2,303} - \frac{1}{2}S^\circ_{O_2,303}$$

$$= -162.18\frac{J}{mol\cdot K} - 0.48\frac{J}{mol\cdot K} - \frac{1}{2}\left(0.49\frac{J}{mol\cdot K}\right)$$

$$= -162.91\frac{J}{mol\cdot K}$$

$$\Delta G^\circ_{rxn,303} = \Delta H^\circ_{rxn,303} - T\cdot\Delta S^\circ_{rxn,303}$$

$$= -285671\frac{J}{mol} - 303K\cdot -162.91\frac{J}{mol\cdot K}$$

$$= -236309\frac{J}{mol}$$

Step 5) We can now calculate the maximum possible efficiency of a PEMFC operating at 30ºC.

$$\text{Maximum Efficiency} = \eta_{\max} = \frac{\Delta G^\circ_{rxn,303}}{\Delta H^\circ_{rxn,298}}\times 100$$

$$= \frac{-236309\frac{J}{mol}}{-285830\frac{J}{mol}}\times 100 = 82.7\%$$

RESULT:

The electrochemical efficiency of the fuel cell from load at operating Temperature can be calculated.

PART IV

Experiment Solar PV Emulator

Experiment 5.1.1: Fixed Mode with Irradiance and Temperature.

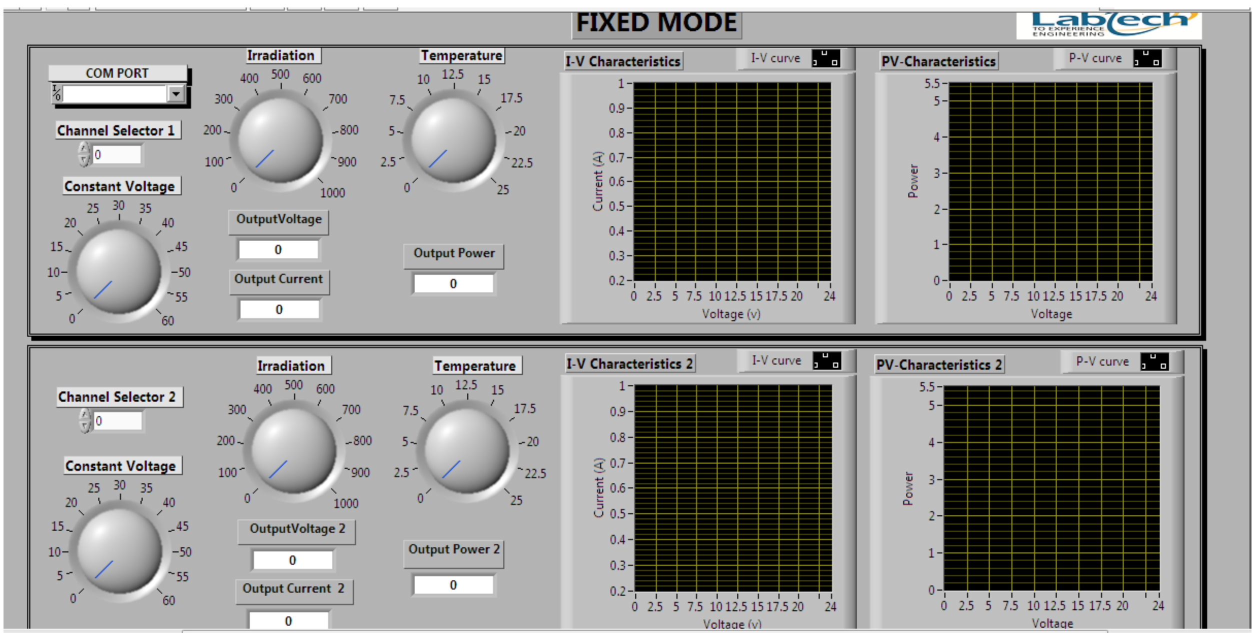
AIM:

To measure the voltage (60v) and current(10A) in Fixed mode with Irradiance and Temperature.

APPARATUS REQUIRED

- Pv emulator trainer
- (0-60)v voltmeter -2 nos
- (0-10)A Ammeter-2 nos
- System(PC)
- Power chord
- Patch chord

FRONT PANEL

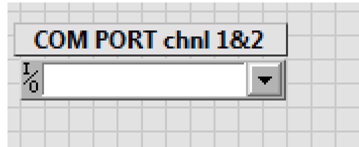


Select communication ports using COM PORT channel 1&2.

Note:- Take Meter Reading in Front Panel Separately for Voltage and Current as both are obtained from same point else it may get short and burst.

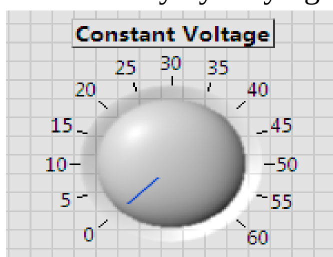
PROCEDURE

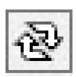
- **Open** S/W program by double clicking the exe file .
- Connect the trainer to AC mains.
- Connect the USB cable from PV Emulator interface to PC Com port.
- Switch ON the MCB.

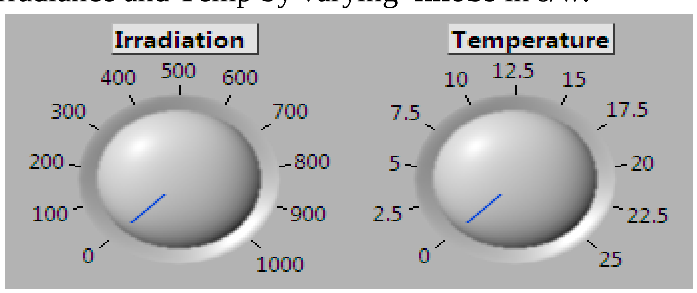


- Select the com port from drop down menu
- Select the channel in which the voltage, Irradiation and Temperature are connected.

  - Use Channel selector to select the 2 different channels.
  - Enter Channel Selector 1 → **1,** to select chnl 1 to operate in fixed mode.
  - Enter Channel Selector 2 → **2,** to select chnl 2 to operate in fixed mode.
- Set Constant Voltage to any particular value initially by varying Knobs in s/w.



- Click run continuous .
- Vary the Channels 1&2 Irradiance and Temp by varying **knobs** in s/w.



- Note down the Set Voltage, Power and Meter Readings
- Verify the output voltage at the Front Panel of Trainer kit.
- After Competing Stop the Program by click Abort Execution 

RESULT:

Thus in Fixed Mode Power, Voltage and Current was determined.

Note: - Select all the required channels before clicking on run button. To add a new channel stop executing the program select the required channel and click on run continuously again.

Experiment 5.1.2: Fixed Mode

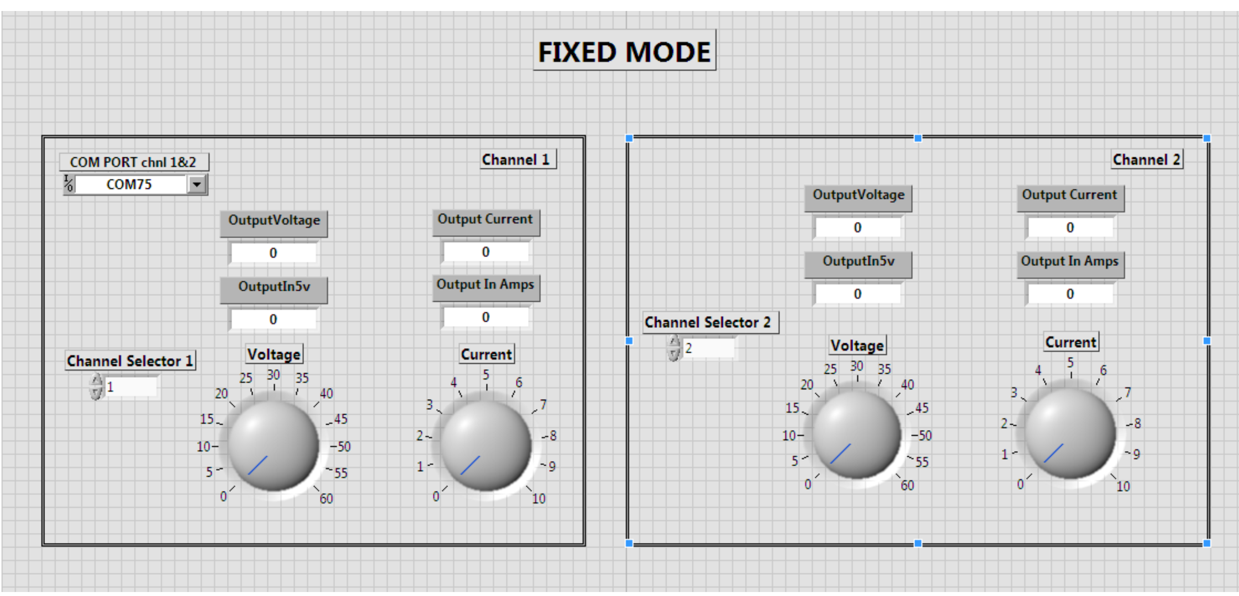
AIM:

To measure the voltage(60v) and current(10A) in Fixed mode.

APPARATUS REQUIRED

- Pv emulator trainer
- (0-60)v voltmeter -2 nos
- (0-10)A Ammeter-2 nos
- System(PC)
- Power chord
- Patch chord

FRONT PANEL

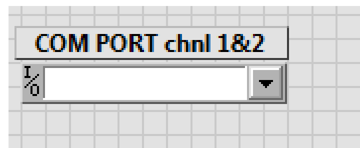


Select communication ports using COM PORT channel 1&2.

Each board has 4 outputs. Therefore a 4 channel system (Each channel requires 2 inputs voltage and current to be given as input to SMPS) can be done by a board.

PROCEDURE

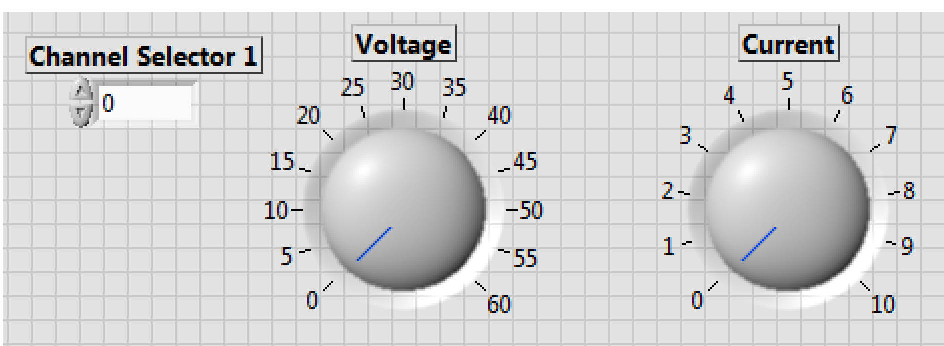
- ❖ **Open** s/w program by double clicking the exe file .
- ❖ Connect the trainer to AC mains.
- ❖ Connect the USB cable from PV Emulator interface to PC Com port.
- ❖ Switch ON the MCB.



- ❖ Select the com port from drop down menu
- ❖ Select the channel from drop down menu.

- Use Channel selector to select the 2 different channels.
- Enter Channel Selector 1 → **1,** to select chnl 1 to operate in fixed mode.
- Enter Channel Selector 2 → **2,** to select chnl 2 to operate in fixed mode.

- ❖ Click run continuous .
- ❖ Vary the Channels 1&2's voltage and current by varying **knobs** in s/w.



- ❖ Note down the Set Voltage and Meter Readings
- ❖ After Competing Stop the Program by click Abort Execution

RESULT:

Thus the open circuit voltage and current was determined.

Note: - Select all the required channels before clicking on run button. To add a new channel stop executing the program select the required channel and click on run continuously again.

Experiment 5.1.3: Table Mode

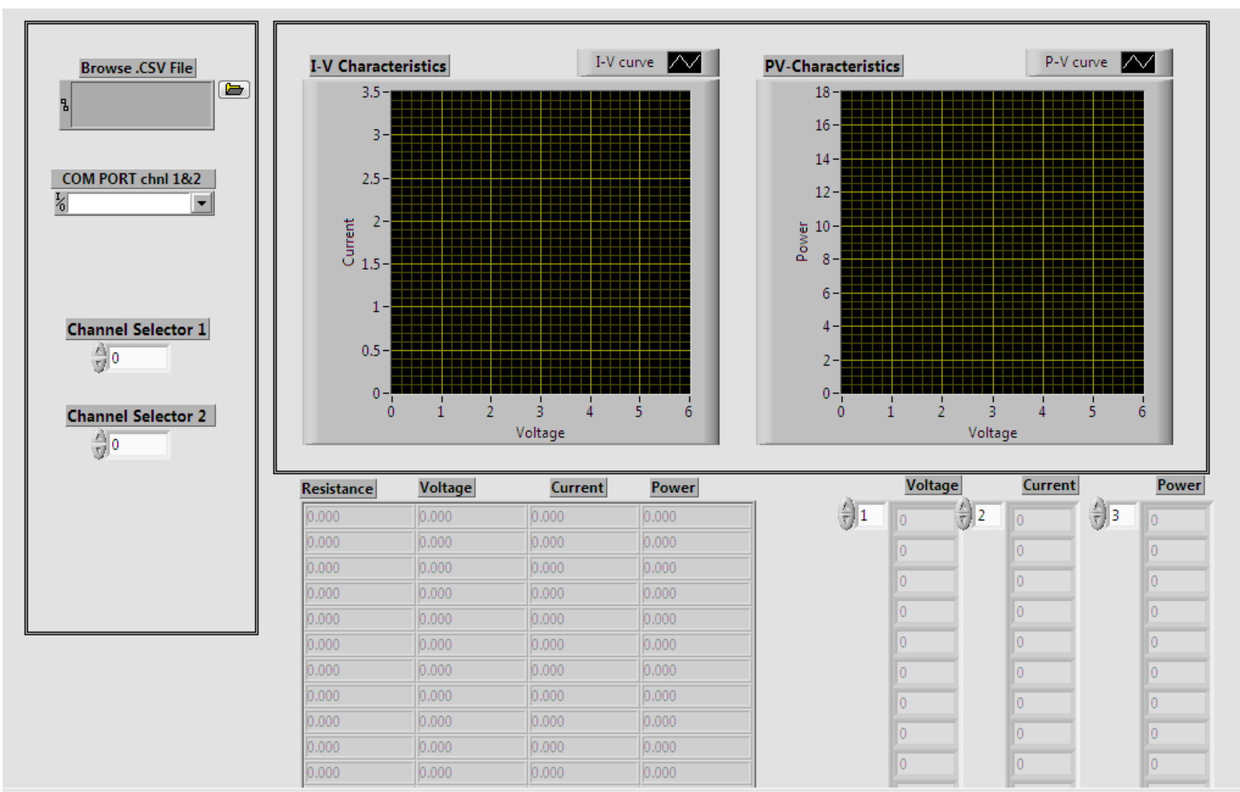
AIM

Table mode lets you browse a stored exe file and the output of the simulated data can be viewed.

APPARATUS REQUIRED

- ❖ Pv emulator trainer
- ❖ (0-60)v voltmeter -2 nos
- ❖ (0-10)A Ammeter-2 nos
- ❖ System
- ❖ Power chord

FRONT PANEL

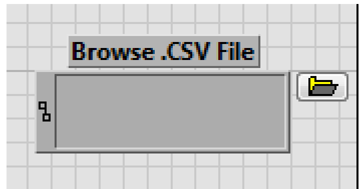


PROCEDURE

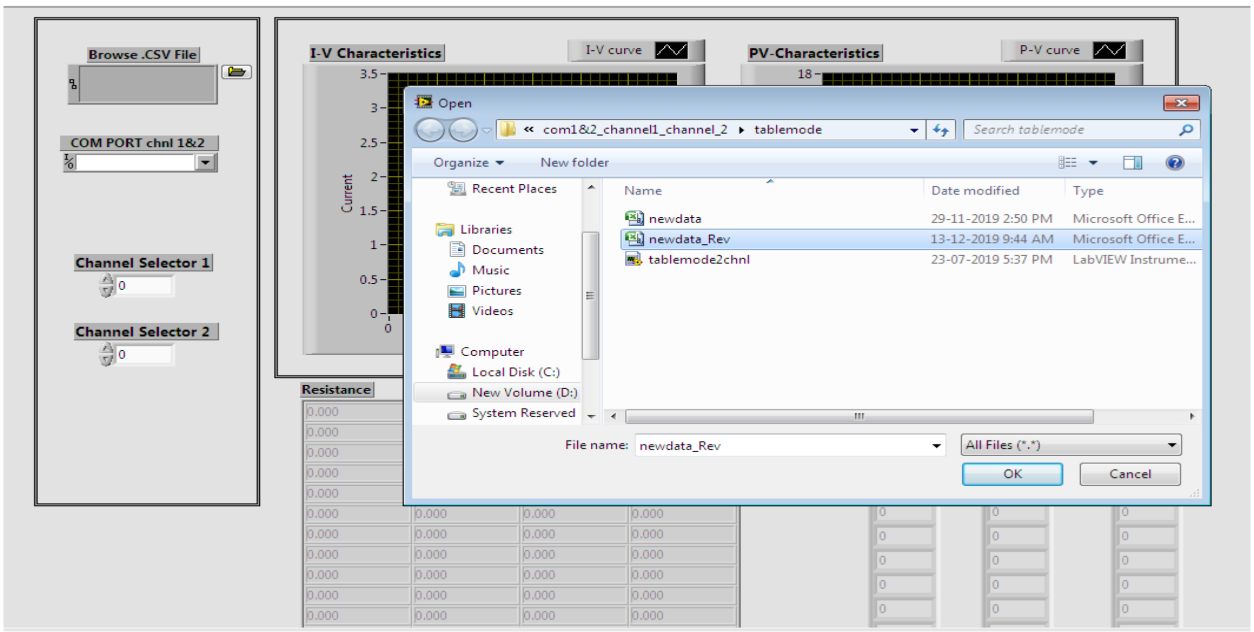
- ❖ **Open** s/w program by double clicking the exe file .
- ❖ Connect the trainer to AC mains.

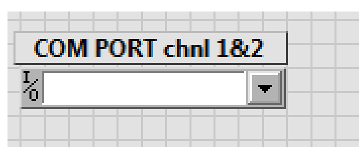
❖ Connect the USB cable from PV Emulator to PC Com port.

❖ Switch ON the MCB.

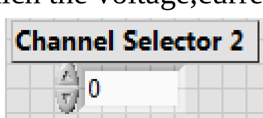
❖ To choose the file to be read, browse 

ie., click on  and select the excel file .

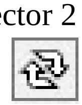


❖ Select the com port from drop down menu 

❖ Select the channel in which the voltage,current are connected,



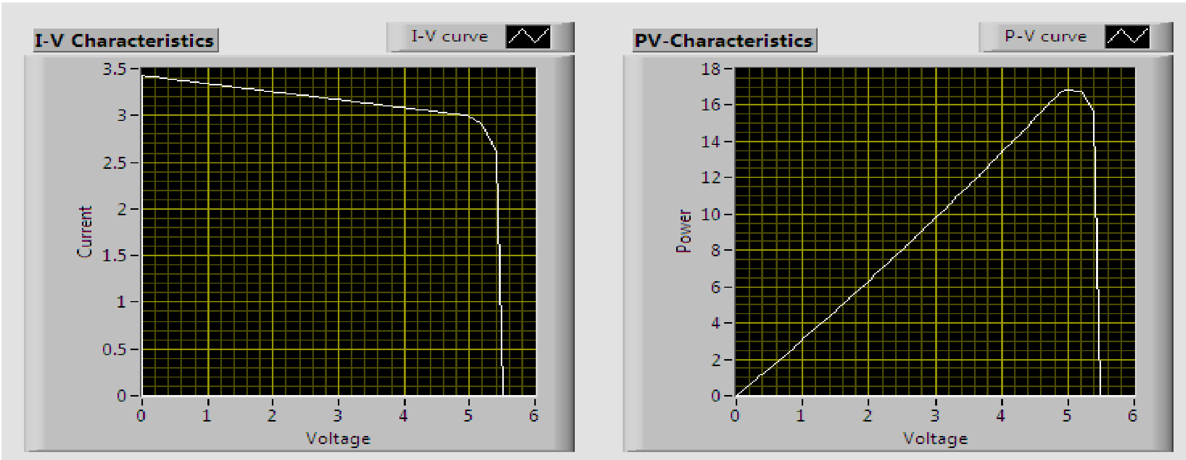
- Use Channel selector to select the 2 different channels.
- Enter Channel Selector 1 → **1,** to select chnl 1 to operate in fixed mode.
- Enter Channel Selector 2 → **2**, to select chnl 2 to operate in fixed mode.

❖ Click run continuous .

❖ I-V and P-V curve will be displayed in the graph and voltage and current will vary at the output, in accordance with the data in the table. All the 2 channels will vary according to the single exe file.

❖ After Competing Stop the Program by click Abort Execution .

Note : - Select all the required channels before clicking on run button. To add a new channel stop executing the program select the required channel and click on run again.



RESULT:

Thus the PV Emulator I V Characteristics was drawn.

Experiment 5.1.4: Fixed Mode in Parallel

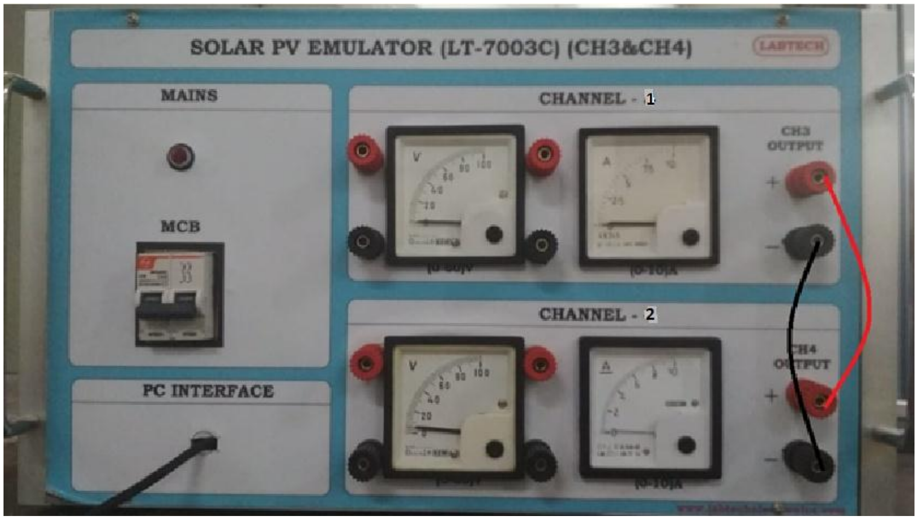
AIM:

To measure the voltage(60v) and current(10A-20A) in Fixed mode in Parallel.

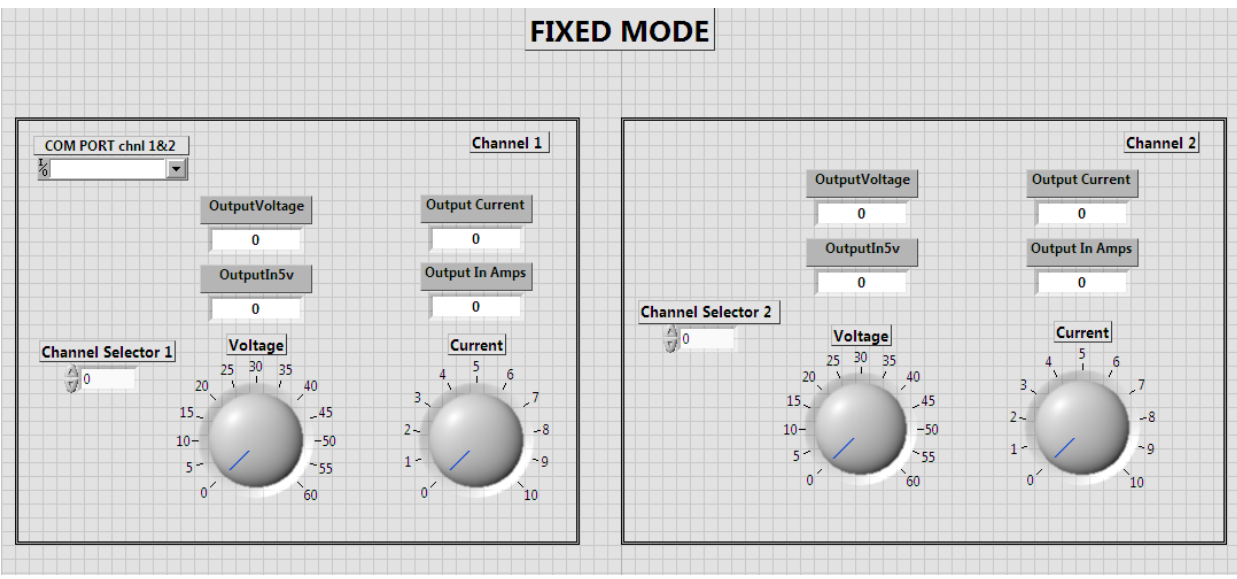
APPARATUS REQUIRED

- Pv emulator trainer
- (0-60)v voltmeter -2 nos
- (0-10)A Ammeter-2 nos
- System
- Power chord
- Patch chord

Patching Diagram :



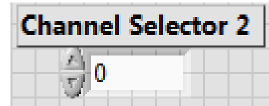
FRONT PANEL



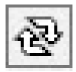
PROCEDURE

- **Open** S/W program by double clicking the exe file
- Connect the trainer to AC mains.
- Connect the USB cable from Trainer kit to PC Com port.
- Switch ON the MCB
- Select the com port from drop down menu

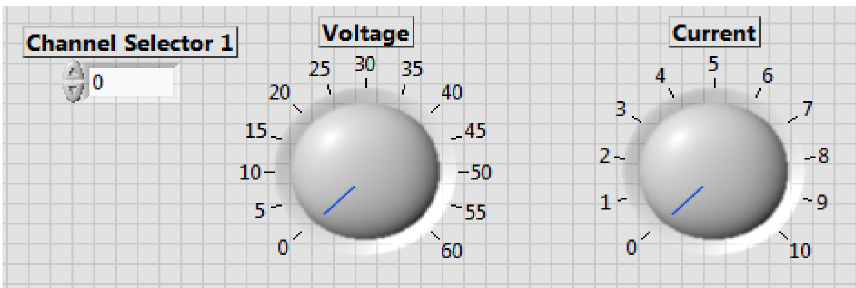
❖ Select the channel from drop down menu, 



- Use Channel selector to select the 2 different channels.
- Enter Channel Selector 1 → **1,** to select chnl 1 to operate in fixed mode.
- Enter Channel Selector 2 → **2,** to select chnl 2 to operate in fixed mode.

❖ Click run continuous .

❖ Vary the Channels 1&2's voltage and current by varying **knobs** in s/w.



❖ Note down the Set Voltage and Meter Readings

❖ Verify the output voltage and current at the output of Front Panel where current increases and voltage is constant.

❖ After Competing Stop the Program by click Abort Execution  .

RESULT:

Thus the voltage and current was determined for Parallel combination.

Note: - Select all the required channels before clicking on run button. To add a new channel stop executing the program select the required channel and click on run continuously again.

Experiment 5.1.5: Fixed Mode in Series

AIM:

To measure the voltage(60v-120v) and current(10A) in Fixed mode in Series.

APPARATUS REQUIRED

❖ PV Emulator trainer

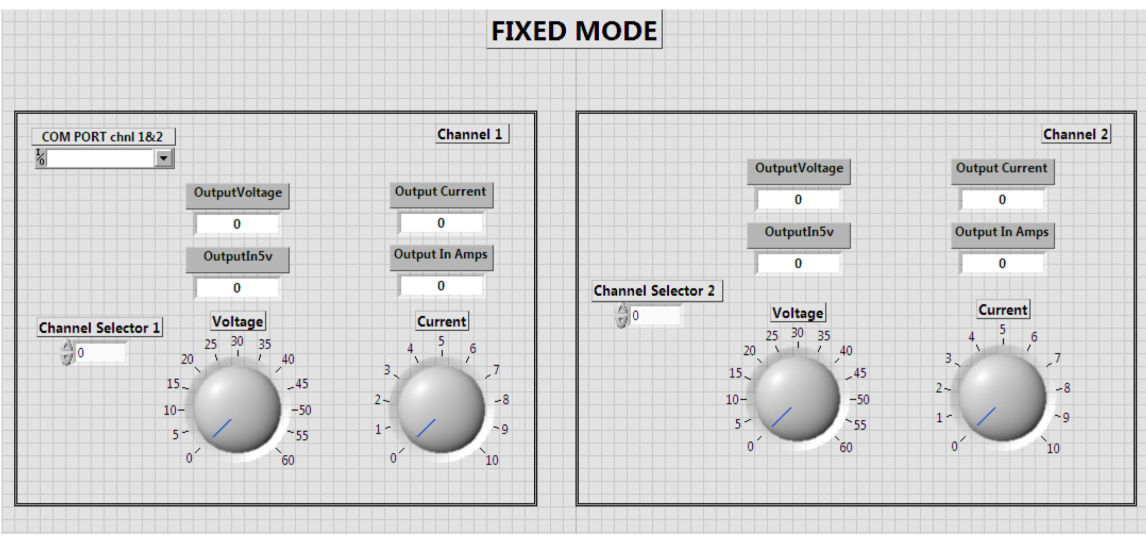
❖ (0-60)v voltmeter -2 nos

❖ (0-10)A Ammeter-2 nos

- ❖ System
- ❖ Power chord
- ❖ Patch chord

Patching Diagram :

FRONT PANEL

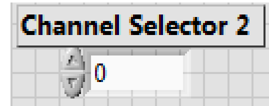


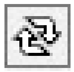
PROCEDURE

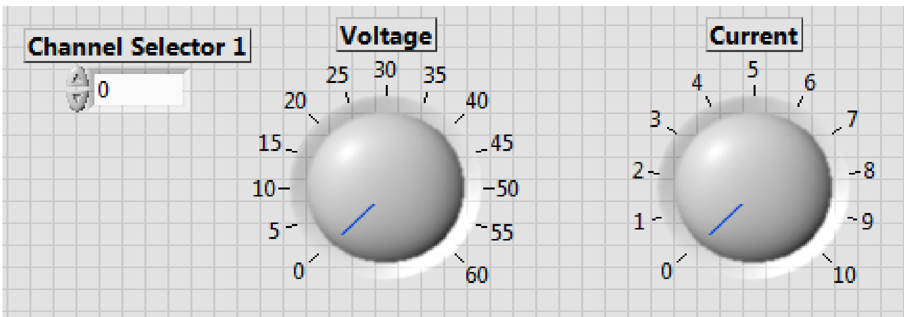
- ❖ **Open** S/W program by double clicking the exe file
- ❖ Connect the trainer to AC mains.
- ❖ Connect the USB cable from Trainer Kit to PC Com port.
- ❖ Switch ON the MCB

- ❖ Select the com port from drop down menu

- ❖ Select the channel from drop down menu. 



  - Use Channel selector to select the 2 different channels.
  - Enter Channel Selector 1 → **1,** to select chnl 1 to operate in fixed mode.
  - Enter Channel Selector 2 → **2,** to select chnl 2 to operate in fixed mode.
- ❖ Click run continuous .
- ❖ Vary the Channels 1&2's voltage and current by varying **knobs** in s/w.



- ❖ Note down the Set Voltage and Meter Readings
- ❖ Verify the output voltage at the output of Front Panel where current remains constant and voltage increases.
- ❖ After Competing Stop the Program by click Abort Execution  .

RESULT:

Thus the voltage and current was determined for Series connection.

Note: - Select all the required channels before clicking on run button. To add a new channel stop executing the program select the required channel and click on run continuously again.

Solar PV Energy System Experiments with PV Emulator

EXPERIMENT : 5.1.6

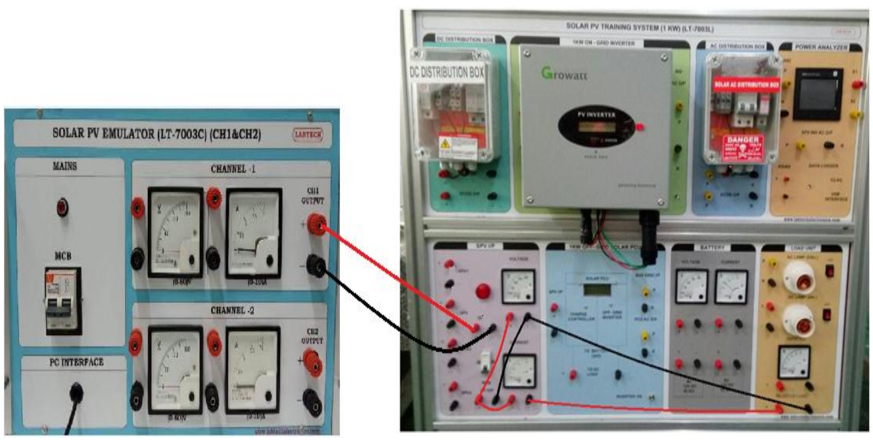
AIM:

To Study the P-V and V-I characteristics of PV Emulator module.

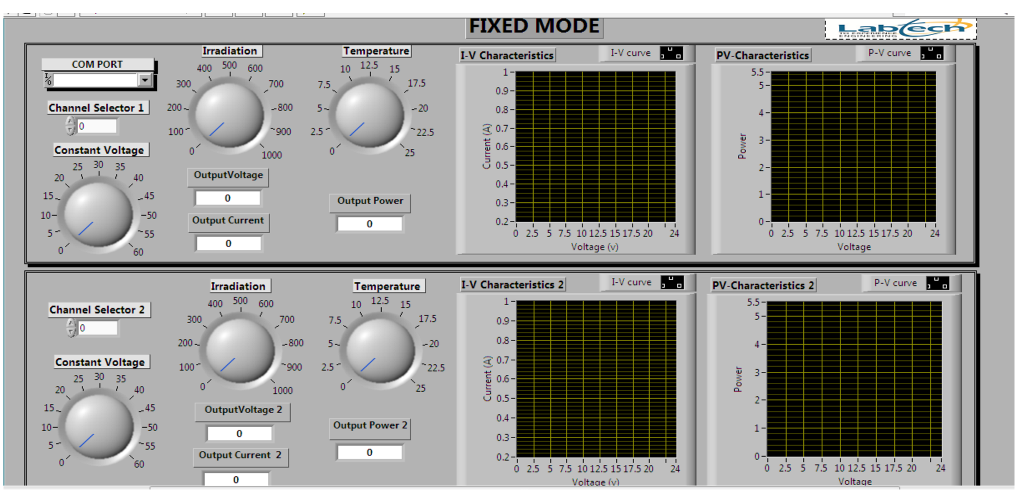
APPARATUS REQUIRED:

- ❖ Solar PV Emulator trainer.
- ❖ Solar PV training system.
- ❖ Resistive Load.
- ❖ DC Ammeter and DC Voltmeter.
- ❖ Patch Chords.

CIRCUIT DIAGRAM:



S/w Front View :

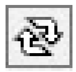


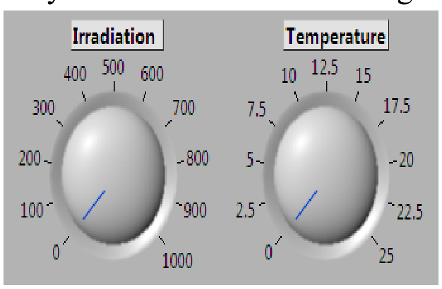
PROCEDURE:

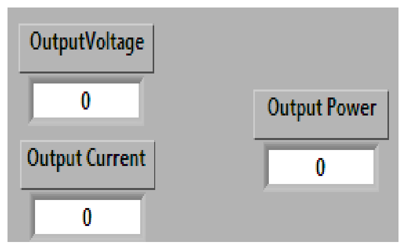
- ❖ Connect the Patch Cards as shown in circuit diagram.
- ❖ Switch ON Both the trainer.
- ❖ Connect the USB cable from Emulator Trainer kit to PC Com port.
- ❖ Switch ON the MCB.
- ❖ Open s/w program exe file, Select COM Port, Channel Selector.

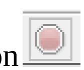
  Channel Selector 1 → **1**

  Channel Selector 2 → **2**

- o Click run continuous .
- o Vary the Channels 1&2's voltage and current by varying **knobs** in software.



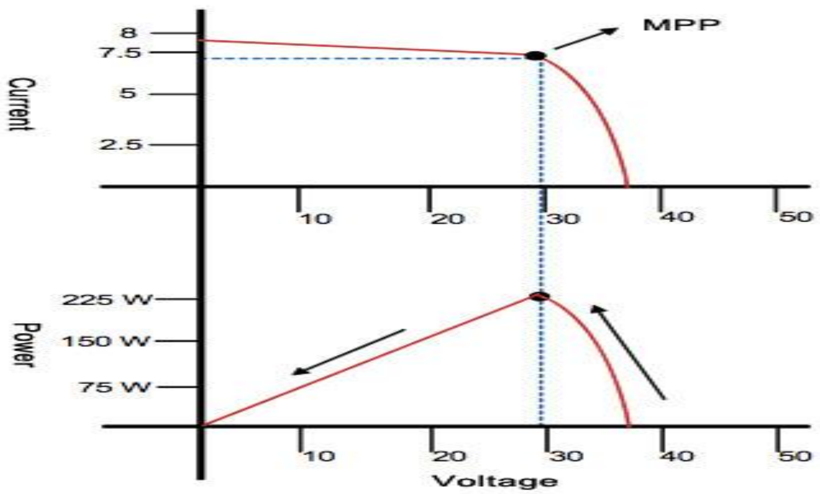


- ❖ Output of one channel PV Emulator is connected to the variable load (resistive load) through ammeter and voltmeter.
- ❖ Vary the load resistance and measure the voltage and current.
- ❖ Tabulate the reading and plot the P-V and V-I graphs.
- ❖ After Competing Stop the Program by click Abort Execution  .

TABULATION:

SL. No	Voltage (V)	Current (A)	Power (W)
1	20	2	40
2	20	2.5	50
3	20	3	60

MODEL GRAPH:



RESULT:

Thus the P-V and V-I characteristics of PV Emulator is same as single PV module was studied.

EXPERIMENT: 5.2.2

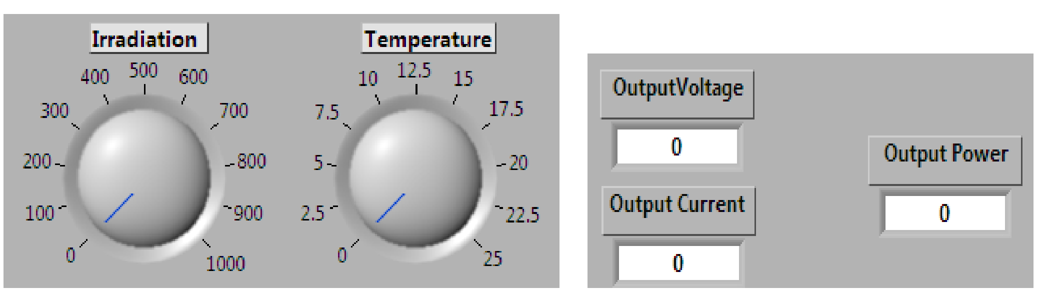
AIM:

To see performance of Grid connected solar PV Emulator system.

APPARATUS REQUIRED:

- Solar PV Emulator trainer.
- Solar PV training system.
- Patch Chords
- Load Lamp

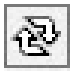
PATCHING DIAGRAM:



PROCEDURE:

- Make the connection as per patching diagram.
- Output of PV Emulator is connected to the SPV I/P.
- Switch ON Both the trainer.
- PV Emulator channel1 and channel 2 is connected in series to increase the voltage, to switch ON inverter.
- Connect the USB cable from Emulator Trainer kit to PC Com port.
- Switch ON the MCB
- Open s/w program exe file, Select COM Port, Channel Selector.

  Channel Selector 1 - 1

  Channel Selector 2 - 2
- Click run continuous .
- Vary the Channels 1&2's voltage and current by varying knobs in software and set to required voltage and current.
- Generate power from solar PV Emulator and transmit to the transmission line grid.
- Generated power can be monitored by using multifunction meter.
- After Competing Stop the Program by click Abort Execution 

RESULT:

Thus the performance of Grid connected solar PV Emulator was studied.

PART V

Experiments MATLAB Simulation

EXPERIMENT NO: 6 (MatLab Simulation Experiments)

<u>Experiment 6.1:</u>

Aim:- Simulation study on Solar PV Energy System(1kW) for Off-Grid Inverter.

Apparatus:

PC with MatLab software

Procedure :

1. Double click and open the Simulink model of off-grid. Fig 1. shows the simulink model.

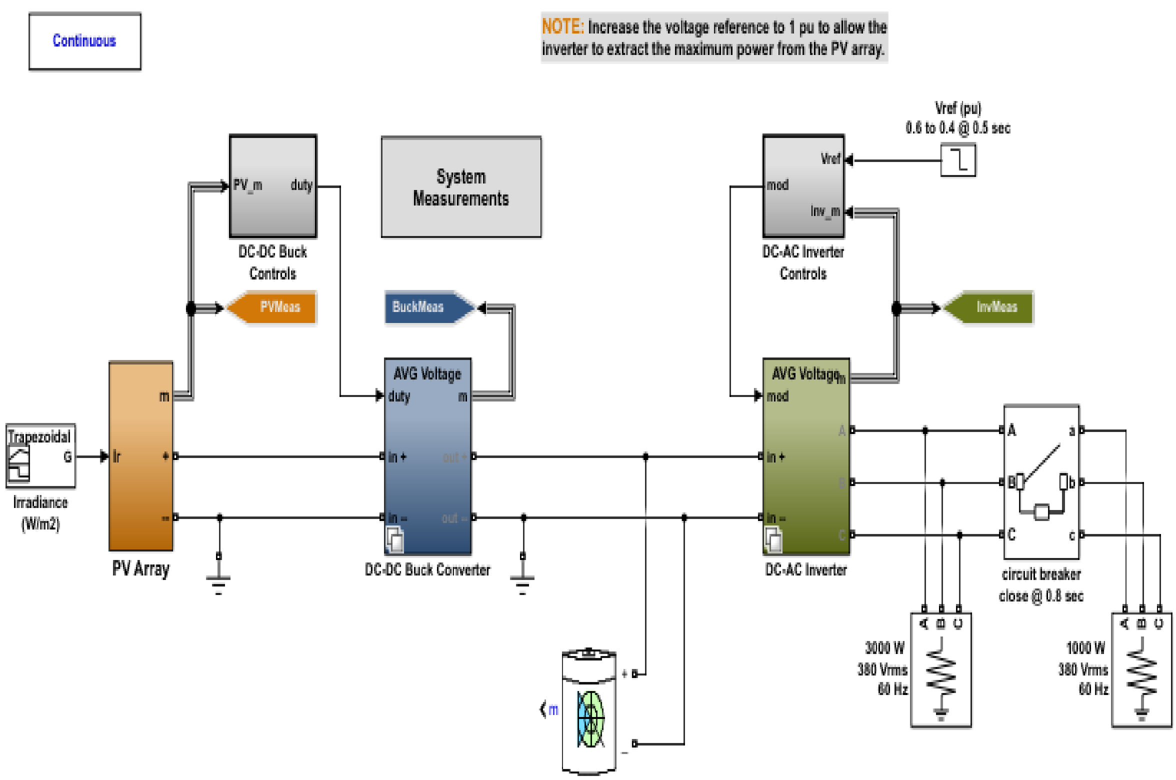


Fig 1

Each Block Explanation :

- **PV Array(Solar Panel) :**

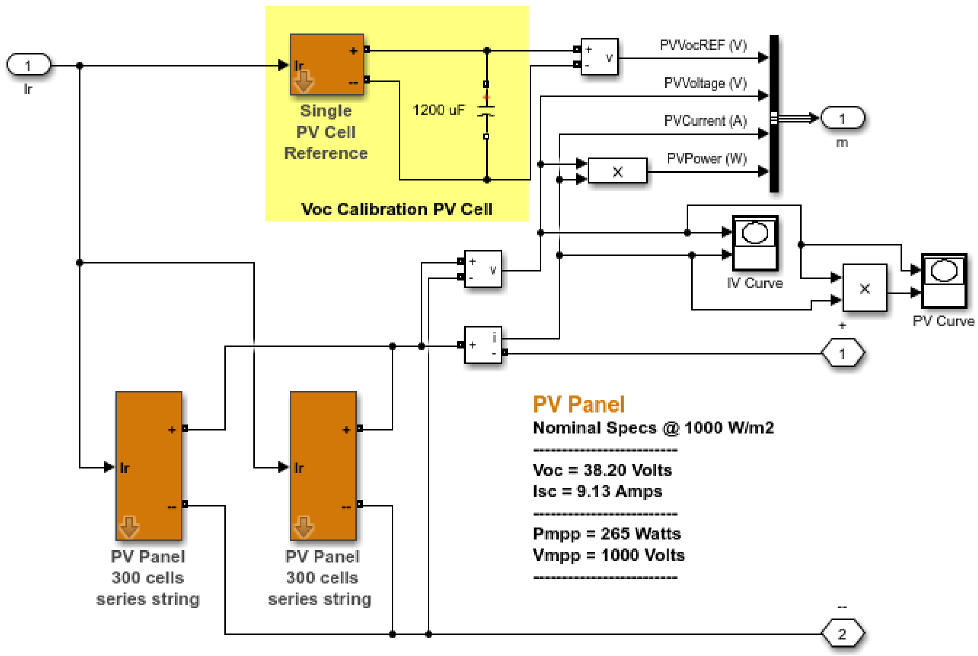


Fig 2.

- A Panel consists of 10 parallel strings.
- Each string has 30 modules connected in series which is 300 cells multiplied by factor N which is 1.67.
- Here 2 Panel connected in Parallel gets added up and give **1kwp** as in fig 4.
- Note that the model menu allows you to plot the **I-V and P-V characteristics** of the selected module or of the whole array as in fig 5

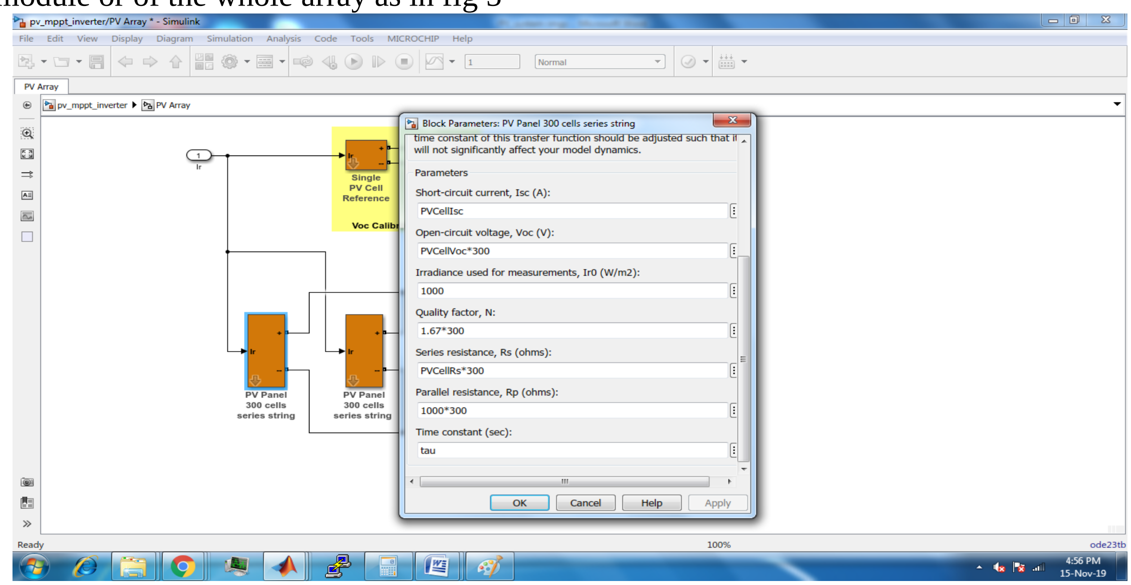


Fig 4.

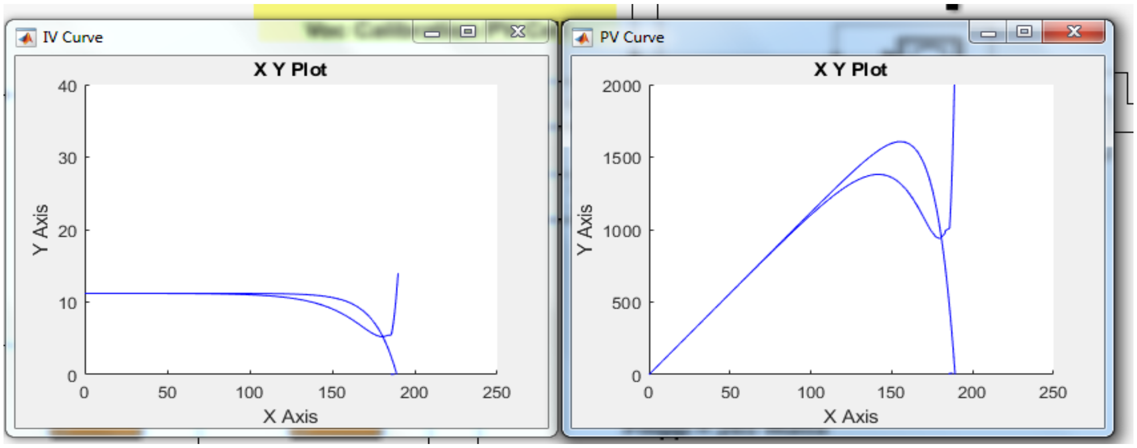


Fig 5.

- **Charge Controller(MPPT and Buck Converter) :**

DC-DC Buck Controls/MPPT :

- **MPPT**(Maximum Power Point Tracking) is used to track the peak power to maximize the produced energy. The maximum power point in the power voltage graph is identified by algorithms, that optimizes the match between the solar array (PV panels), and the battery bank or utility grid.
- PV module has nonlinear characteristics, it is necessary to model to make a complete utilization of solar energy in available time.
- Many maximum power point tracking algorithms are available for a solar panel in order to produce maximum output. It is very necessary that it is operated consistently at the maximum power point.
- The conventional MPPT methods are the **Perturb and Observe(P&O)** (Hill climbing) method, the **Incremental Conductance(INC)** method, **Fractional open circuit voltage** method and the **Fractional short circuit Current** method.

- Here we use **Fractional Open Circuit Voltage Algorithm**, here MPP voltage is always a constant fraction of the Voc, the Voc of the cell in the PV Array is measured and used as an input to the controller.
- It can be tried out for P&O and INC algorithms also.

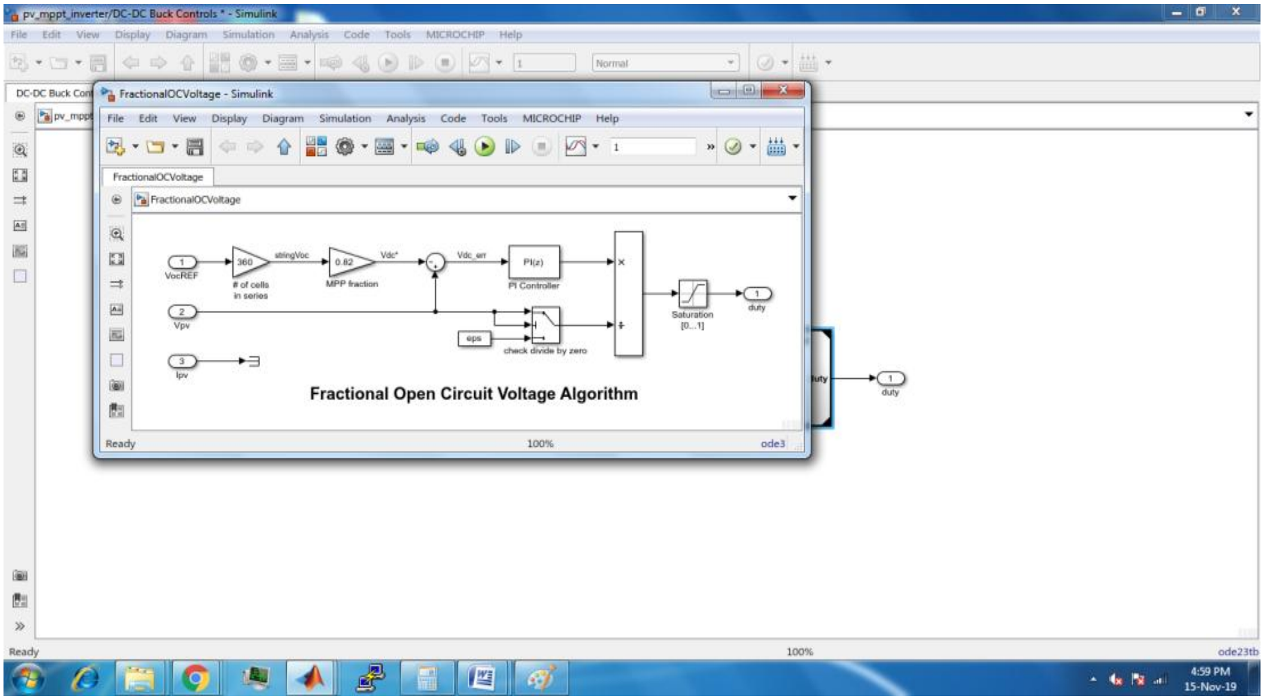


Fig 6.

DC-DC Buck Converter :

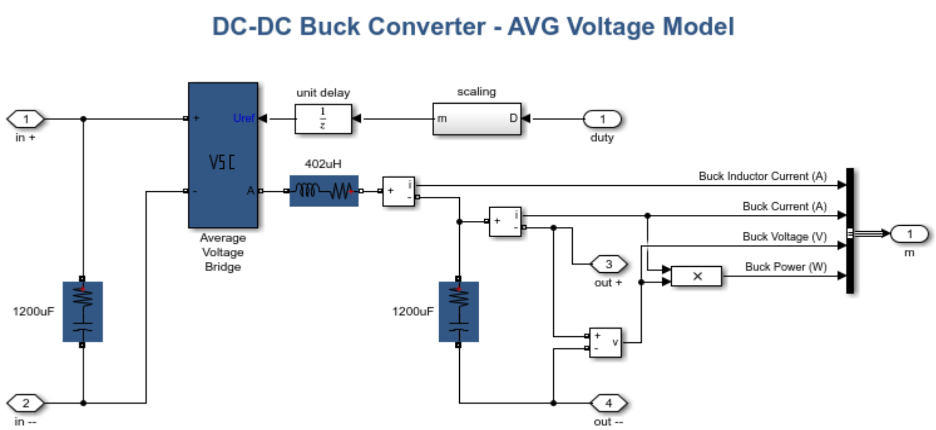


Fig 7.

- **Buck converter** steps down voltage from its input to its output. It is a class of switched-mode power supply typically containing at least two semiconductors and at least one energy storage element, a capacitor, inductor, or the two in combination.
- Hence Average Voltage Gain(AVG) is obtained by Voltage Source Converter(VSC) done by PWM which come from Buck converter to control output.

- **Battery Bank :**

  - Batterys are used to Charge and Discharge the Energy that is being generated.
  - Battery Charges and give energy to Inverter and when energy is not getting generated it Discharges and give energy to Inverter.
  - Battery value is set based on Battery Specification provided ie., Maximum **Voltage**(**v**) is **24** and Maximum **Capacity**(**Ah**) is **42**.

- **DC-AC Inverter :**

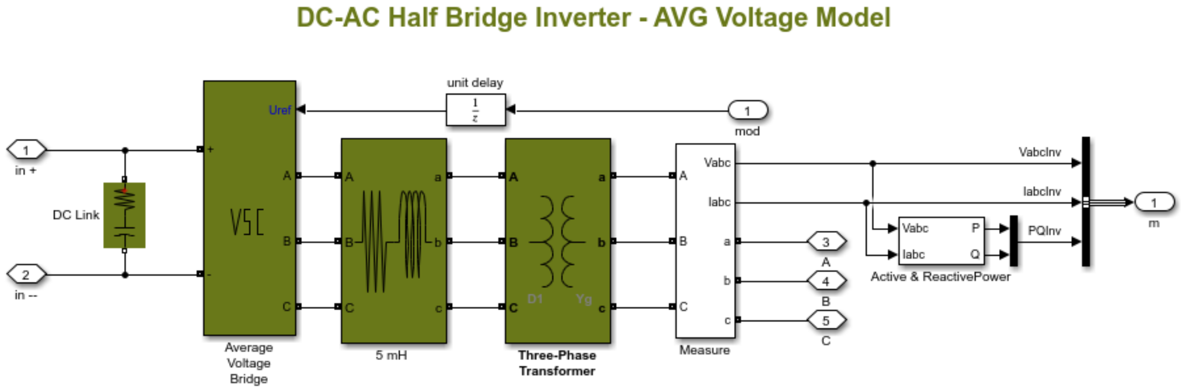


Fig 8.

- The converter is modeled using a 3-level bridge PWM-controlled. The inverters choke RL and a small harmonics filter C are used to filter the harmonics generated by the AVG bridge.
- A three-phase transformer is used to connect the inverter to the utility distribution system.

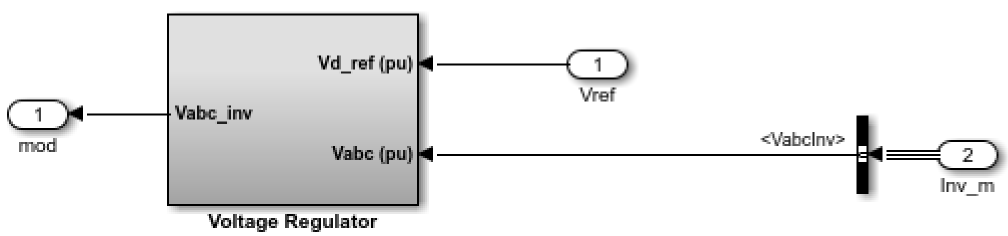


Fig 9.

- Hence DC is converted to AC signal and it is regulated to a desired set point voltage for a fixed load that will limit the current flowing through the inverter.

And hence it is supplied to the house appliances using Circuit Breaker.

Simulation :

- Run the simulation by Pressing Run Button  and observe the resulting signals on the various scopes.

- The initial input irradiance to the PV array model is 1000 W/m2 These values correspond very well to the expected values from the PV module manufacturer specifications.

- Go to System Measurements, double click on DC Measurements and AC Measurements and view the Output Graph.

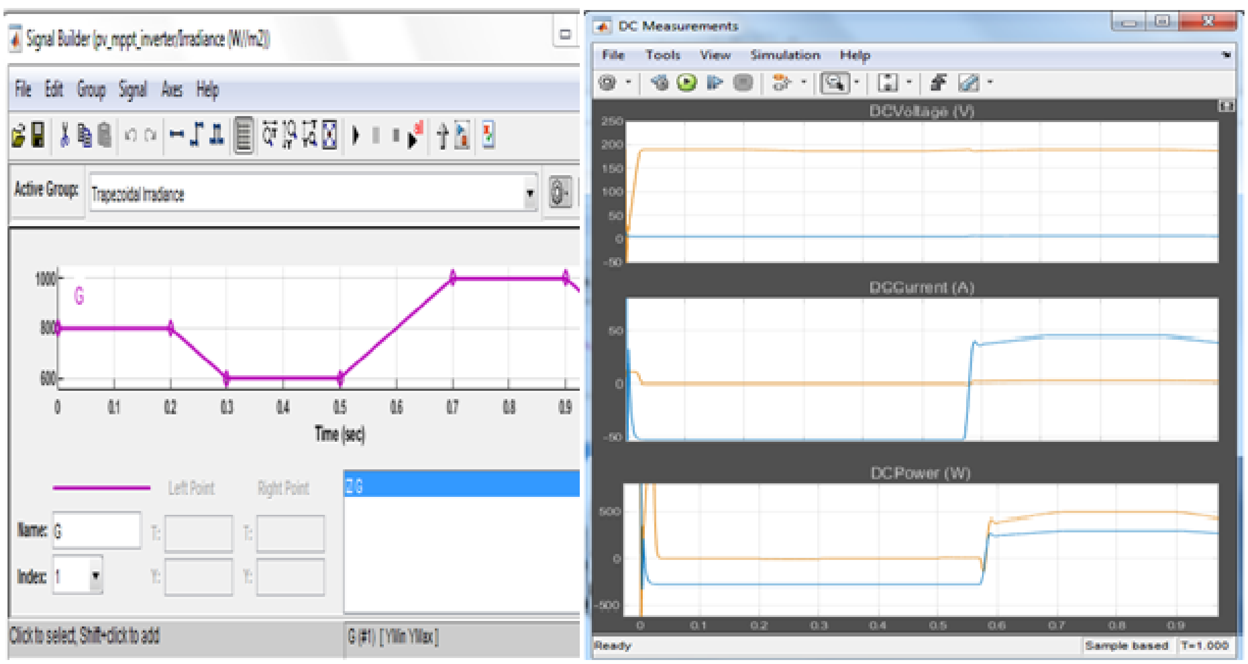
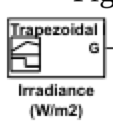


Fig 10.

- Open Irradiance block(Signal Builder) 

here we can set irradiance of different values same as sunlight how it differs with time based on this input we can verify output in DC Measurements.

- Orange line is PV output and Blue line is Buck output.

- we can see DC Power is maximum at time 0.7 and start decreasing at 0.9 when irradiance is maximum(1000 at time 0.7) and Buck output is decreased than PV output as it is step downed.

Hence for different input irradiance we can see different output of Power being generated at MPP and used for applications through Simulation.

Result :

Thus the Simulation study on Solar PV Energy System(1kW) for Off-Grid Inverter is done.

Experiment 6.2:

Aim:- Simulation study on Solar PV Energy System(1kW) for On-Grid Inverter.

Apparatus:

- PC with MatLab software.

Diagram :

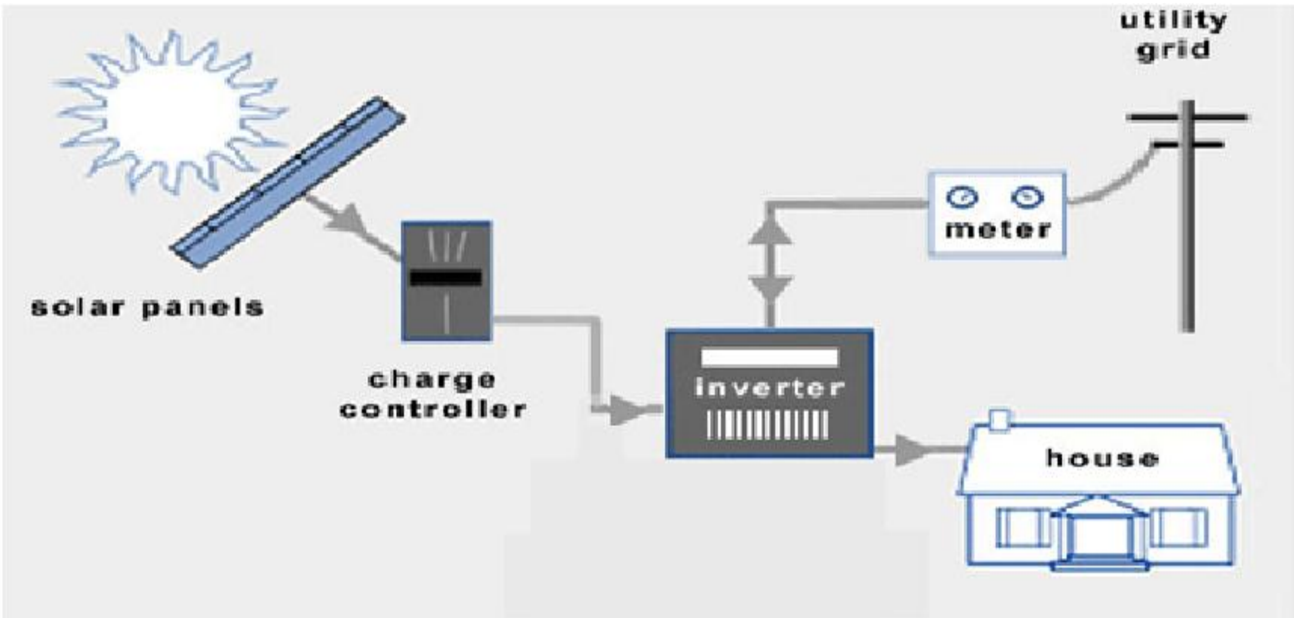


Fig 1.

Procedure :

1. Double click and open the Simulink model of off-grid. Fig 2. shows the simulink model.

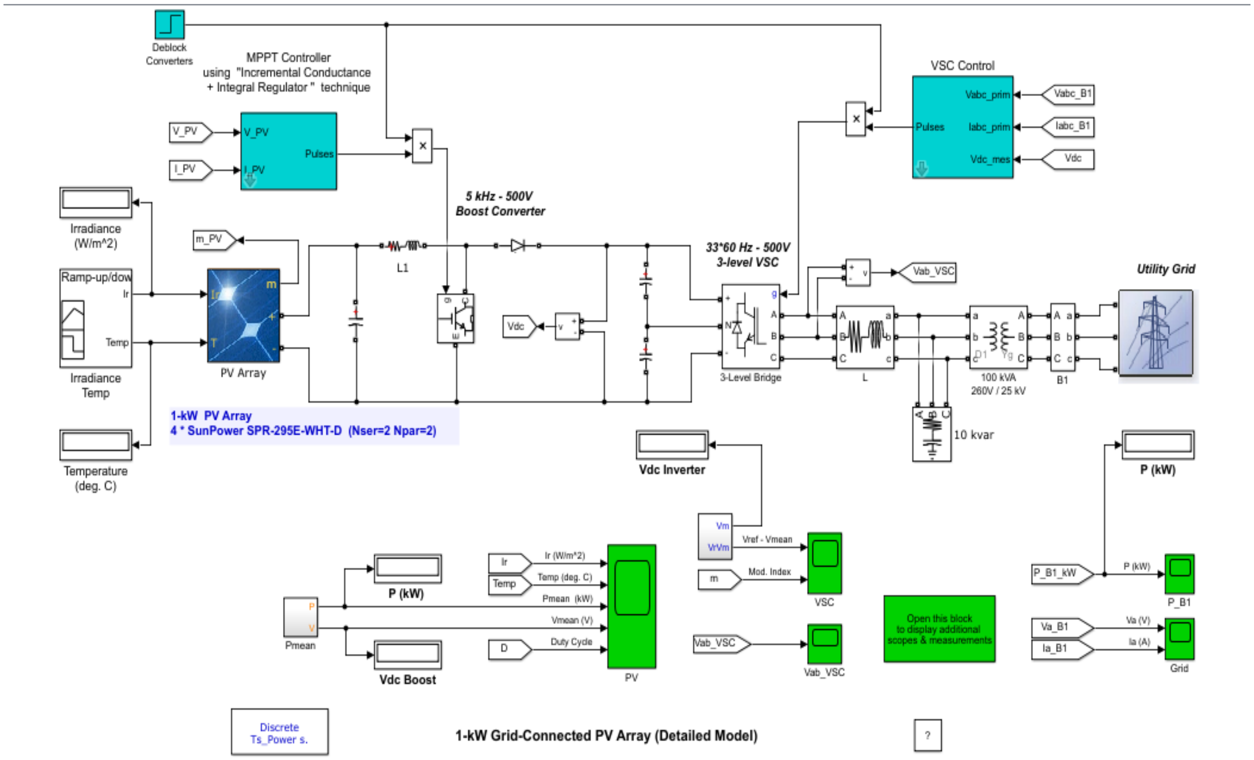


Fig 2.

A 1-kW PV array is connected to a 25-kV grid via a DC-DC boost converter and a three-phase three-level Voltage Source Converter (VSC).

Maximum Power Point Tracking (MPPT) is implemented in the boost converter by using the model 'Incremental Conductance + Integral Regulator' technique.

Each Block Explanation :

- **PV Array(Solar Panel) :**
    - **PV array** delivering a maximum of 1 kW at 1000 W/m^2 sun irradiance.
    - For PV Array the input irradiation and temperature are set using this block and we can vary the input by shifting the points as shown in fig 3.

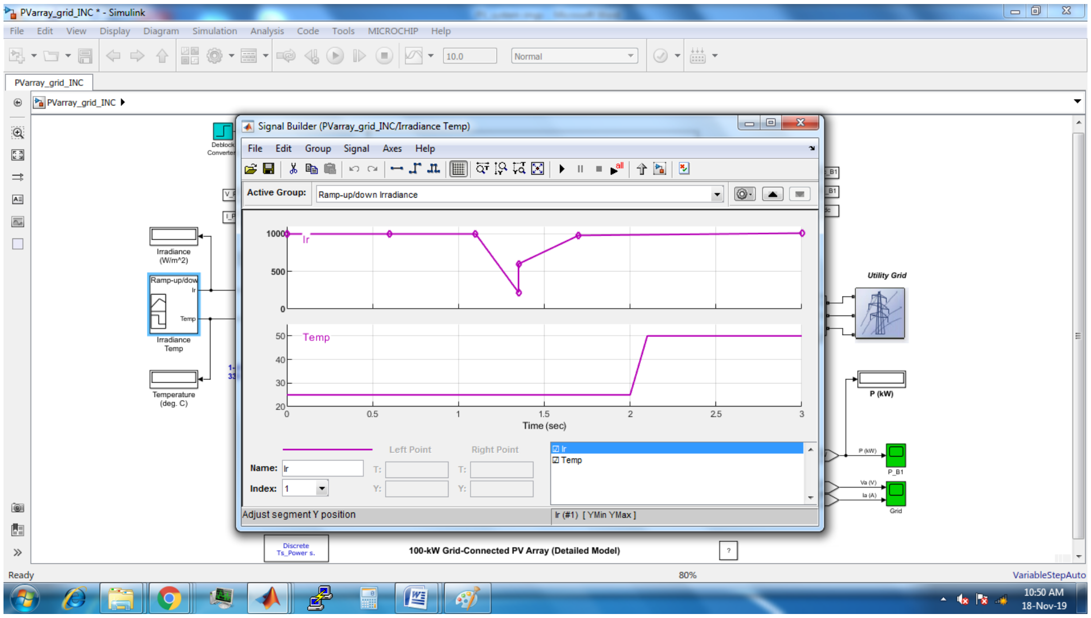


Fig 3.

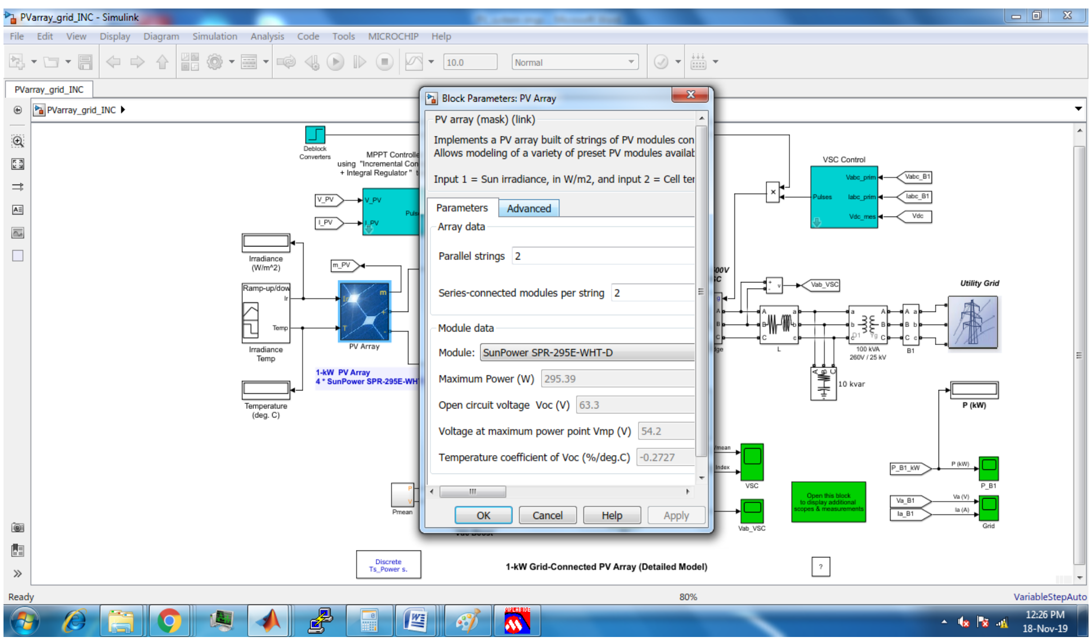


Fig 4.

- A Panel consists of 2 parallel strings.
- Each string has 2 modules connected in series which is 4 cells multiplied by 295 as we set the module to SunPower SPR-295E-WHT-D.

- Hence it give **1kwp** as in fig 4.
- Note that the model menu allows you to plot the **I-V and P-V characteristics** of the selected module or of the whole array as in fig 5.

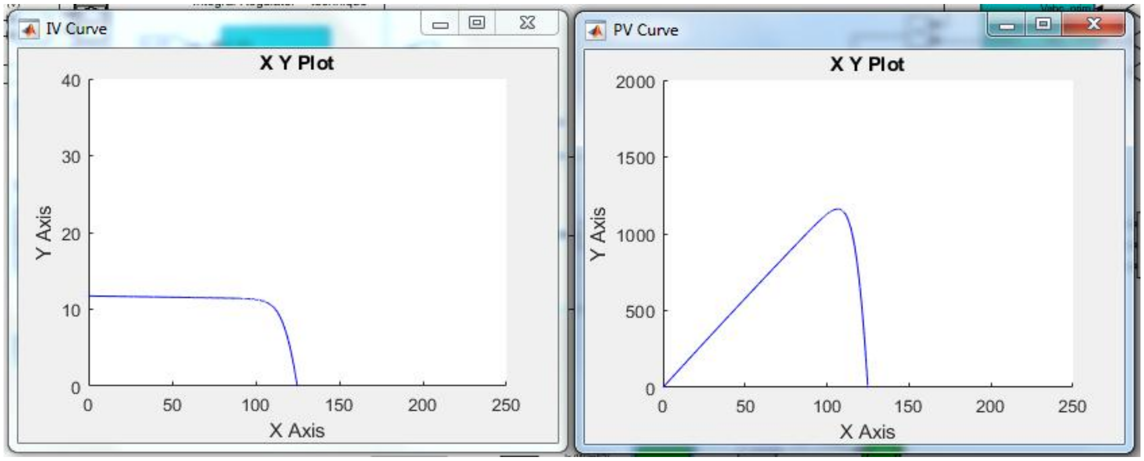


Fig 5.

Charge Controller(MPPT and Boost Converter) :

- **MPPT Controler :**
  - **MPPT**(Maximum Power Point Tracking) is used to track the peak power to maximize the produced energy.
  - PV module has nonlinear characteristics, it is necessary to model to make a complete utilization of solar energy in available time.
  - Many maximum power point tracking algorithms are available for a solar panel in order to produce maximum output. It is very necessary that it is operated consistently at the maximum power point.
  - The conventional MPPT methods are the **Perturb and Observe(P&O)** (Hill climbing) method, the **Incremental Conductance(INC)** method, **Fractional open circuit voltage** method and the **Fractional short circuit Current** method.
  - Here we use **Incremental Conductance(INC) Algorithm**, here it will identify the suitable duty cycle ratio in which converter should operate to maximum point, that optimizes the match between the solar array (PV panels), and the battery bank or utility grid.
  - **INC** offers the main advantage of providing high efficiency under rapidly changing atmospheric conditions, so it has been employed in the model.

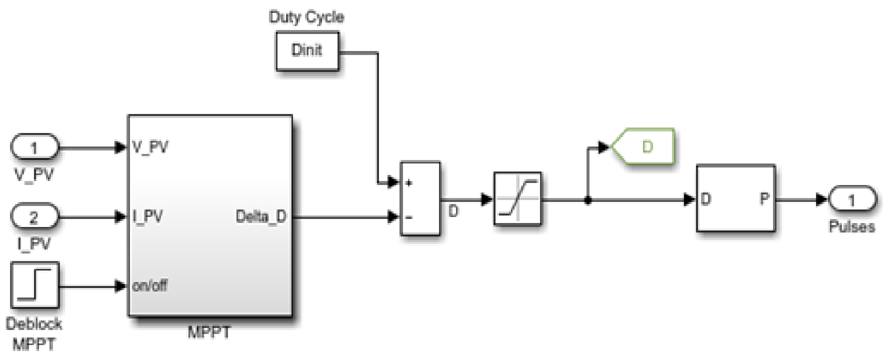


Fig 6.

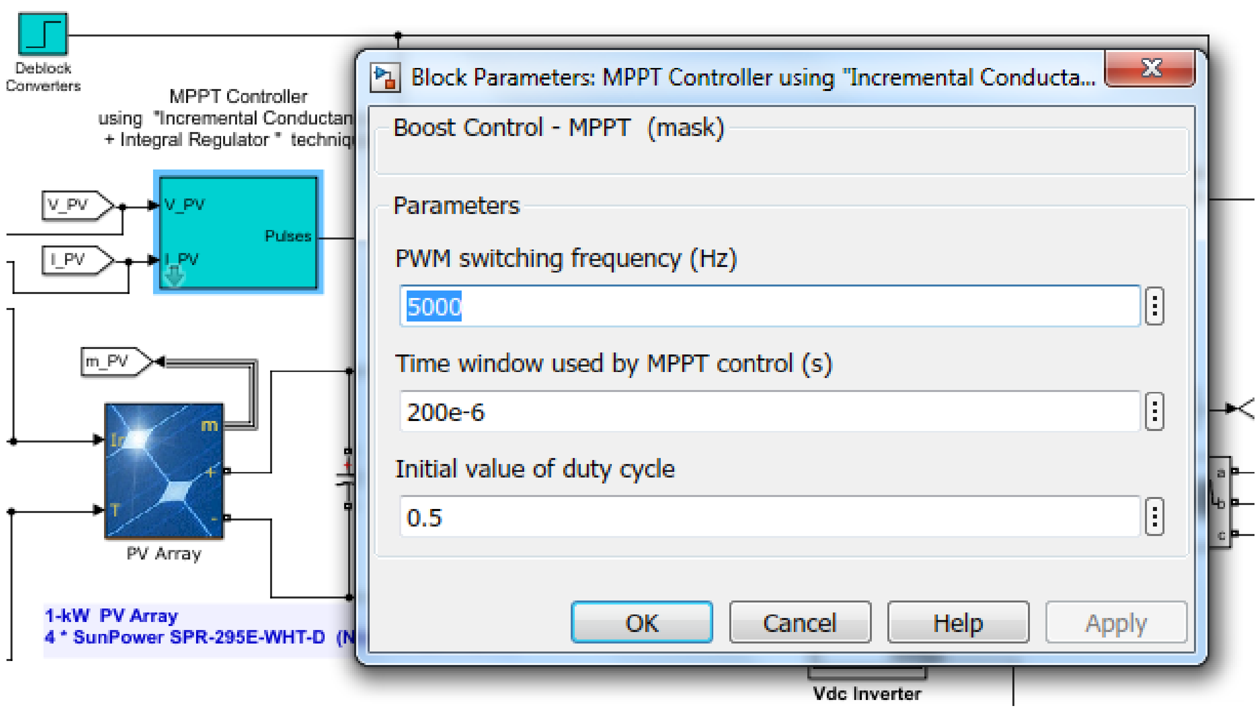


Fig 7.

We can set frequency and initial duty cycle for MPPT based on which it works.

- Switching duty cycle is optimized by a MPPT controller that uses the 'Incremental Conductance + Integral Regulator' technique.
- This MPPT system automatically varies the duty cycle in order to generate the required voltage to extract maximum power.

- **DC-DC Boost Converter :**

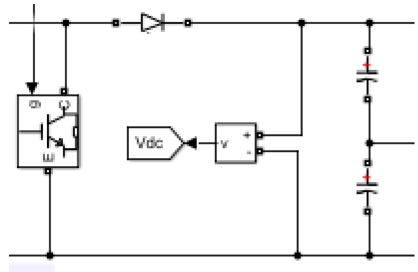


Fig 8.

- ○ **Boost converter** steps up voltage from its input to its output.
- ○ **5-kHz DC-DC boost converter** increasing voltage from PV natural voltage (273 V DC at maximum power) to 500 V DC.

- **VSC Control/DC-AC Inverter :**

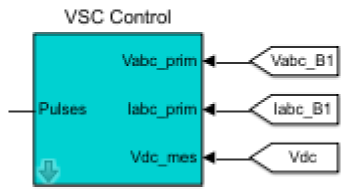
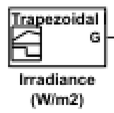


Fig 9.

- The converter is modeled using a 3-level bridge PWM-controlled.
- The VSC converts the 500 V DC link voltage to 260 V AC and keeps unity power factor.
- The VSC control system uses two control loops:
  - an external control loop which regulates DC link voltage to +/- 250 V and
  - an internal control loop which regulates Id and Iq grid currents (active and reactive current components).
    - Id current reference is the output of the DC voltage external controller.
    - Iq current reference is set to zero in order to maintain unity power factor.
    - Vd and Vq voltage outputs of the current controller are converted to three modulating signals Uabc_ref used by the PWM Generator.
- The control system uses a sample time of 100 microseconds for voltage and current controllers as well as for the PLL synchronization unit. Pulse generators of Boost and VSC converters use a fast sample time of 1 microsecond in order to get an appropriate resolution of PWM waveforms.
- **10-kvar capacitor bank** filtering harmonics produced by VSC.
- **100-kVA 260V/25kV three-phase coupling transformer is** used to connect the inverter to the utility distribution system.
- **Utility grid** (25-kV distribution feeder + 120 kV equivalent transmission system).

And hence from Grid we can use the Power that is Generated to Applications.

Simulation :

- Run the simulation by Pressing Run Button  and observe the resulting signals on the various scopes.
- The initial input irradiance to the PV array model is 1000 W/m2.
- Open Irradiance block(Signal Builder) 

here we can set irradiance of different values same as sunlight how it differs with time based on this input we can verify output in DC Measurements.
- Simulation starts with standard test conditions (25 deg. C, 1000 W/m^2).
- From t=0 sec to t= 0.05 sec, pulses to Boost and VSC converters are blocked. PV voltage corresponds to open-circuit voltage. The three-level bridge operates as a diode rectifier and DC link capacitors are charged above 500 V.
- At t=0.05 sec, Boost and VSC converters are de-blocked. DC link voltage is regulated at Vdc=500V. Duty cycle of boost converter is fixed (D= 0.5 as shown on PV scope).
- Steady state is reached at t=0.25 sec. Resulting PV voltage is therefore V_PV = (1-D)*Vdc= (1-0.5)*500=250 V). The PV array output power is 96 kW whereas specified maximum power with a 1000 W/m^2 irradiance is 100.7 kW. Observe on Scope Grid that phase A voltage and current at 25 kV bus are in phase (unity power factor). At t=0.4 sec MPPT is enabled. The MPPT regulator starts regulating PV voltage by varying duty cycle in order to extract maximum power. Maximum power (1kW) is obtained when duty cycle is D=0.454.
- At t=0.6 sec, PV array mean voltage =274 V as expected from PV module specifications.
- From t=0.6 sec to t=1.1 sec, sun irradiance is ramped down from 1000 W/m^2 to 250 W/m^2. MPPT continues tracking maximum power.
- At t=1.2 sec when irradiance has decreased to 250 W/m^2, duty cycle is D=0.461. Corresponding PV voltage and power are Vmean= 268 V and Pmean=24.3 kW. Note that the MMPT continues tracking maximum power during this fast irradiance change.
- From t=1.2 sec to t=2.5 sec sun irradiance is restored back to 1000 W/m^2 and then temperature is increased to 50 deg. C. in order to observe impact of temperature increase. Note that when temperature increases from 25 deg. C to 50 deg. C, the array output power decreases from 1kW to 0.93 kW.

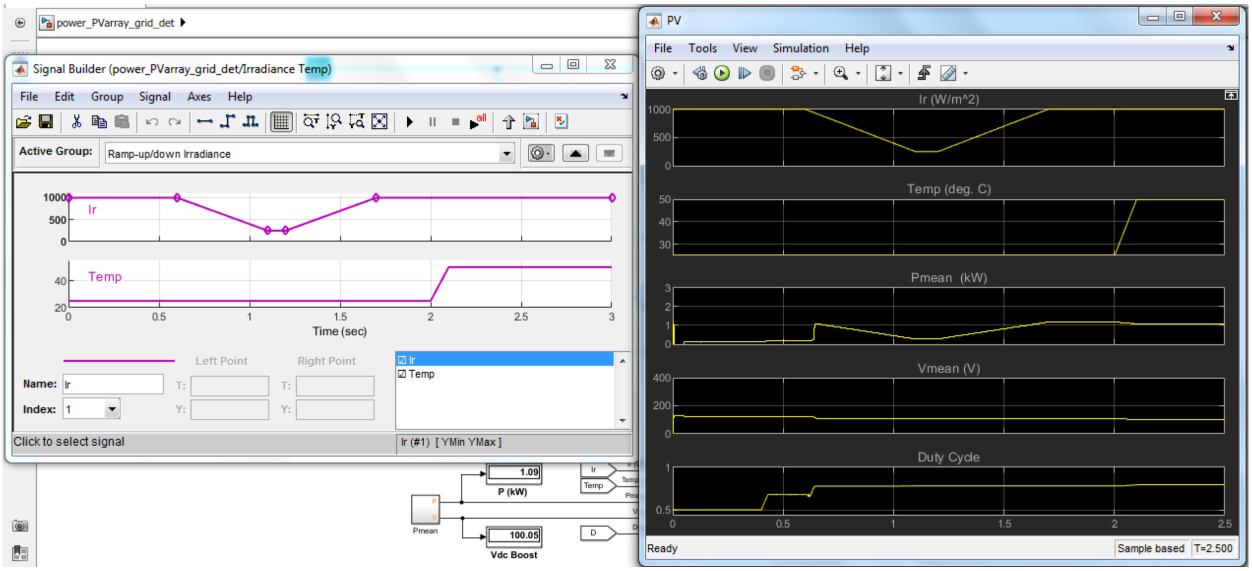


Fig 10.

Output waveform of Vab VSC(Voltage Source Converter).

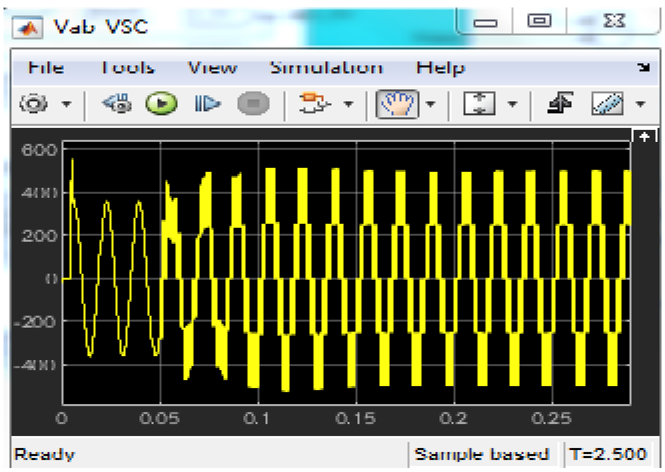


Fig 11.

Hence for different input irradiance we can see different output of Power being generated at MPP and used for applications through Simulation.

Result :

Thus the Simulation study on Solar PV Energy System(1kW) for On-Grid Inverter is done.

Experiment 6.3:

Aim:- Simulation study on Wind Energy System Generator.

Apparatus:

- PC with MatLab software.

Diagram :

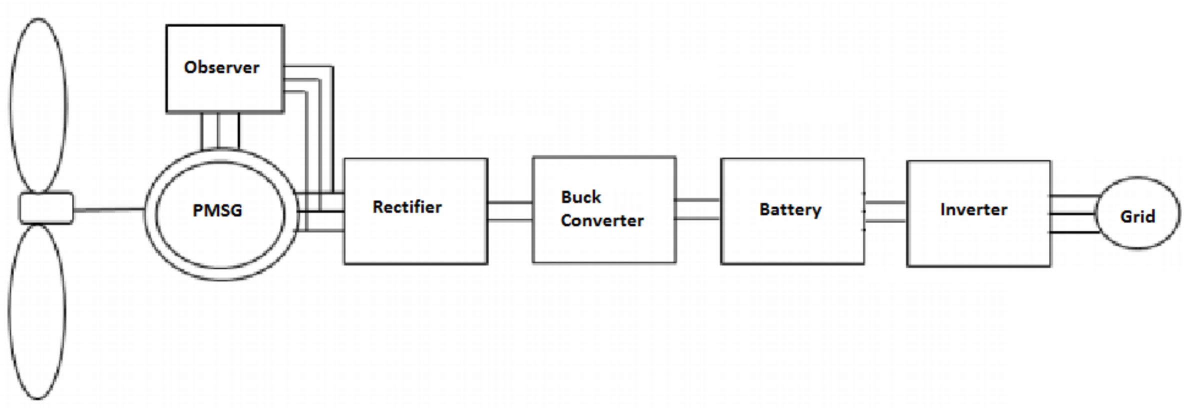


Fig.1: PMSG Wind turbine system.

- Here both induction and synchronous generators are used for wind turbine systems.
- For induction generators in wind power conversion(speed generation) systems we use doubly fed induction rotors as it provides a wide range of speed variation.
- The variable-speed directly-driven multi-pole **permanent magnet synchronous generator (PMSG) wind architecture** is chosen as it offers better performance due to higher efficiency and less maintenance because it does not have rotor current, for maximum power tracking and compares with the results produced.

Procedure :

- Double click and open the Simulink model of wind. Fig 2. shows the simulink model.

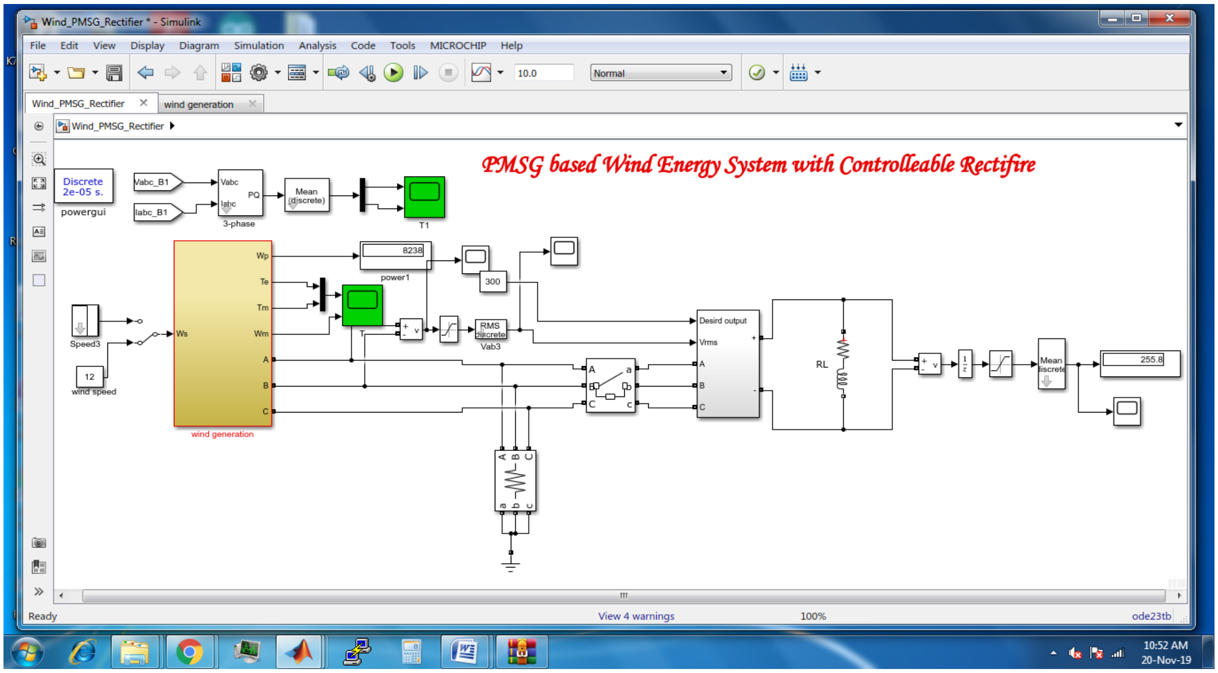


Fig 2.

Each Block Explanation :

➢ **Wind Speed :**

The present work considers a constant wind speed equal to 12 m/s. Consequently, the model implementation of the wind speed in Simulink implies the consideration of the base wind speed component. Shown in Fig 3,

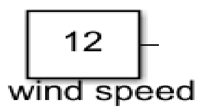


Fig 3.

➢ **Wind Generation :**

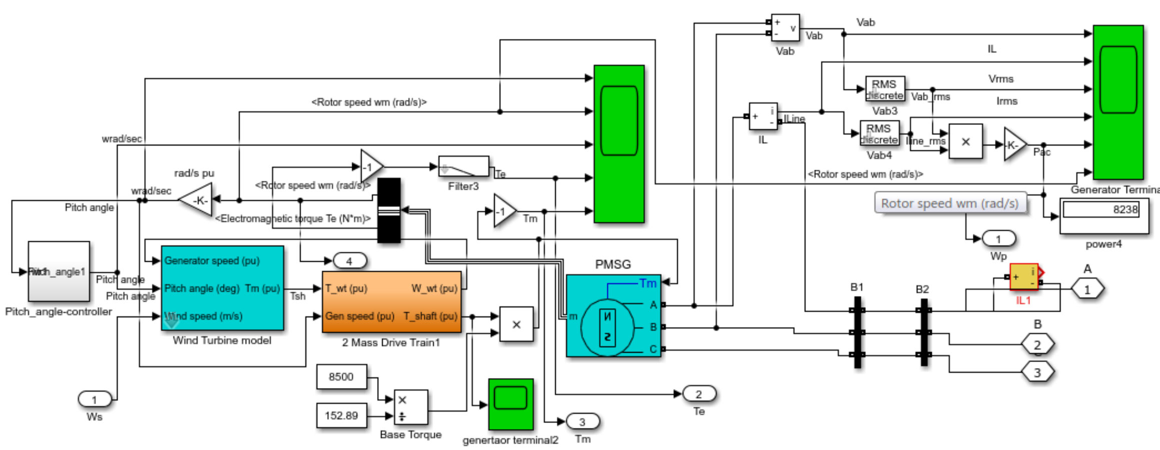


Fig 4.

- **Wind Turbine Model :**

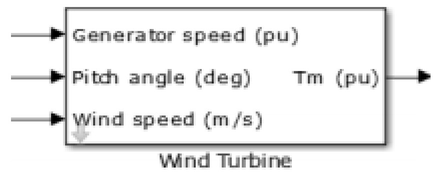


Fig 5.

The **Pm** aerodynamic power of wind turbine(W) is,

$$\mathbf{Pm=0.5Cp(\lambda,\beta)\rho A Vw^3}$$

Where ρ = air density =1.225 Kg/m^3 at T=288 K.

A = the blades swept area(m^2)(A=πR^2,R=radius of blade(m)=38m).

Vw = Wind speed upstream of the rotor(m/s) = 12m/s.

Cp(λ,β)= Power coefficient

β= Pitch angle.

λ = Tip speed ratio.

$$\lambda = \frac{R\,\bar{W}_m}{V}$$

Wm= Rotor speed of the wind speed.

When pitch angle β= 0 and bi speed ratio λ = 6.325 Cp is maximum value,

Cp Of the turbine is then divided by wind power and function of the wind speed, rotational speed, pitch angle.

These calculated values are added in Wind Turbine Model Block Parameters, as shown in Fig 6.

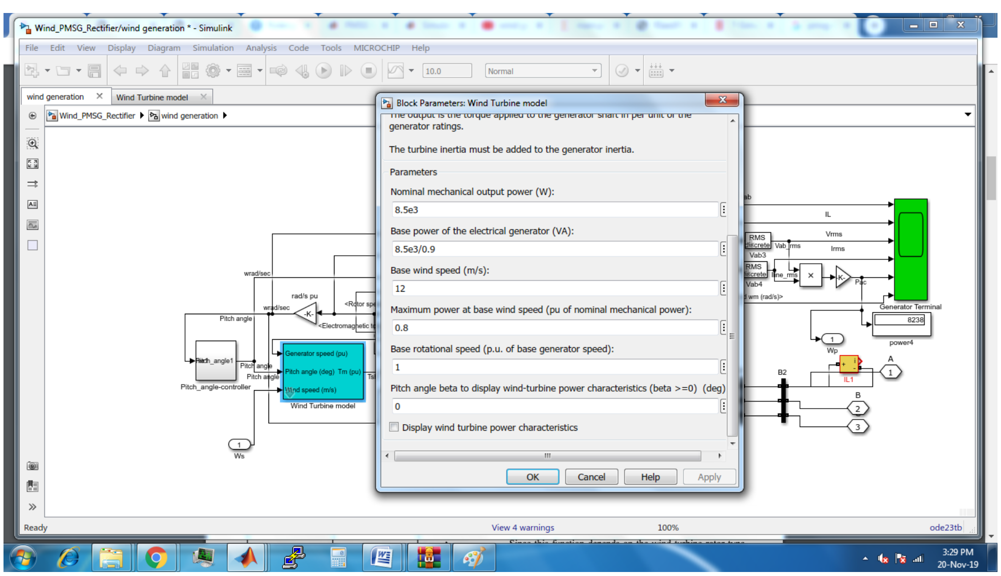


Fig 6.

Where Pw=8.5e3W,

Apparent Power(VA)=Actual Power(W)/Power Factor(pf) = 8.5e3/0.9,

V=12m/s,

Pmax=0.8pu,

Rotational speed(rpm)=1,

Pitch Angle=0.

The Plot/Characteristics curv for Cp vs λ, is shown in Fig 7.

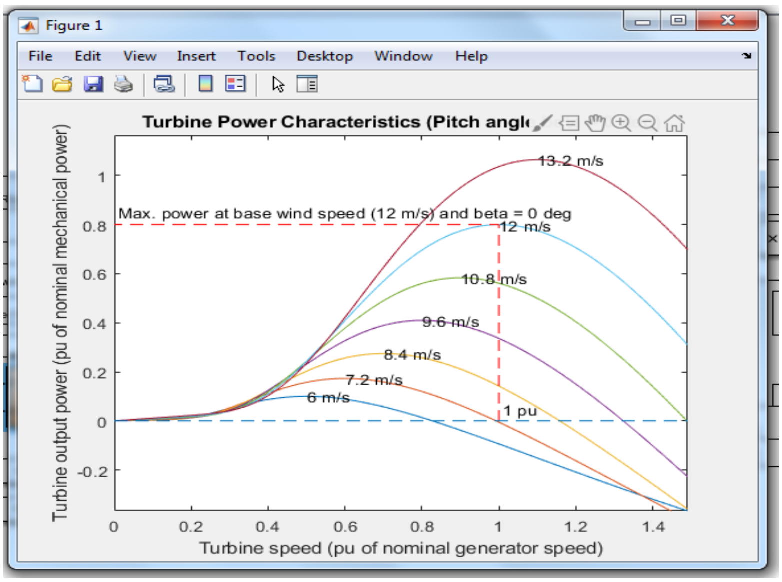
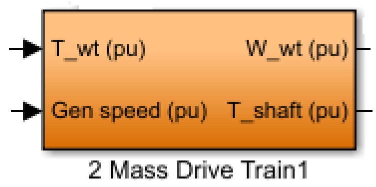


Fig 7.

- **2 Mass Drive Train :**
    - 2-mass model based wind turbine is used in this system for providing mechanical torque/input to Permanent Magnet Synchronous Generator(PMSG).
    - The drive train of a wind turbine generator system consists of blade-pitching mechanism with a spinner, a hub with blades, a rotor shaft and a gearbox with breaker and generator.
    - Gearbox is not considered because it causes greater weight, losses, costs and demands maintenance a gearless structure represents an efficient and robust answer.
    - The common way to model the drive train is to treat the system as a number of discrete masses connected together.
    - When the complexity of the study varies, the complexity of the drive train differs.



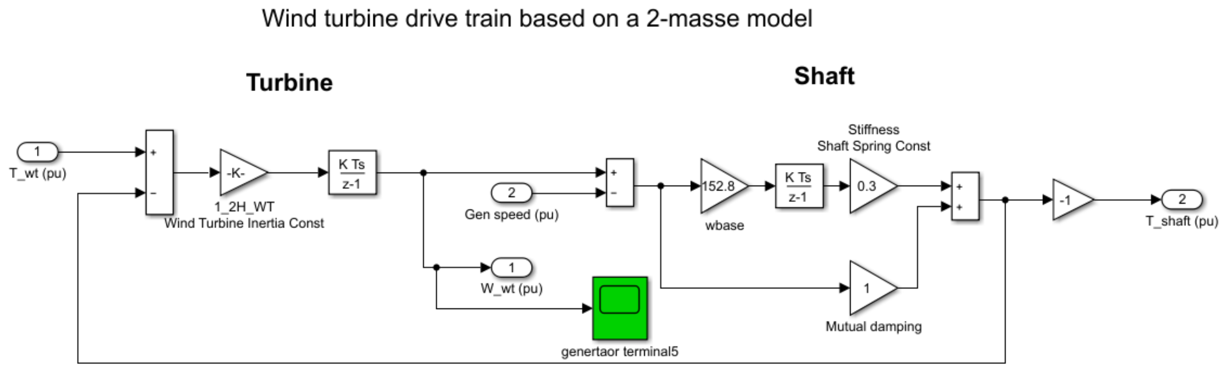


Fig 8.

- **PMSG :**
  Permanent Magnet Synchronous Generator(PMSG)

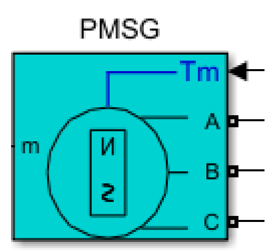


Fig 9.

  - The PMSG has been considered as a system which makes possible to produce electricity from the mechanical energy obtained from the wind.
  - The dynamic model of the PMSG is derived from the two phase synchronous reference frame.
  - The synchronization between the d-q rotating reference frame and the abc-three phase frame is maintained by utilizing a phase locked loop (PLL).

- 3-phase power generated from this system, changing wind velocity is also presented in this model.

- **Rectifire :**

  - Practically, the wind speed is constantly varying and so the PMSG produces variable-voltage and variable-frequency output. A three-phase diode rectifier is used to convert the output to dc.

- Phase controlled AC-DC converters employing thyristors are extensively used for changing constant ac input voltage to controlled dc output voltage. Fig no10. Shows the simulink model of three phase bridge rectifier.

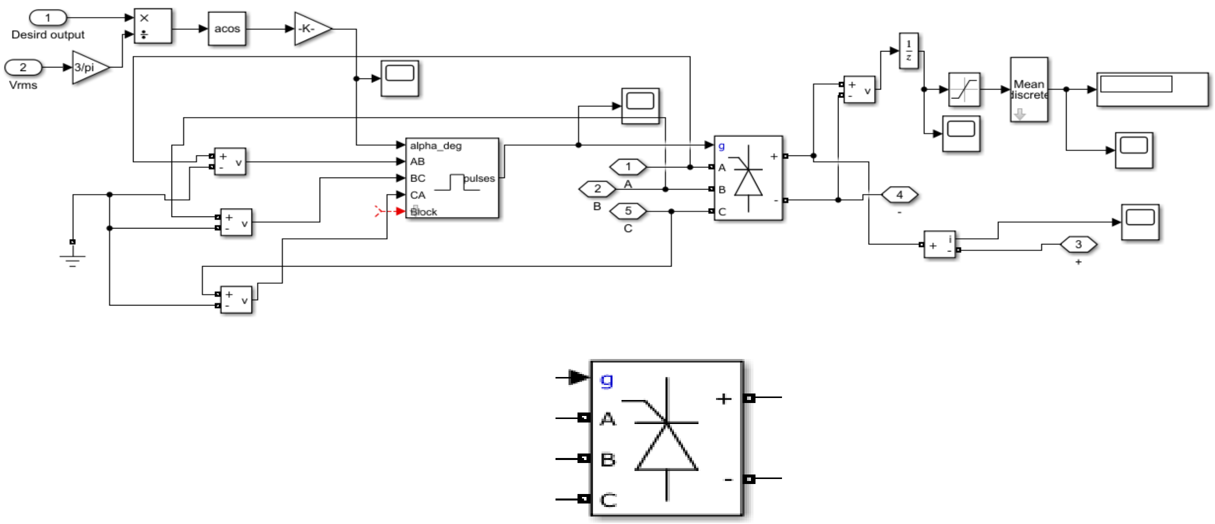


Fig 10.

- **Charge Controller(MPPT and Buck Converter) :**

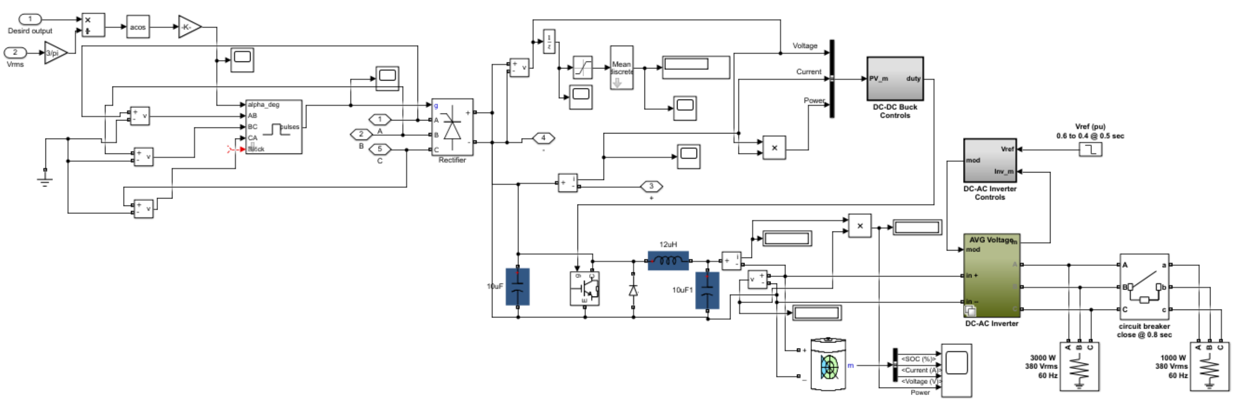


Fig 11.

DC-DC Buck Controls/MPPT :

- **MPPT**(Maximum Power Point Tracking) is used to track the peak power to maximize the produced energy. The maximum power point in the power voltage graph is identified by algorithms, that optimizes the match between the solar array (PV panels), and the battery bank or utility grid.
- PV module has nonlinear characteristics, it is necessary to model to make a complete utilization of solar energy in available time.

- Many maximum power point tracking algorithms are available for a solar panel in order to produce maximum output. It is very necessary that it is operated consistently at the maximum power point.
- The conventional MPPT methods are the **Perturb and Observe(P&O)** (Hill climbing) method, the **Incremental Conductance(INC)** method, **Fractional open circuit voltage** method and the **Fractional short circuit Current** method.

- Here we use **Fractional Open Circuit Voltage Algorithm**, here MPP voltage is always a constant fraction of the Voc, the Voc of the cell in the PV Array is measured and used as an input to the controller.
- It can be tried out for P&O and INC algorithms also.

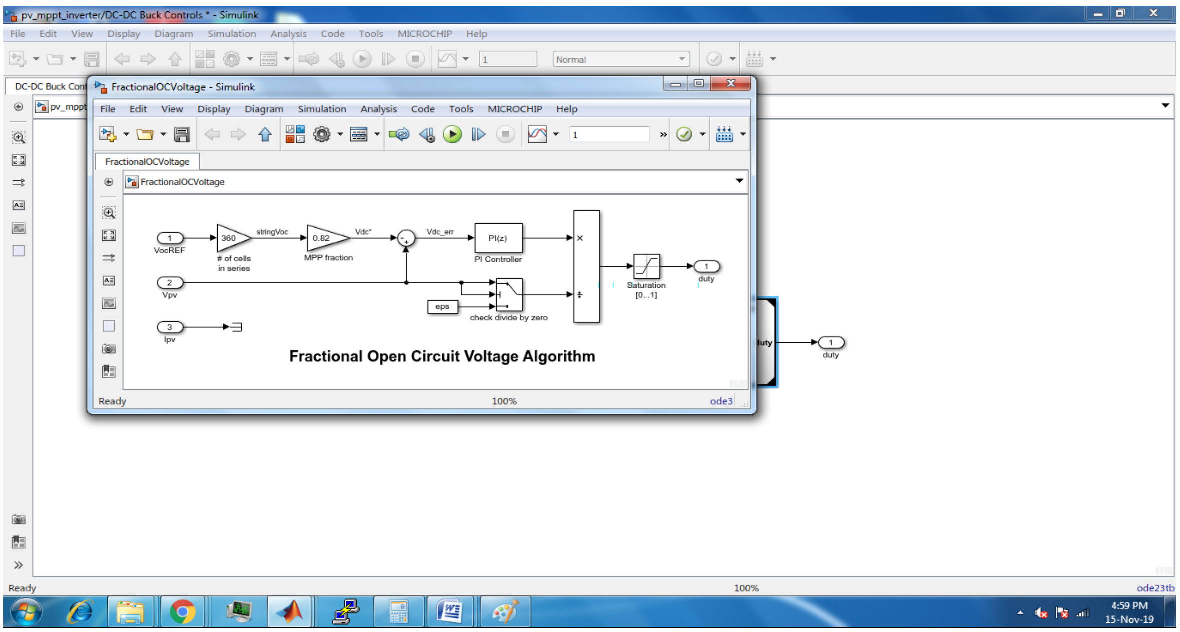


Fig 12.

DC-DC Buck Converter :

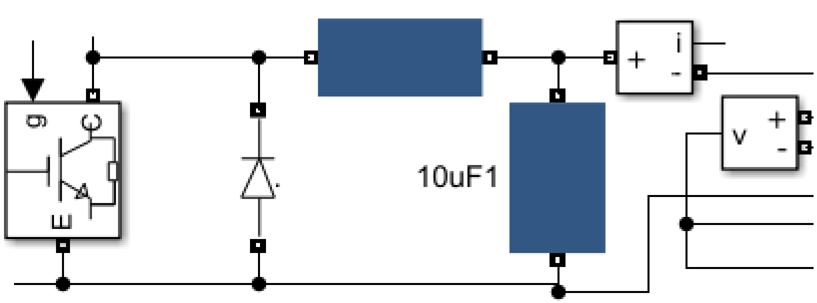


Fig 13.

- **Buck converter** steps down voltage from its input to its output. It is a class of switched-mode power supply typically containing at least two semiconductors and at least one energy storage element, a capacitor, inductor, or the two in combination.
- Hence Average Voltage Gain(AVG) is obtained by Voltage Source Converter(VSC) done by PWM which come from Buck converter to control output.

- **Battery Bank :**
  - Batterys are used to Charge and Discharge the Energy that is being generated.
  - Battery Charges and give energy to Inverter and when energy is not getting generated it Discharges and give energy to Inverter.
  - Battery value is set based on Battery Specification provided ie., Maximum **Voltage**(**v**) is **24** and Maximum **Capacity**(**Ah**) is **42**.

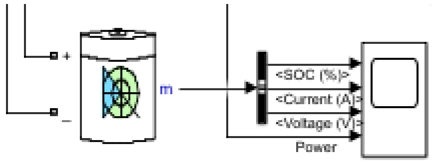


Fig 14.

- **DC-AC Inverter :**

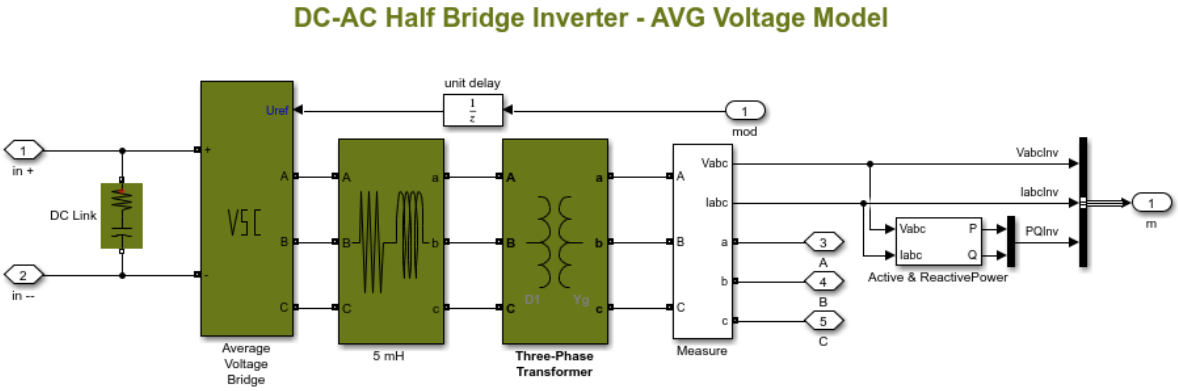


Fig 15.

- The converter is modeled using a 3-level bridge PWM-controlled. The inverters choke RL and a small harmonics filter C are used to filter the harmonics generated by the AVG Bridge.
- A three-phase transformer is used to connect the inverter to the utility distribution system.

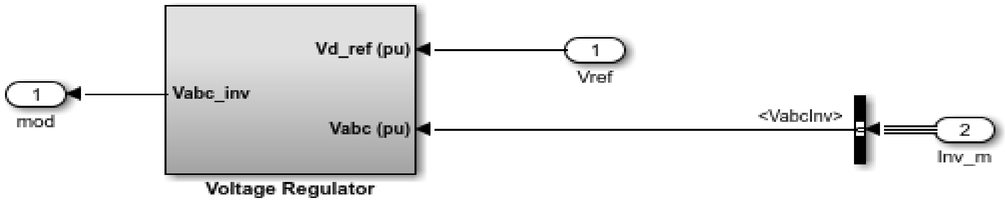


Fig 16.

- In order to enable the inverter to track the maximum power output, the output of the wind turbine generator must be controlled by adjusting the modulation index M of the reference sinusoidal signal of the PWM inverter.
- The sensor less controller is designed to determine the operating dc voltage of the inverter at various speeds.
- This action is achieved by controlling the pulse width of the inverter.
- Hence Inverter converts the DC power into 3 phase AC power and it is regulated to a desired set point voltage for a fixed load that will limit the current flowing through the inverter.

And hence it is supplied to the house appliances using Circuit Breaker.

Simulation :

- Run the simulation by Pressing Run Button  and observe the resulting signals on the various scopes.

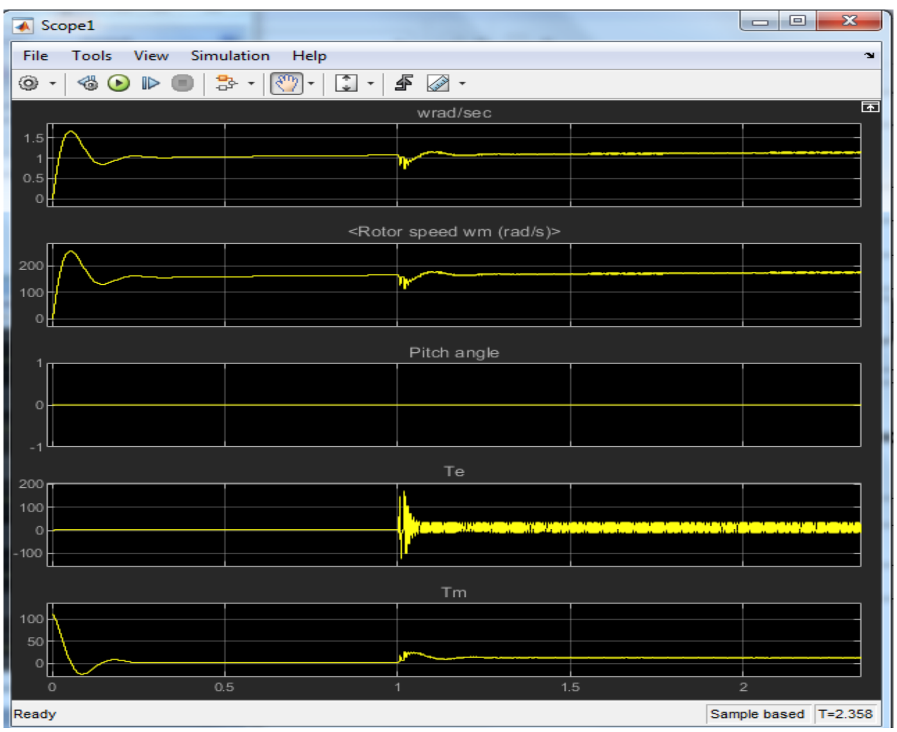


Fig 17.

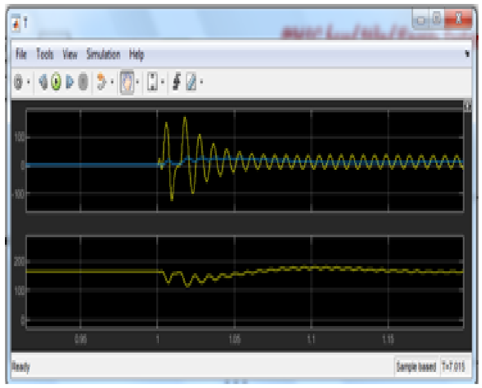


Fig 18.

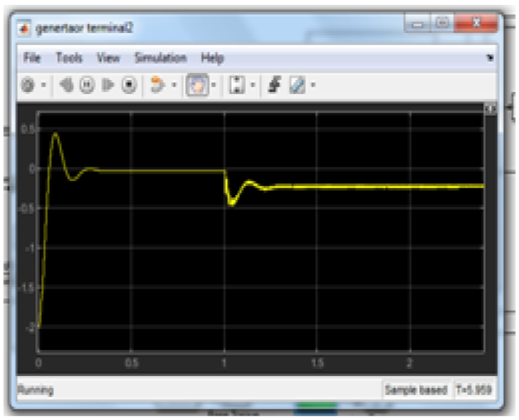


Fig 19.

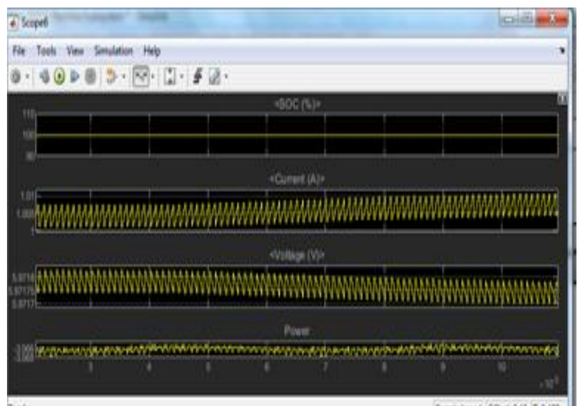


Fig 20.

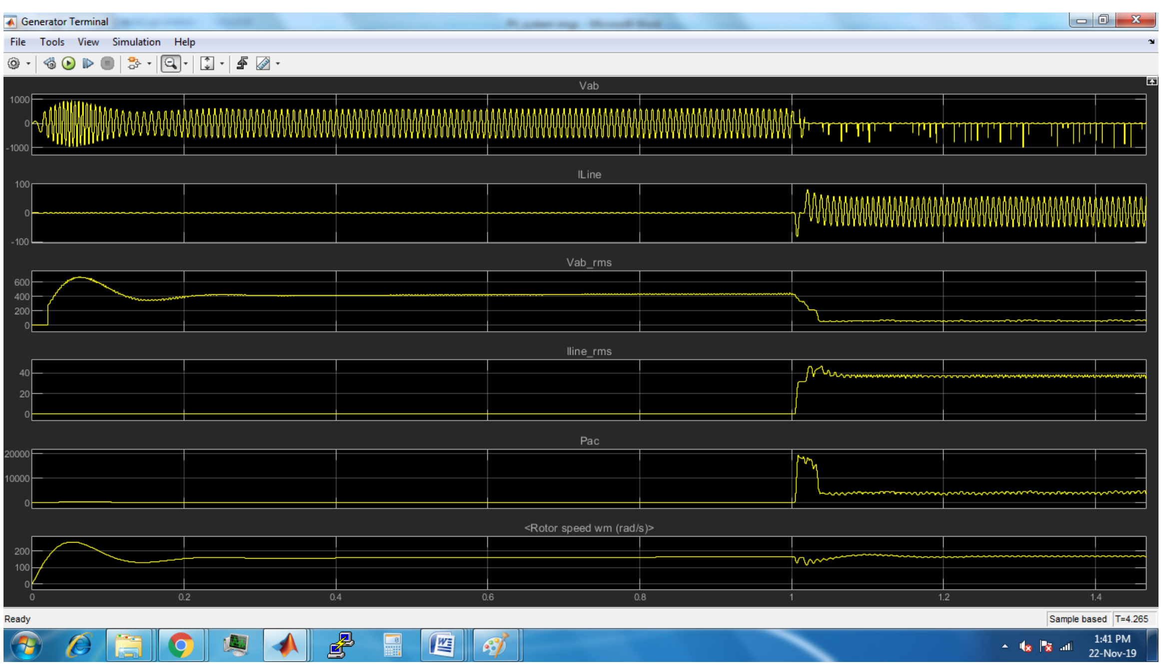


Fig 21.

Figures 17, 18, 19, 20 and 21 show different characteristics of the simulated wind system.

Fig 17, represent the variation of Rotor speed with Gain, Rotor speed without Gain, Pitch Angle = 0, ElectroMagnetic Torque and Torque to drive the generator.Here we can see as Torque to drive the generator decreases the Rotor speed increases and goes constant at time T=1.2sec.And Torque is provided to PMSG from time T=1sec.

Fig 18, represent the Torque and Rotor speed. Here we can see how Torque is getting Generated and based on which Rotor speed is being Produced as they are inversely proportional. For step change in wind speed from 10 to 12m/s is shown with respect to time in seconds, caused a very small change in the speed (from 180rad/s to 190rad/s).

Fig 19, represent the Shaft movement.

Fig 20, represent the state of charge SOC%, battery Current (A), battery terminal Voltage (v), output Power (w).

Fig 21, represent the Vab, ILine, Vab_rms, ILine_rms, Pac and Rotor Speed wm. Here we can see how voltage and current are inversely proportional as ILine_rms increases the Vab_rms decreases and power is the multiple of IV.

RESULT:

Thus the Simulation study on Wind Energy System is done.

Experiment 6.4:

Aim:- Simulation study on Hybrid PV Solar and Wind Energy System Generator.

Apparatus:

- PC with Mat Lab software.

Diagram :

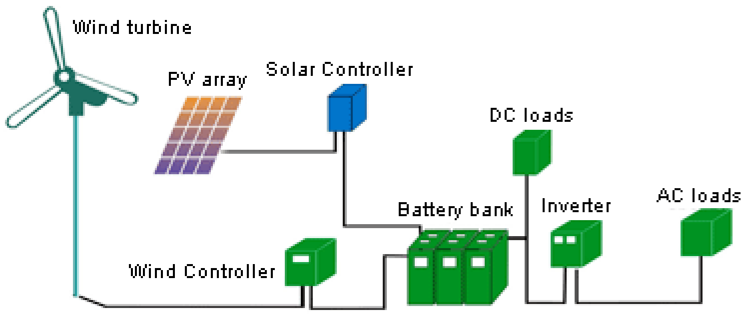


Fig 1.

This hybrid system allows maximum utilization of freely available renewable energy sources like wind and photovoltaic energies. An adaptive MPPT algorithm will be used for the system.

This configuration allows the two sources to supply the load separately or simultaneously depending on the availability of the energy sources. The turbine rotor speed is the main determinant of mechanical output from wind energy and Solar cell operating voltage in the case of output power from solar energy. Permanent Magnet Synchronous Generator is coupled with wind turbine for attaining wind energy conversion system.

Procedure :

- Double click and open the Simulink model of wind. Fig 2. Shows the simulink model.

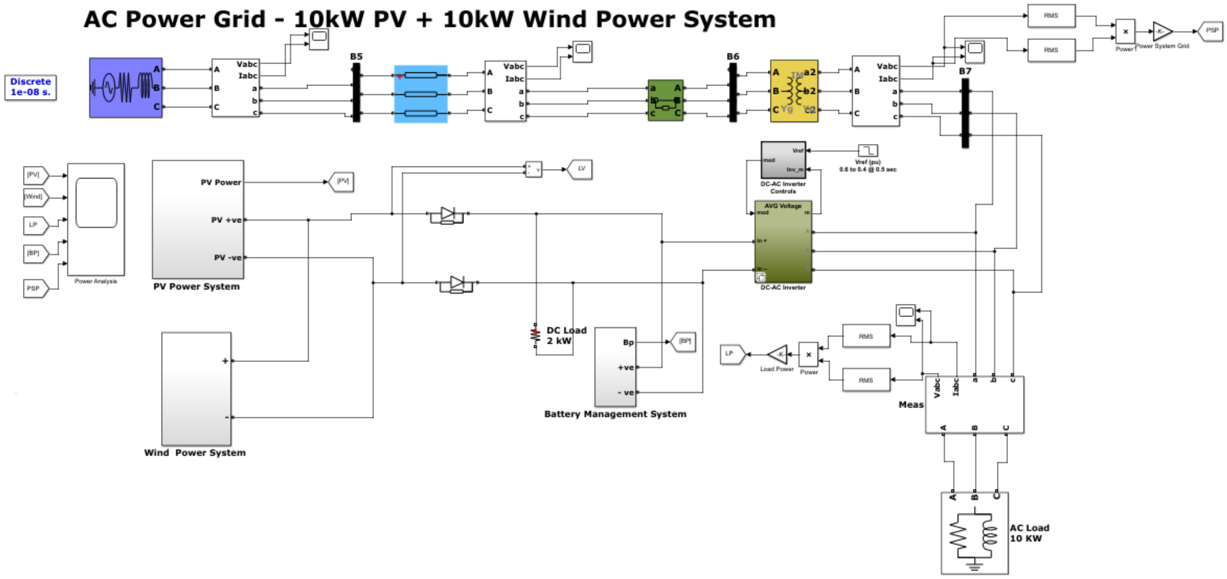
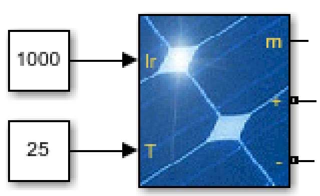


Fig 2.

Each Block Explanation :

- **PV Power System :**
  - **PV Array :**

    Irradiance is 1000 and Temperature is 25.
    Parallel strings is 7 and series is 5 = 7*5 = 35.
    Module selected is LG300 = 35*300 = 10500 = 10 kw Panel Power.



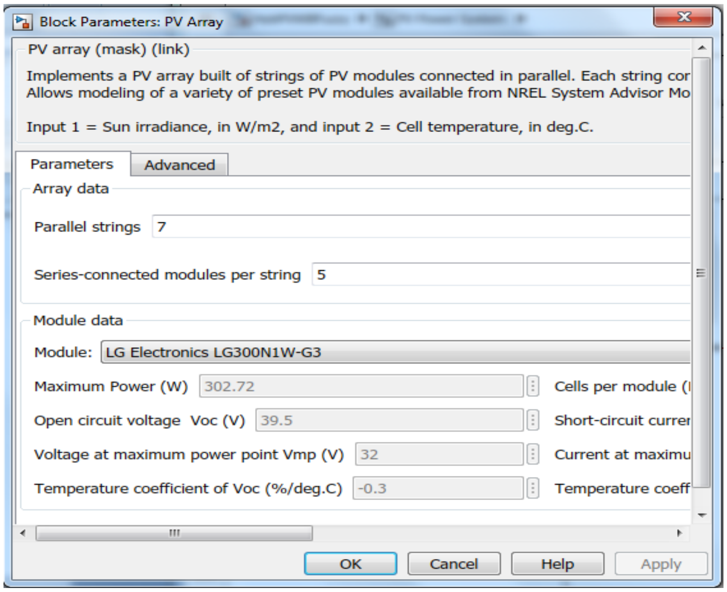


Fig 3.

- **MPPT Controller :**

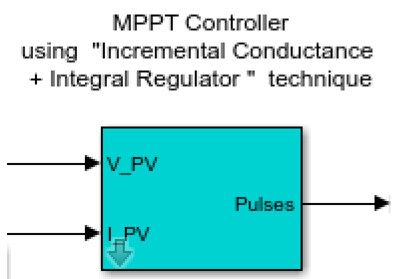


Fig 4.

- **MPPT**(Maximum Power Point Tracking) is used to track the peak power to maximize the produced energy.

- PV module has nonlinear characteristics, it is necessary to model to make a complete utilization of solar energy in available time.

- Many maximum power point tracking algorithms are available for a solar panel in order to produce maximum output. It is very necessary that it is operated consistently at the maximum power point.

- The conventional MPPT methods are the **Perturb and Observe(P&O)** (Hill climbing) method, the **Incremental Conductance(INC)** method, **Fractional open circuit voltage** method and the **Fractional short circuit Current** method.

- Here we use **Incremental Conductance(INC) Algorithm**, here it will identify the suitable duty cycle ratio in which converter should operate to maximum point, that optimizes the match between the solar array (PV panels), and the battery bank or utility grid.

- **INC** offers the main advantage of providing high efficiency under rapidly changing atmospheric conditions, so it has been employed in the model.

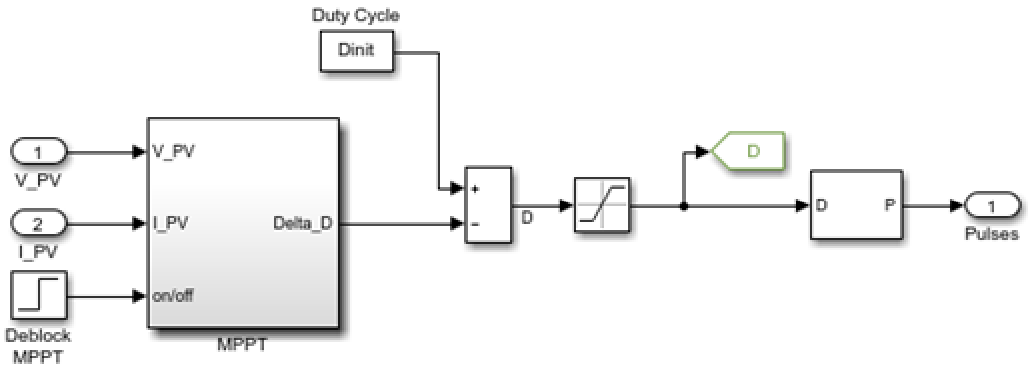


Fig 5.

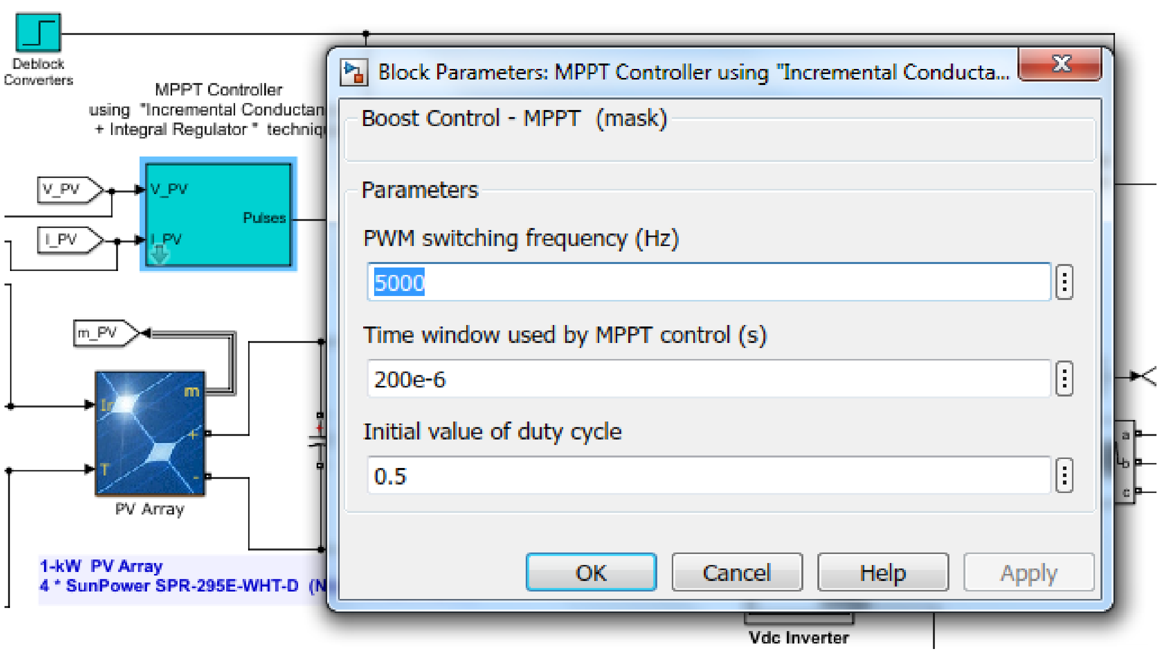


Fig 6.

We can set frequency and initial duty cycle for MPPT based on which it works.

- Switching duty cycle is optimized by a MPPT controller that uses the 'Incremental Conductance + Integral Regulator' technique.
- This MPPT system automatically varies the duty cycle in order to generate the required voltage to extract maximum power.

- **DC-DC Boost Converter :**

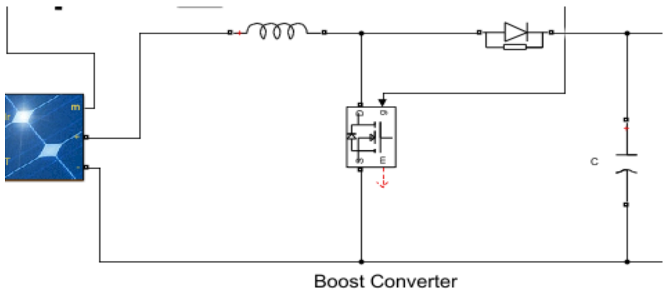


Fig 7.

  - **Boost converter** steps up voltage from its input to its output.

Wind Power System :

- **Wind Generation :**

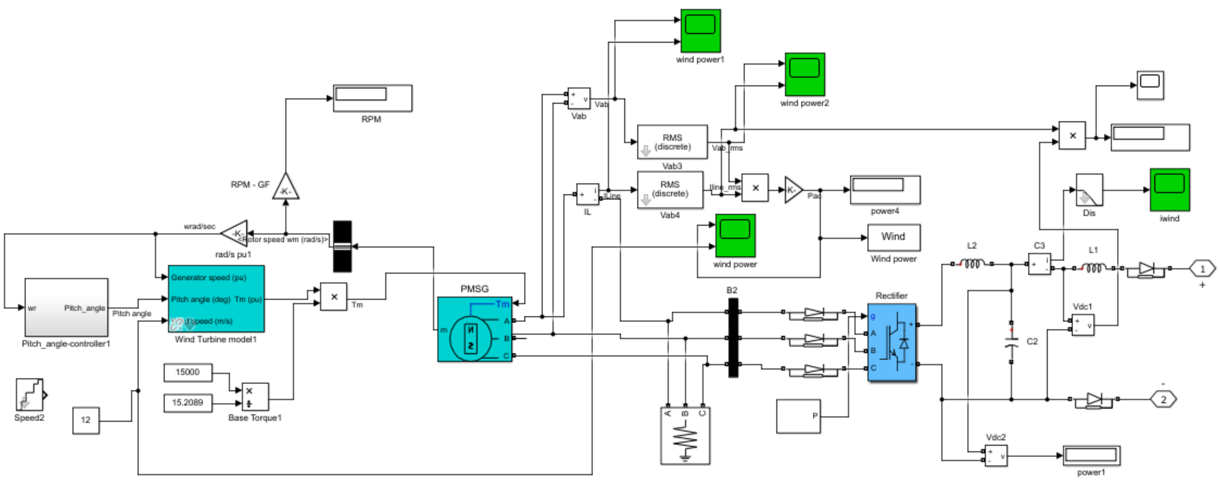


Fig 8.

- **Wind Speed :**

The present work considers a constant wind speed equal to 12 m/s. Consequently, the model implementation of the wind speed in Simulink implies the consideration of the base wind speed component. Shown in Fig 3,

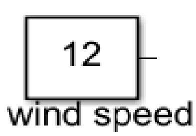


Fig 9.

- **Wind Turbine Model :**

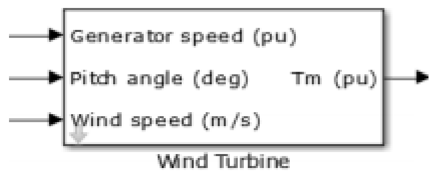


Fig 10.

The **Pm** aerodynamic power of wind turbine(W) is,

$$\mathbf{Pm=0.5Cp(\lambda,\beta)\rho AVw^3}$$

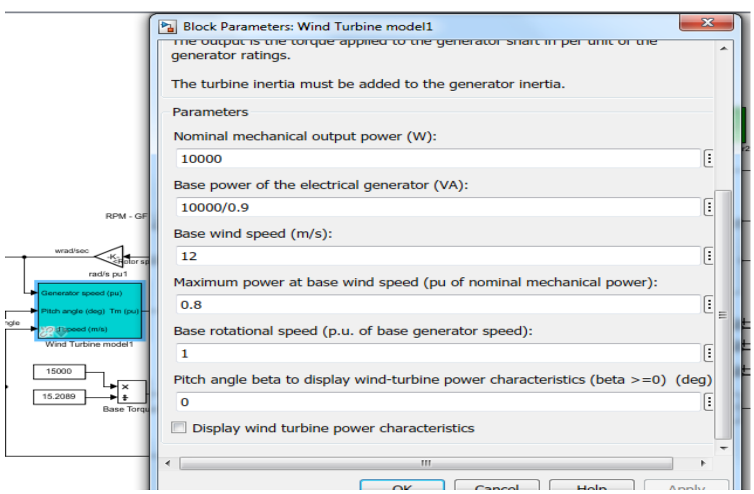


Fig 11.

Where Pw=10000,

Apparent Power(VA)=Actual Power(W)/Power Factor(pf) = 10000/0.9,

V=12m/s,

Pmax=0.8pu,

Rotational speed(rpm)=1,

Pitch Angle=0.

- **PMSG :**
  Permanent Magnet Synchronous Generator(PMSG)

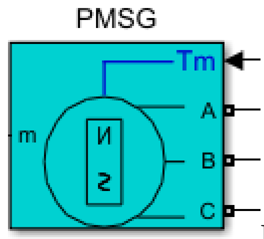


Fig 12.

  - The PMSG has been considered as a system which makes possible to produce electricity from the mechanical energy obtained from the wind.
  - The dynamic model of the PMSG is derived from the two phase synchronous reference frame.
  - The synchronization between the d-q rotating reference frame and the abc-three phase frame is maintained by utilizing a phase locked loop (PLL).

  3-phase power generated from this system, changing wind velocity is also presented in this model.

- **Rectifire :**

    - Practically, the wind speed is constantly varying and so the PMSG produces variable-voltage and variable-frequency output. A three-phase diode rectifier is used to convert the output to dc.
    - Phase controlled AC-DC converters employing thyristors are extensively used for changing constant ac input voltage to controlled dc output voltage. Fig no. shows the simulink model of three phase bridge rectifier.

➢ **To Resist the high Current and Voltage flow to Battery we use Diode in parallel with series RC Snubber circuit and DC Load.**

➢ **Battery Management System :**

- **Battery Bank :**

- Batterys are used to Charge and Discharge the Energy that is being generated.
- Battery Charges and give energy to Inverter and when energy is not getting generated it Discharges and give energy to Inverter.
- Battery value is set based on Battery Specification provided ie., Maximum **Voltage**(**v**) is **200** and Maximum **Capacity**(**Ah**) is **50**.
- It is converted to Bi-directional via Battery/electrolyzer controller.

- **DC-AC Inverter :**

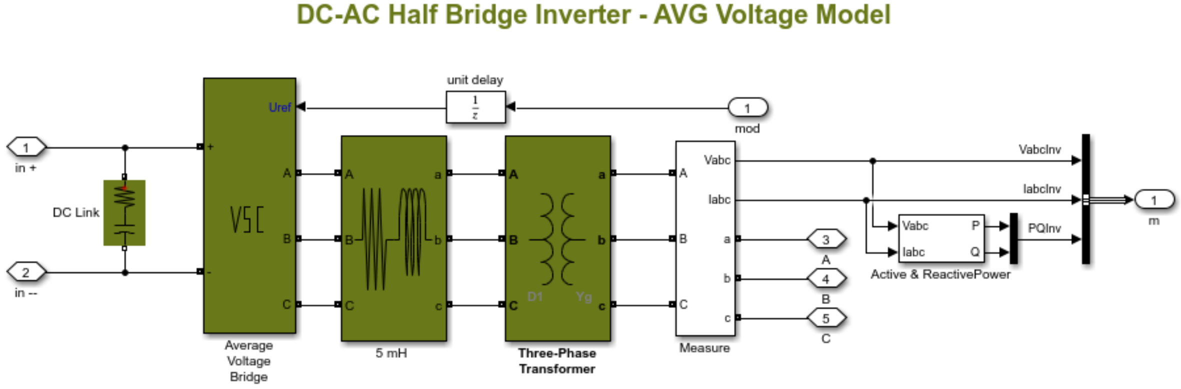


Fig 8.

- The converter is modeled using a 3-level bridge PWM-controlled. The inverters choke RL and a small harmonics filter C are used to filter the harmonics generated by the AVG bridge.
- A three-phase transformer is used to connect the inverter to the utility distribution system.

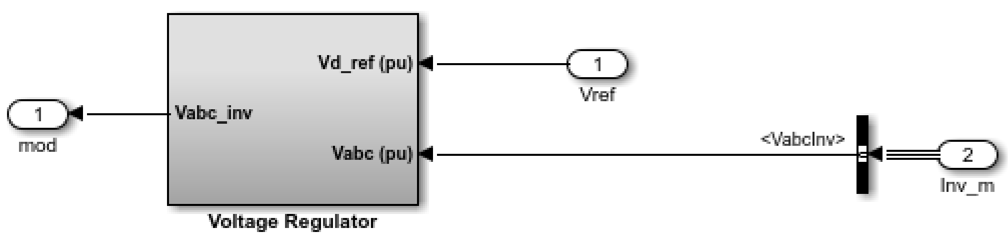
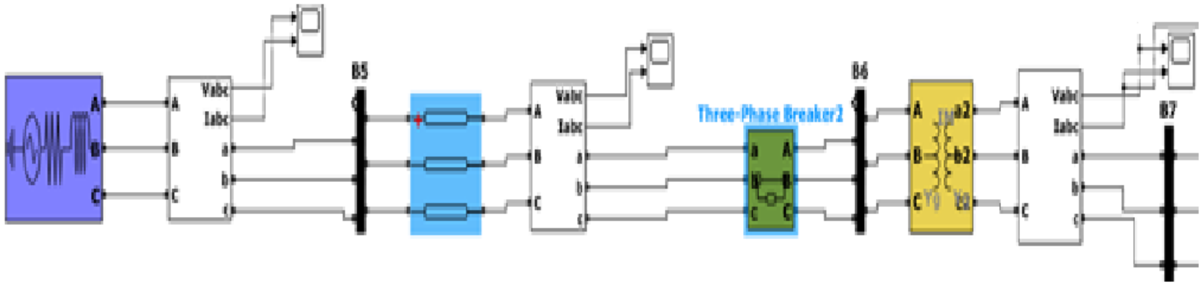


Fig 9.

- Hence DC is converted to AC signal and it is regulated to a desired set point voltage for a fixed load that will limit the current flowing through the inverter.
- It is given to Three Phase VI-Measurements and then to AC load.
- Through Three Phase Selector the power is sent again to Three Phase VI-Measurements which is given to grid and to Three Phase Transformer Inductance to boost voltage level and decrease line losses, each Phase is open and closed by Three Phase Breaker and have used Load to resist the high VI flow, which is then given to AC Appliances.



And hence it is supplyed to the house appliances using Circuit Breaker.

Simulation :

- Run the simulation by Pressing Run Button and observe the resulting signals on the various scopes.
- Figures 16, 17, 18, 19, 20, 21, 22, 23 and 24 show different characteristics of the simulated Hybrid PV and wind system.

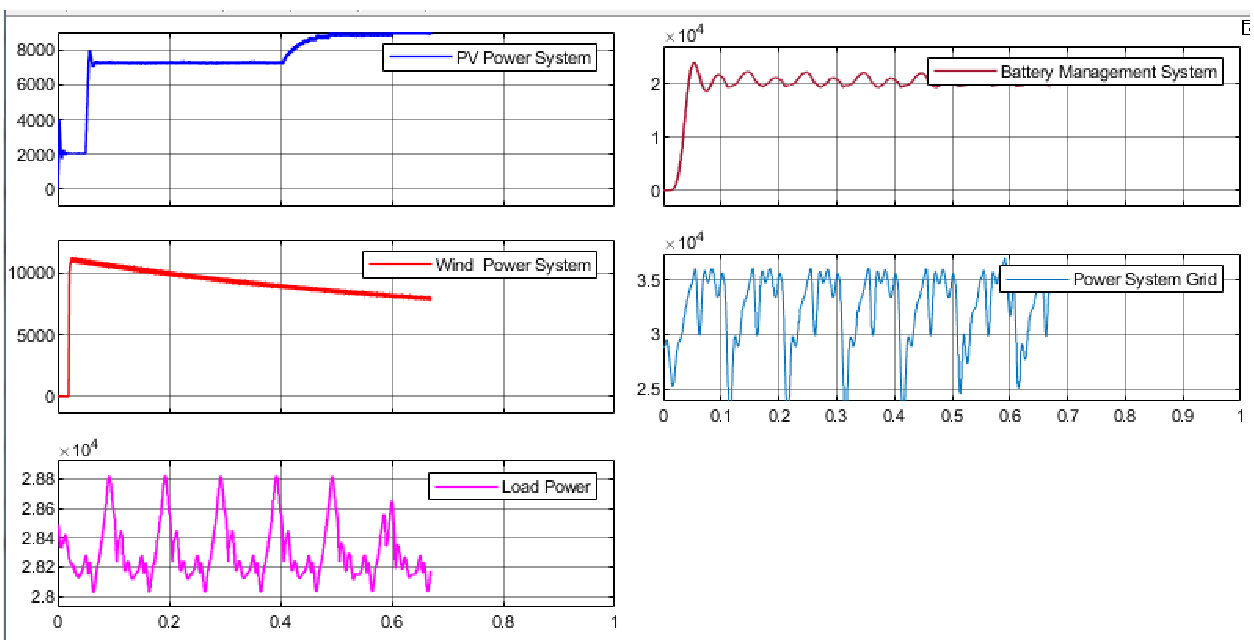


Fig 16.

Fig 16, represent the variation of PV Power System, Wind Energy, Load Power(LP), Battery Power(BP) and Power System Grid(PSP). Here we can see that we get high Solar Energy and Wind Energy is Produced and the Power getting generated in each stage.

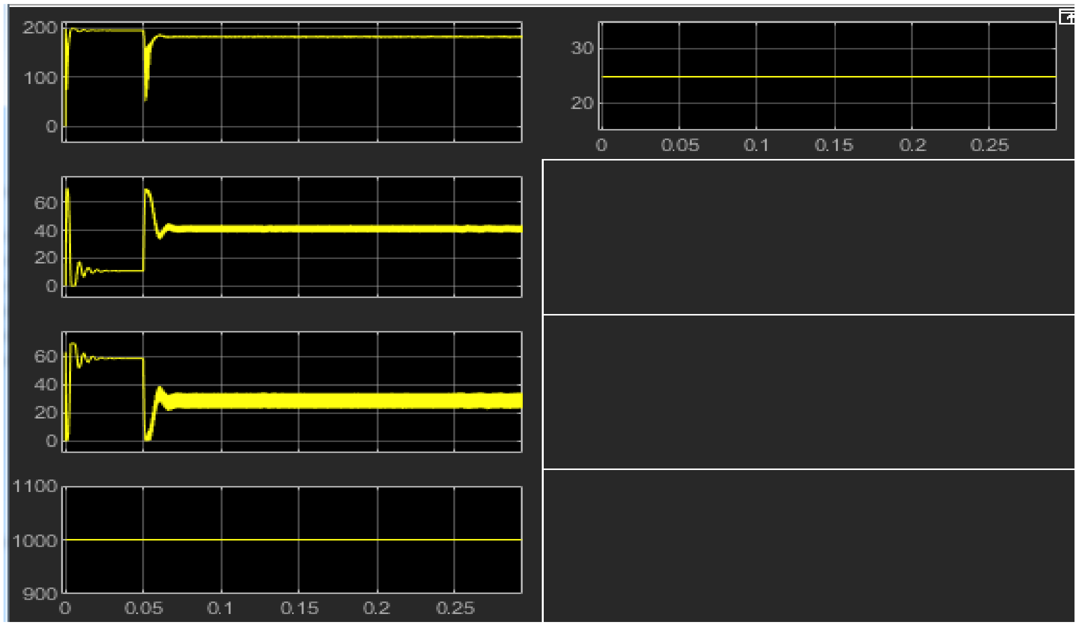


Fig 17.

Fig 17, represent the variation of Power Voltage, Current, IDiode, Irradiance(1000w/m²) and Temperature(25deg c) of Solar PV System.

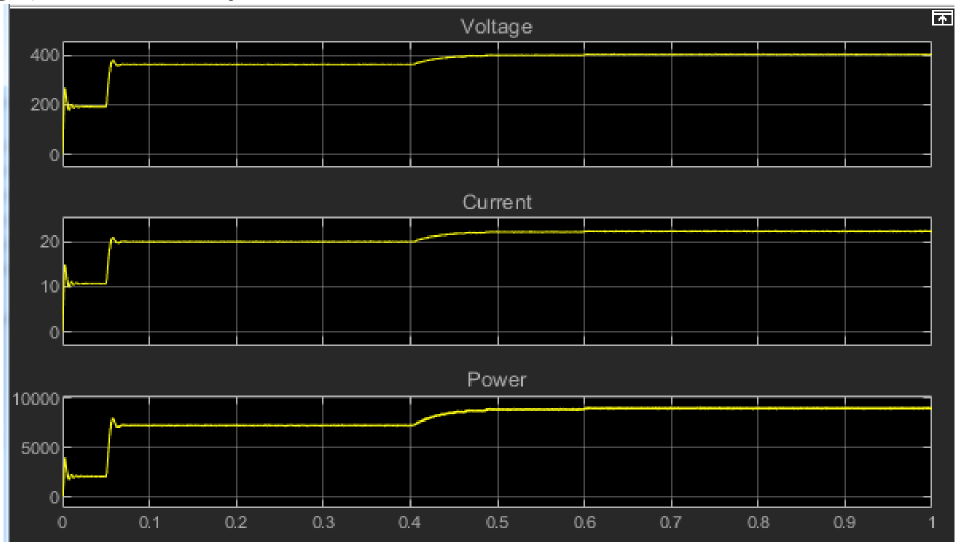


Fig 18.

Fig 18, represent the variation of Voltage, Current and Power after the Boost Circuit in Solar PV System. We see how Power Increases as Voltage and Current Increases.

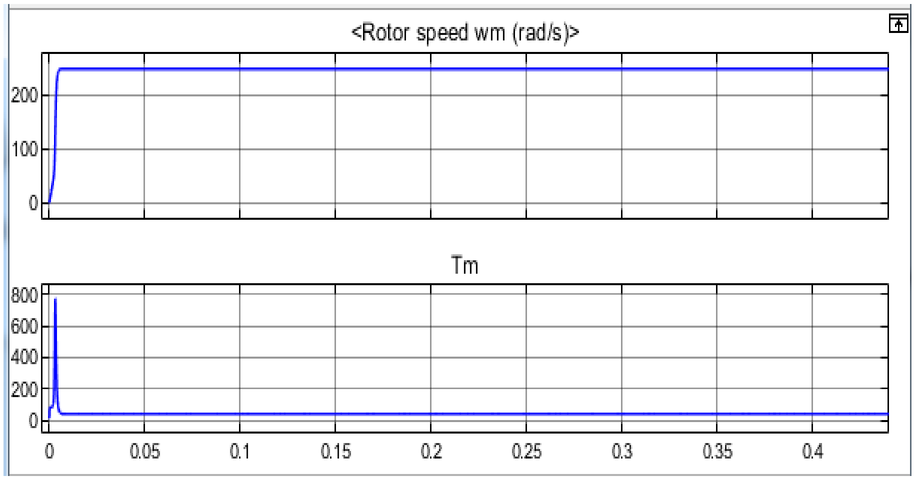
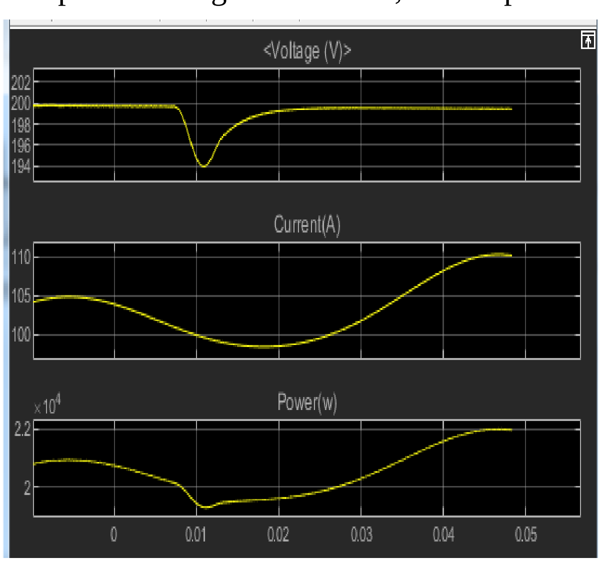


Fig 19.

Fig 19, represent the Rotor speed and Torque. Here we can see how Torque is getting Generated and based on which Rotor speed is being Produced ie., Rotor speed increases as Torque decreases.



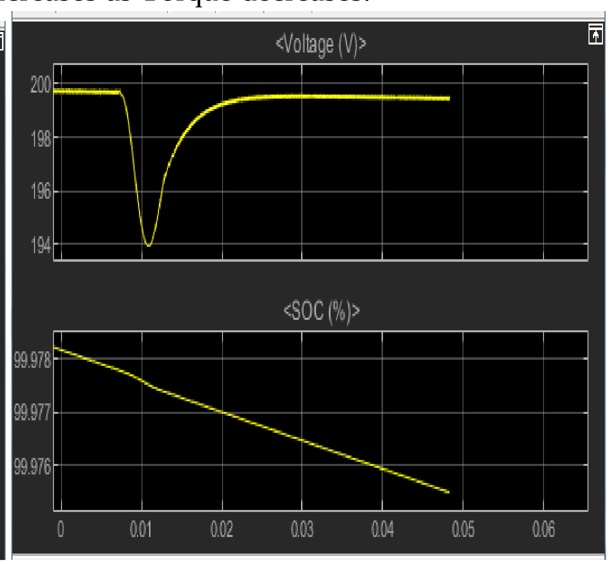
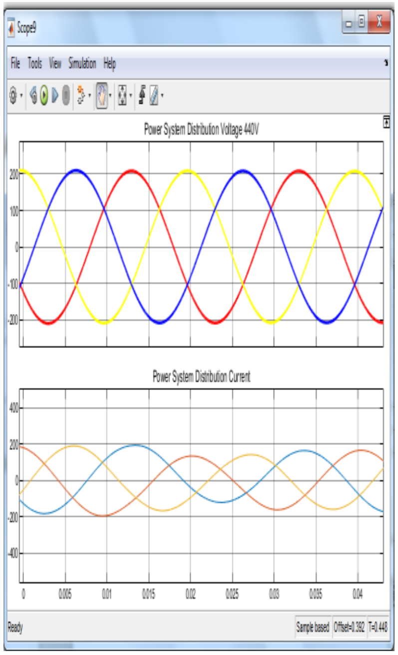
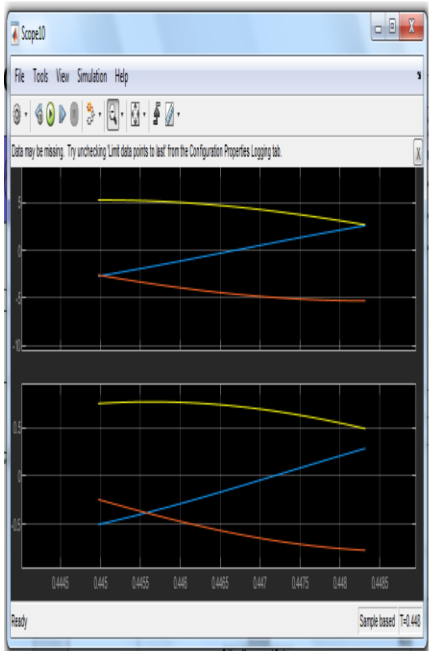


Fig 20. Fig 21.

Fig 20, represent the Voltage, Current and Power of Wind Energy System. We see how Power Increases as Voltage and Current Increases.

Fig 21, represent the Voltage(V) and state of charge SOC%.





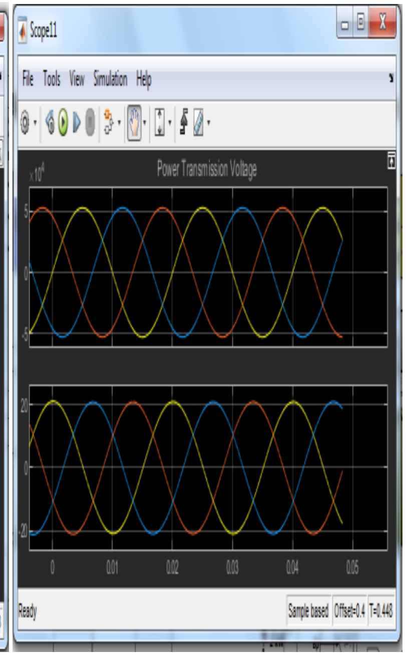


Fig 22.　　Fig 23.　　Fig 24.

Fig 22,23 and 24, represent the Voltage(Vabc) and Current(Iabc). As it is supplied to Grid the voltage and current passes through each stage before it is used by application ie., **Fig 22** is the distribution voltage and current supply from Inverter, **Fig 23** is the supply that is processed through Three Phase Transformer Inductance to boost voltage level and decrease line losses, each Phase is open and closed by Three Phase Breaker and then the VI is Plotted, **Fig 24** is the supply that used Load to resist the high VI flow, then the VI is Plotted.

Hence the supply is then given to AC Appliances.

RESULT:

Thus the Simulation study on Hybrid PV Solar and Wind Energy System Generator is done.

Experiment 6.5:

Aim:- Simulation study on Intelligent Controllers for Hybrid PV Solar and Wind Energy System Generator.

Apparatus:

- PC with Mat Lab software.

Diagram :

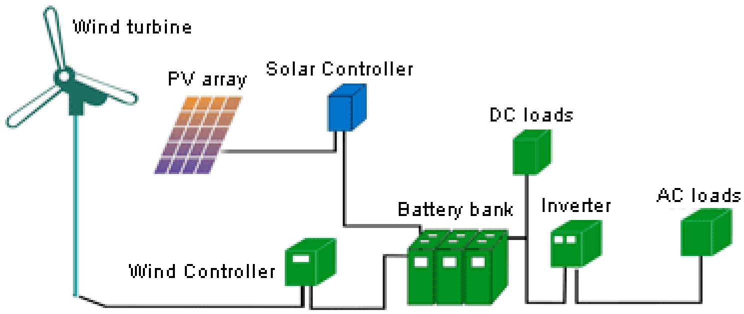
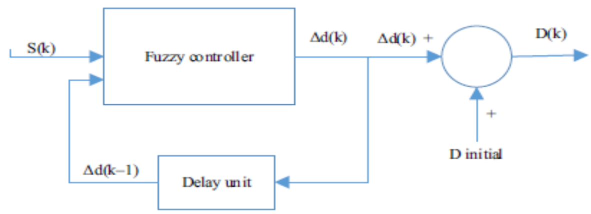


Fig 1.

This hybrid system allows maximum utilization of freely available renewable energy sources like wind and photovoltaic energies. An adaptive MPPT algorithm will be used for the system along with Fuzzy logic.

FLC is the most widely used MPPT technique because of its faster response time, better accuracy and greater robustness than the conventional and the artificial-intelligence-based techniques, The conventional FLC includes the input parameters of the error (E) and the change of error (CE), where E is the change of power divided by the change of voltage or current, and CE is the derivative of E, while the output of the FLC is the change in the duty ratio (d).



The first input is the error or the slope tangent of the P-I curve at which the location of the operating point is indicated. The second input is the previous change of duty ratio d(k-1) that moves the operating point to reach the MPP, while the output is the new implied change of duty ratio (d).

This MPPT Fuzzy logic is used for **SPV**, **Wind, Battery** and also with **Inverter** that is why we call it as **intelligent controller**.

Procedure :

- Double click and open the Simulink model of IC Hybrid. Fig 2, Shows the simulink model.

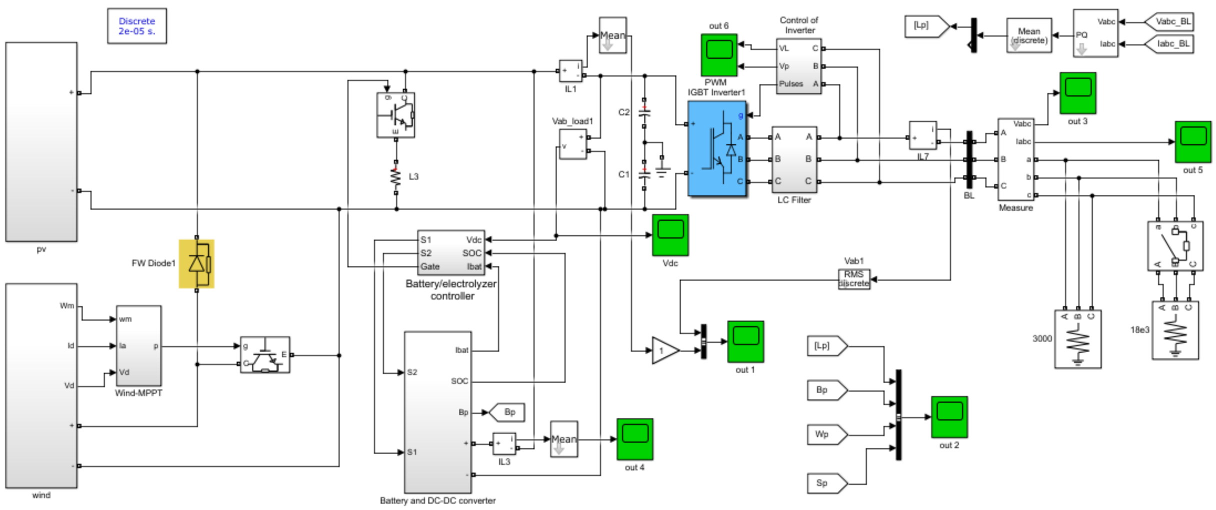


Fig 2.

Note : In Command Window type a command below to add this fuzzy control to model.

>> FUZZY=readfis('FUZZY.fis');

Each Block Explanation :

- **PV Power System :**

  - **PV Array :**
    PV Array cell is designed with irradiance of 1000w/m2.

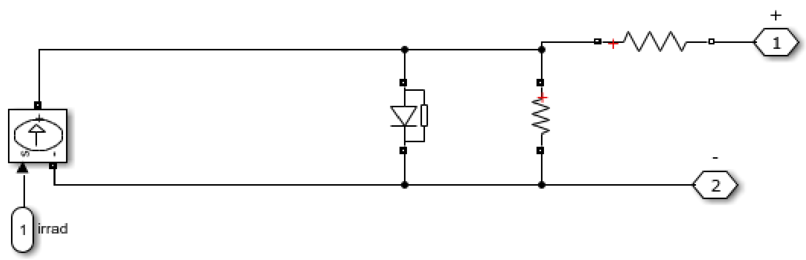


Fig 3.

  - **MPPT Controller :**

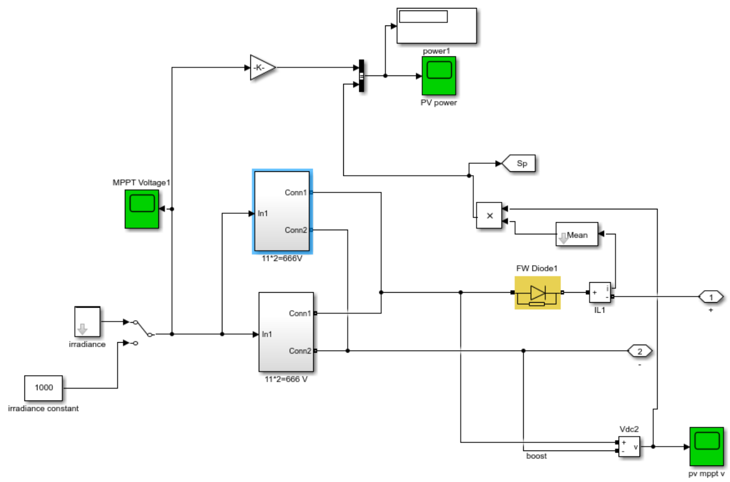


Fig 4.

- **DC-DC Boost converter** step-up voltage from its input to its output.

Wind Power System :

- **Wind Generation :**

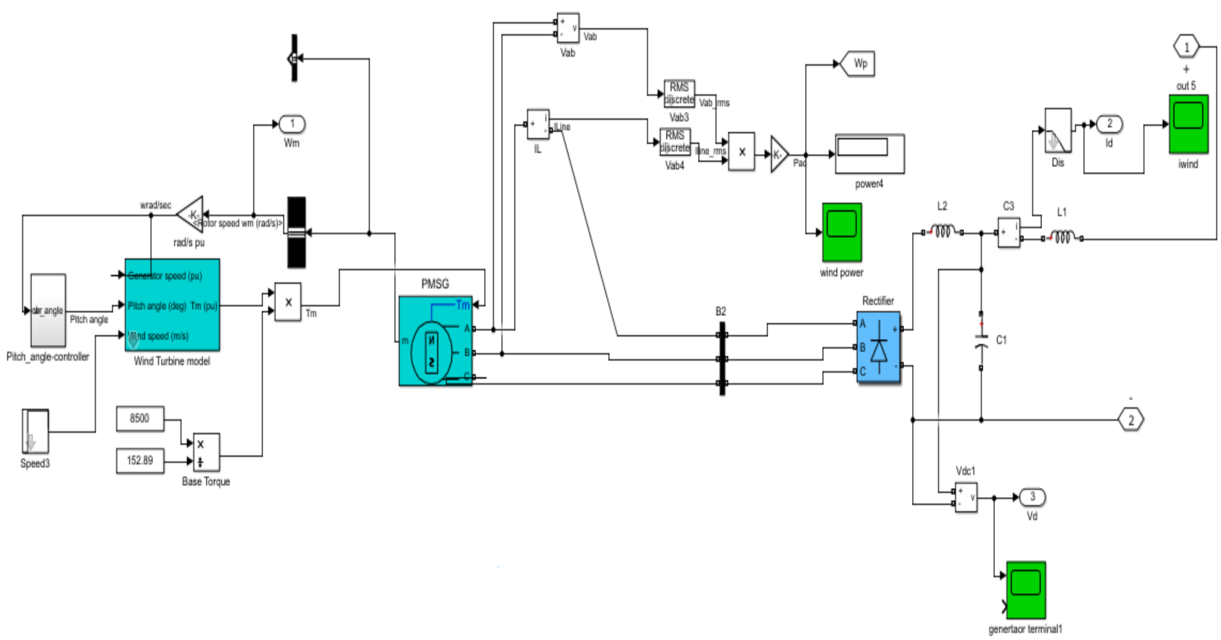


Fig 5.

- **Wind Speed :**

The present work considers a base wind speed equal to 12 m/s. Consequently, the model implementation of the wind speed in Simulink implies the consideration of the base wind speed component.

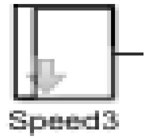


Fig 6.

- **Wind Turbine Model :**

Fig 7.

The **Pm** aerodynamic power of wind turbine(W) is,

$$\mathbf{Pm=0.5Cp(\lambda,\beta)\rho AVw^3}$$

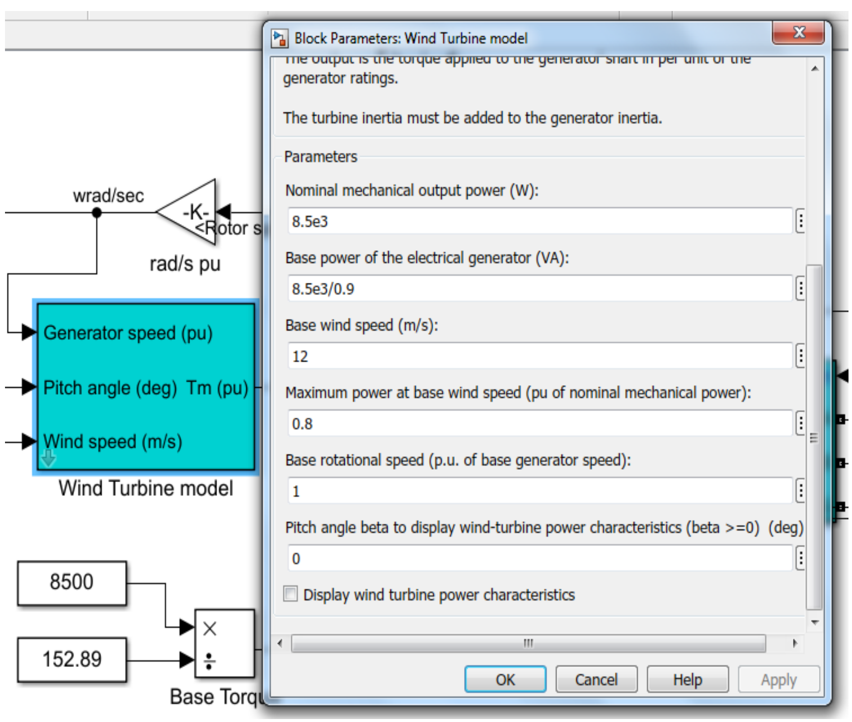


Fig 8.

Where Pw= 8.5e3,

Apparent Power(VA)=Actual Power(W)/Power Factor(pf) = 8.5e3/0.9,

V=12m/s,

Pmax=0.8pu,

Rotational speed(rpm)=1,

Pitch Angle=0.

- **PMSG :**
  Permanent Magnet Synchronous Generator(PMSG)

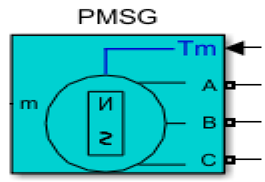


Fig 9.

  - The PMSG has been considered as a system which makes possible to produce electricity from the mechanical energy obtained from the wind.
  - The dynamic model of the PMSG is derived from the two phase synchronous reference frame.
  - The synchronization between the d-q rotating reference frame and the abc-three phase frame is maintained by utilizing a phase locked loop (PLL).

    3-phase power generated from this system, changing wind velocity is also presented in this model.

- **Rectifire :**

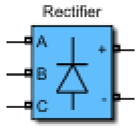


Fig 10.

  - Practically, the wind speed is constantly varying and so the PMSG produces variable-voltage and variable-frequency output. A three-phase diode rectifier is used to convert the output to dc.
  - Phase controlled AC-DC converters employing thyristors are extensively used for changing constant ac input voltage to controlled dc output voltage. Fig no.10 shows the simulink model of three phase bridge rectifier.

  - **MPPT Controller :**

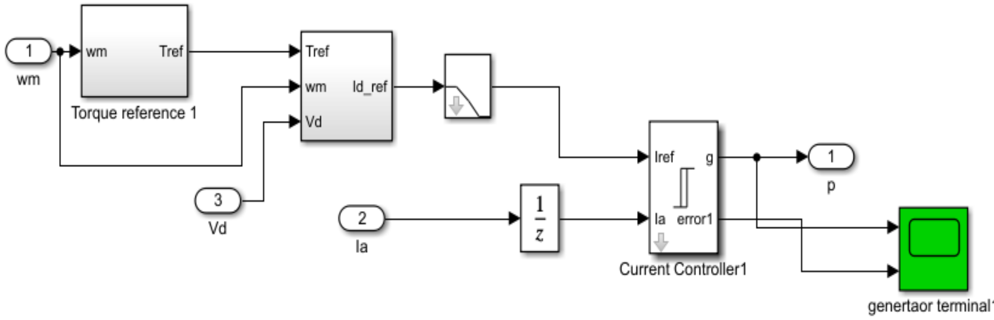


Fig 11.

- **DC-DC Boost Converter :**

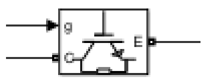


Fig 12.

- **Boost converter** steps up voltage from its input to its output.

➢ **Battery Management System :**

- **Battery Bank and DC-DC converter:**

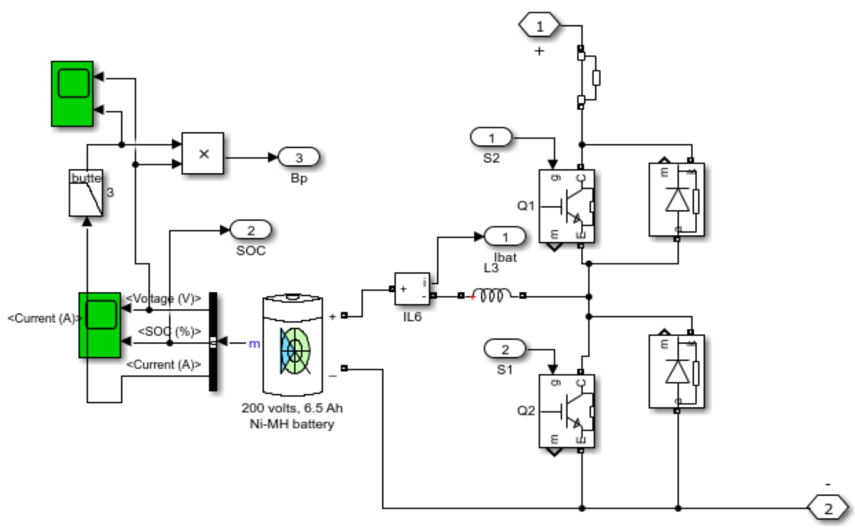


Fig 13.

- Batterys are used to Charge and Discharge the Energy that is being generated.
- Battery Charges and give energy to Inverter and when energy is not getting generated it Discharges and give energy to Inverter.

- It is converted to Battery/electrolyzer controller which is a fuzzy control.

  - **Fuzzy Controller :**

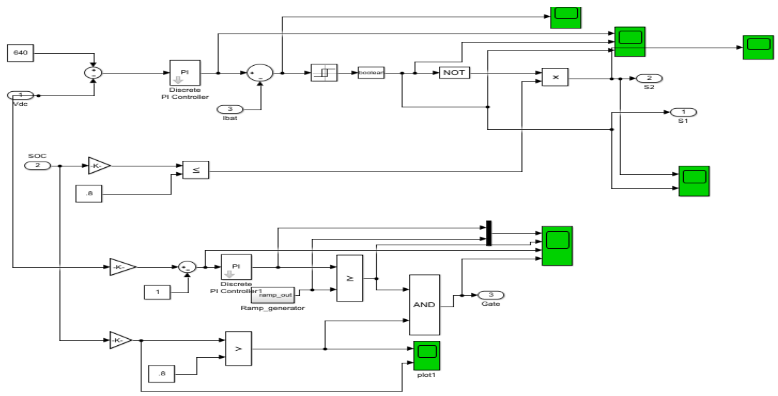


Fig 14.

It is given as a feed back and also to IGBT as gate pulse to open.

- **DC-AC Inverter :**

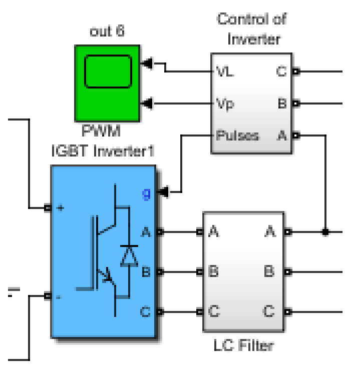


Fig 15.

- A three-phase transformer is used to connect the inverter to the utility distribution system.

- Hence DC is converted to AC signal and it is regulated to a desired set point voltage for a fixed load that will limit the current flowing through the inverter.
- It is given to Three Phase VI-Measurements and then its **controlled** through **control of inverter** to get **feedback** and then to AC load.

- **Fuzzy Controller :**

Control of Inverter

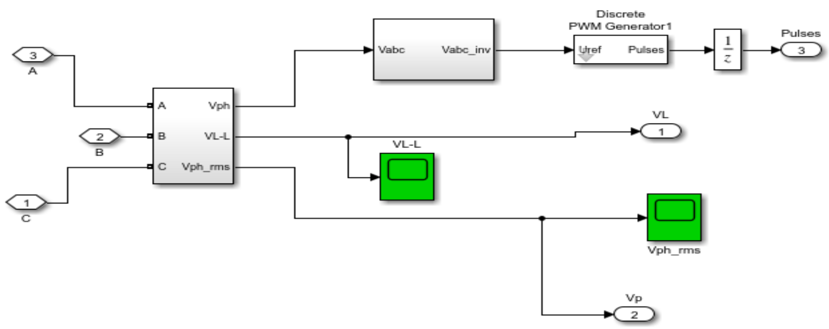


Fig 16.

This controller circuit output is given as a feedback to IGBT Inverter for high performance.

- Through Three Phase Selector the power is sent again to Three Phase VI-Measurements which is given to grid.

And hence it is supplied to the house appliances using Circuit Breaker.

Simulation :

- Run the simulation by Pressing Run Button  and observe the resulting signals on the various scopes.
- All the Figures show different characteristics of the simulated IC Hybrid PV and wind system.

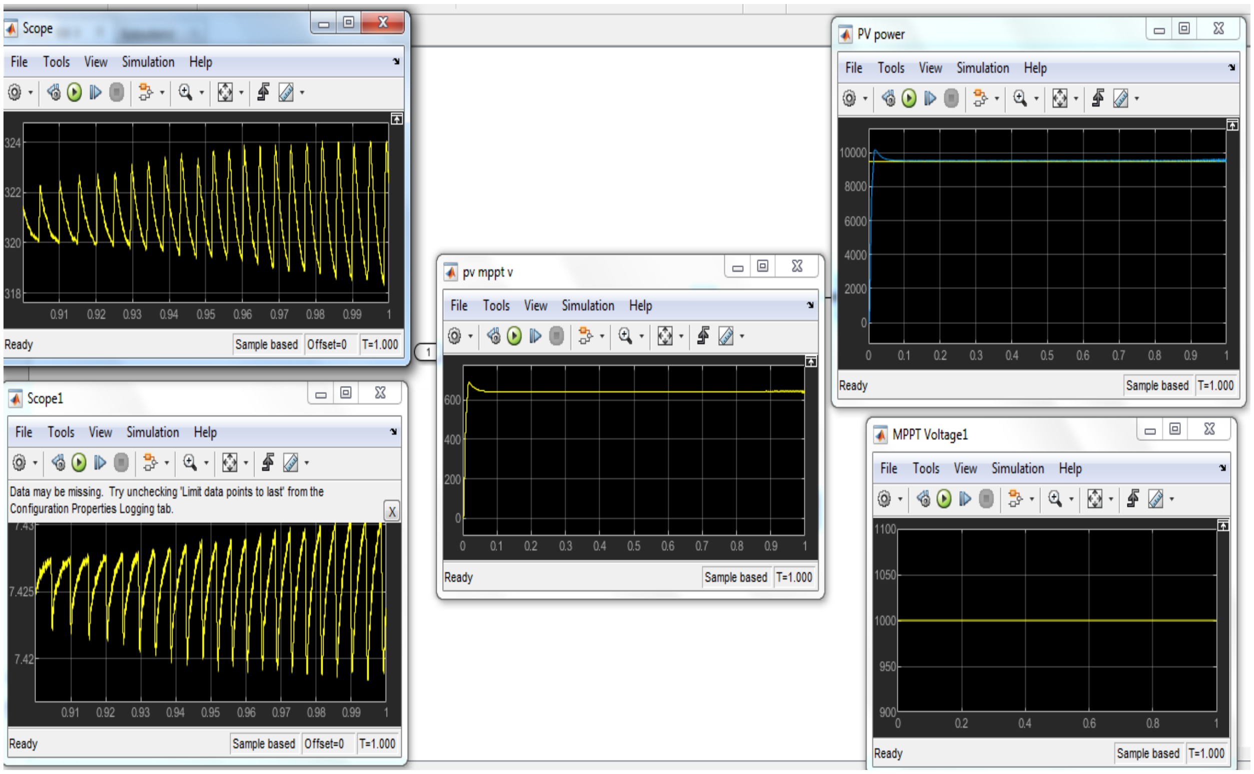


Fig 17.

Fig 17, represent the variation of current, voltage, Power with MPPT voltage of PV Module.

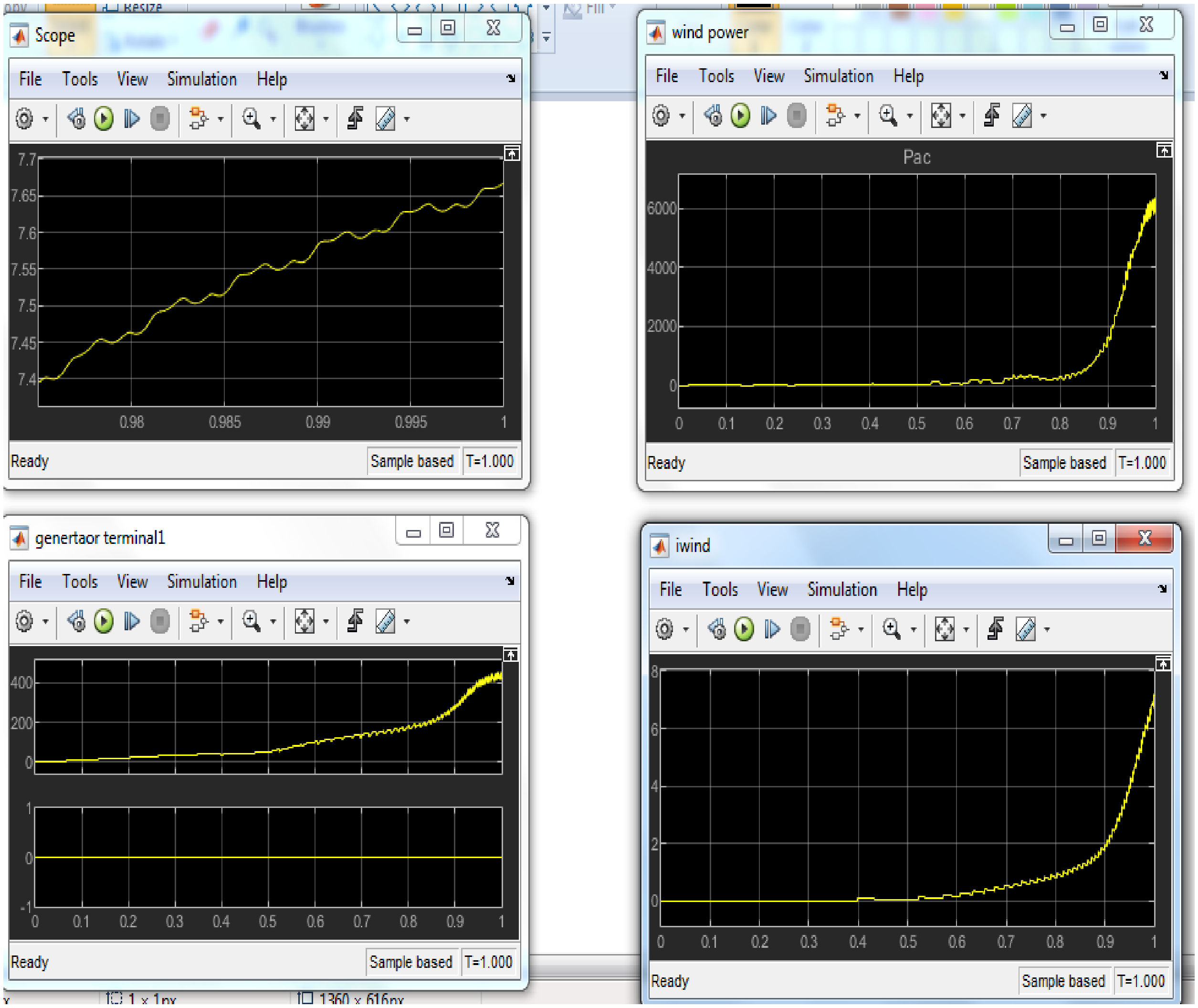


Fig 18.

Fig 18, represent the variation of wind speed, wind power, voltage(Vdc) and iwind(wind power after converting to DC) of wind Module.

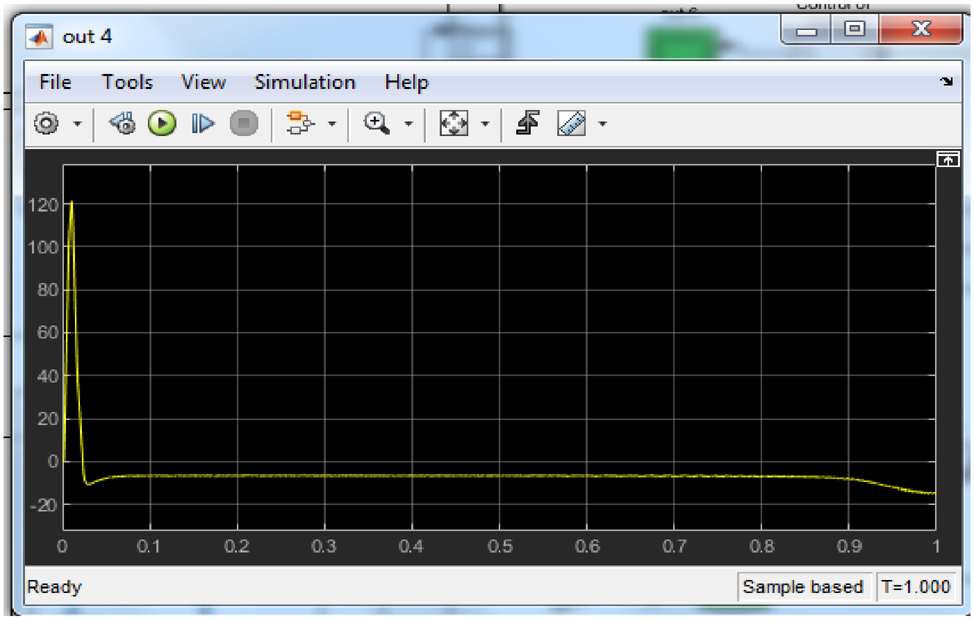


Fig 19.

Fig 19, represent the variation of Battery and DC-DC converter Module.

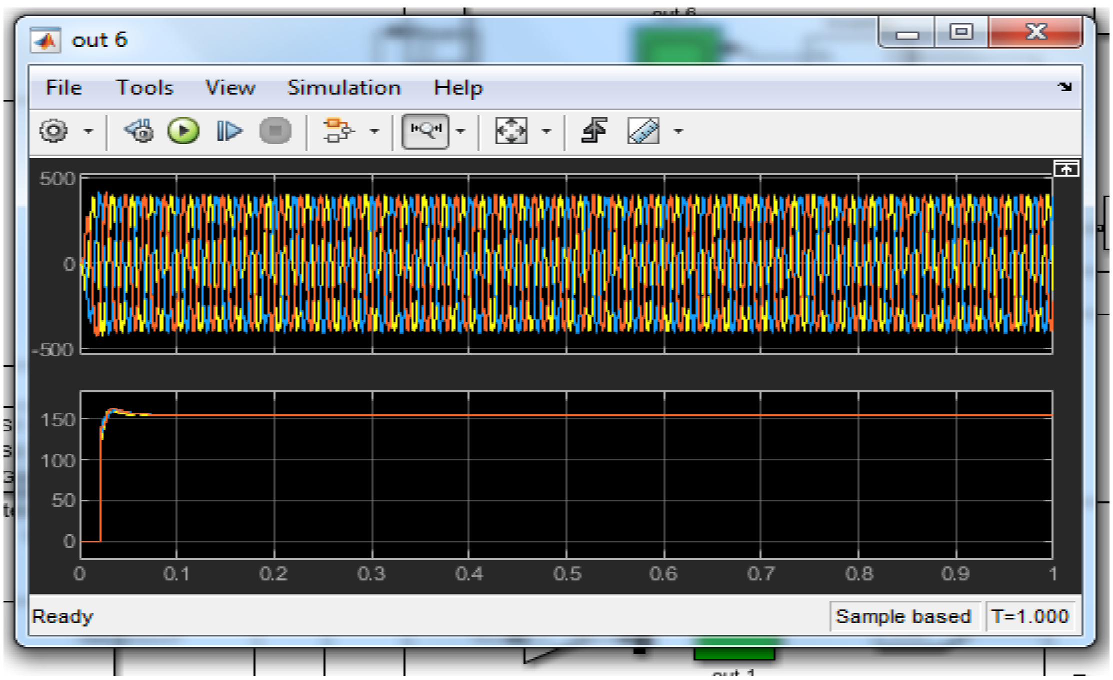


Fig 20.

Fig 20, represent the variation of control of inverter Module output.

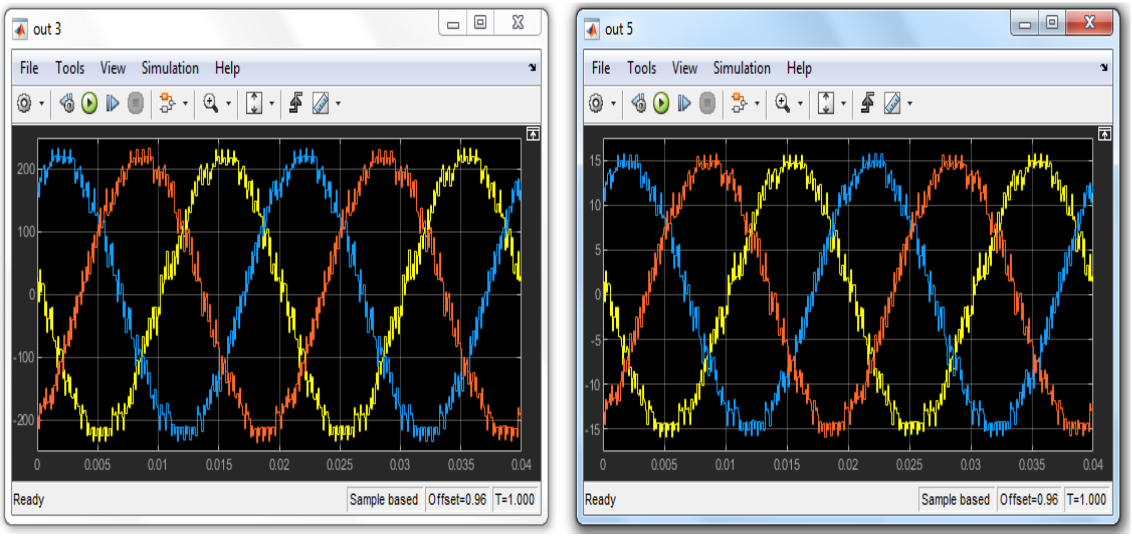


Fig 21.

Fig 21, represent the variation of 3-phase voltage and current Module output.

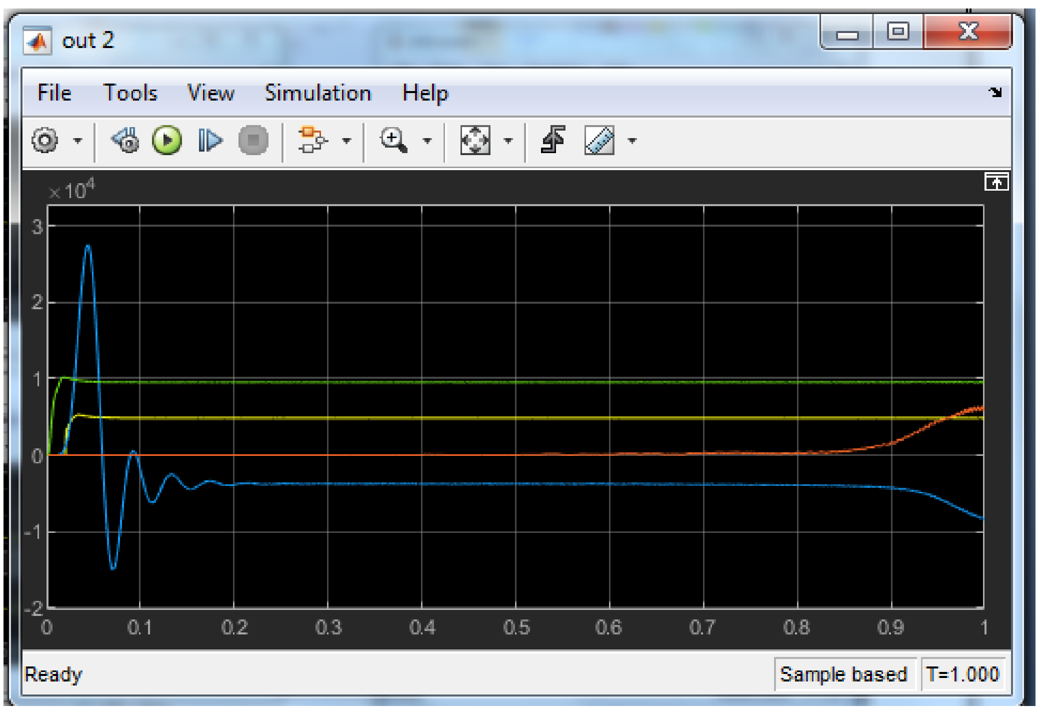


Fig 22.

Fig 22, represent the variation of Inverter power(Lp-yellow), Battery power(Bp-Blue), wind power(Wp-red) and solar power(Sp-green).

RESULT: Thus the Simulation study on Intelligent Controller for Hybrid PV Solar and Wind Energy System Generator is done.

Experiment 6.6:

Aim:- Simulation study on Hydel Power Generator.

Apparatus:

- PC with Mat Lab software.

Diagram :

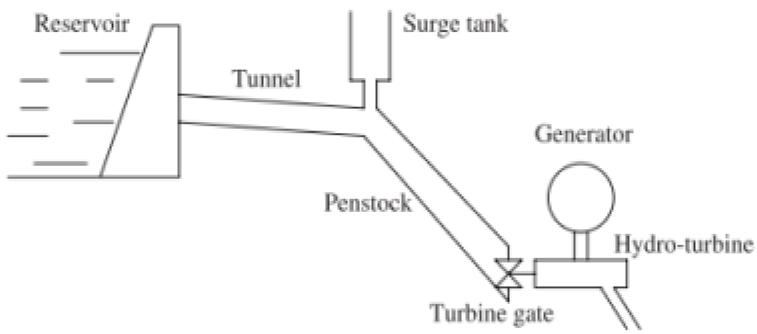


Fig 1.

Hydropower is a clean, predictable, cost competitive and highest efficient convertible renewable energy source. The typical hydropower plant consists of reservoir, tunnel, surge tank, penstock, power house, and electrical power substation as shown in Fig. 1 below where reservoir stores the water and creates head for the generation of power; penstocks carry the water to turbines for the production of mechanical power which drives the synchronous generator to generate electricity. The power generated by hydropower depends on the net head available at the site and quantity of water flowing.

Procedure :

- Double click and open the Simulink model of Hydel power. Fig 2. Shows the simulink model.

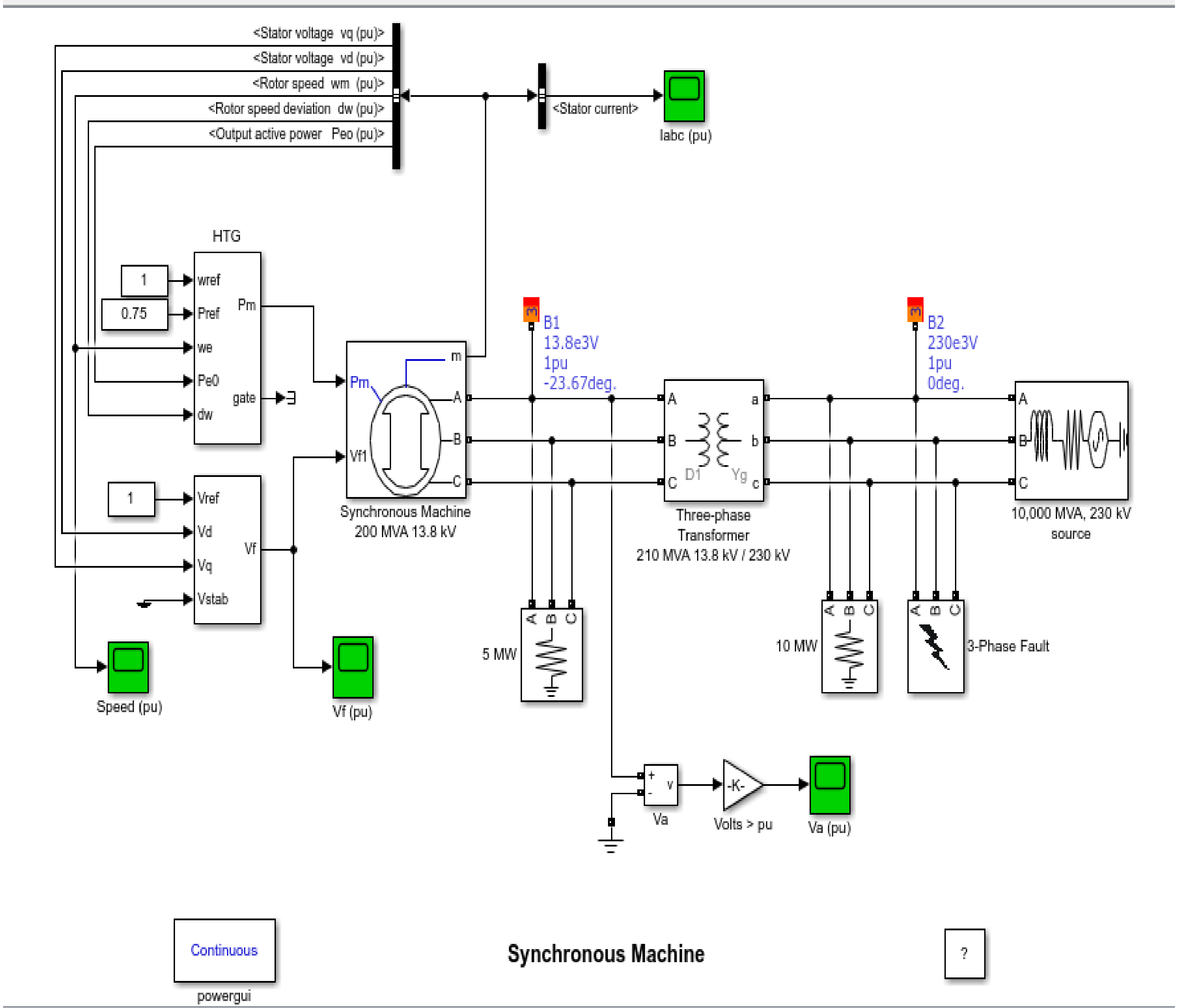


Fig 2.

Each Block Explanation :

- **HTG :**
  Hydraulic Turbine and Governor

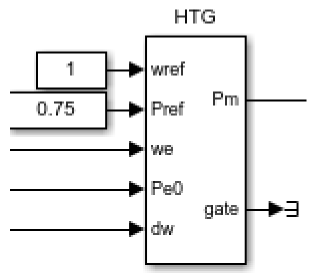


Fig 3.

```
sm="[ 10/3  0.07 ]"
gate="[  0.01  0.97518  -0.1  0.1 ]"
reg="[  0.05  1.163  0.105  0  0.01  ]"
hyd="[  0  2.67  ]"
dref="0"
po="0.751606"
```

- **Excitation System :**

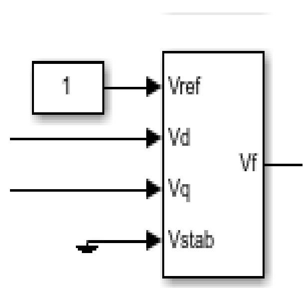


Fig 4.

```
tr="20e-3"
reg="[ 300, 0.001 ]"
exc="[ 1, 0 ]"
tgr="[ 0, 0 ]"
damp="[ 0.001, 0.1 ]"
lim="[ -11.5, 11.5, 0 ]"
v0="[1,1.29071]"
```

- **Synchronous Machine :**

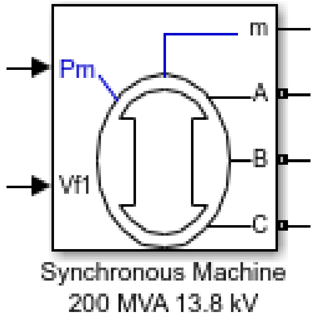


Fig 5.

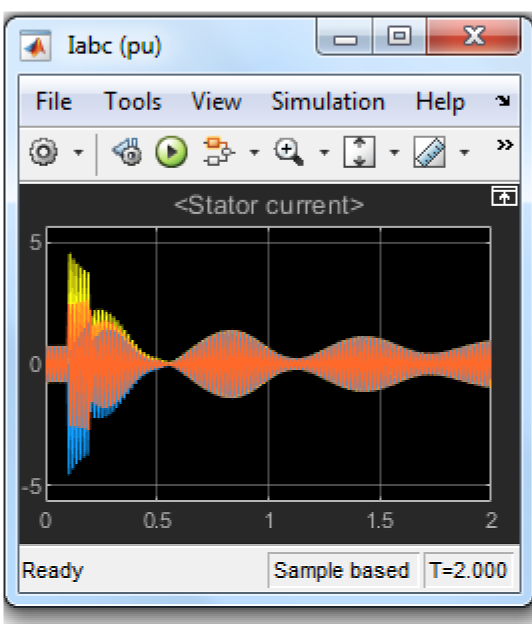
Synchronous motors are a doubly excited **machine**, i.e., two electrical inputs are provided to it. Its stator winding which consists of a We provide three-phase supply to three-phase stator winding, and DC to the rotor winding.

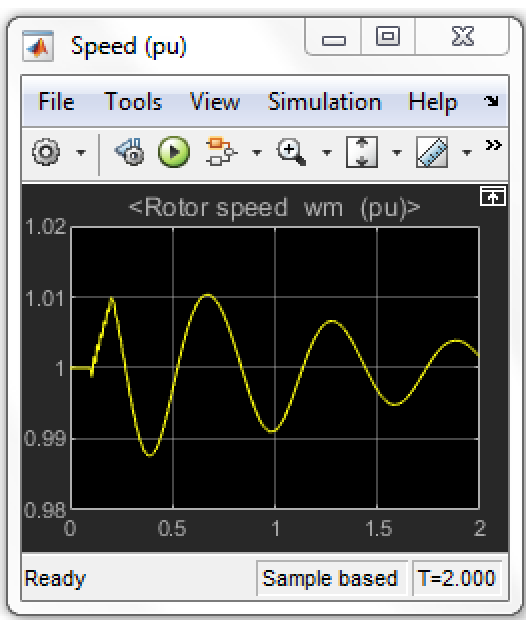
3 phase stator winding carrying 3 phase currents produces 3 phase rotating magnetic flux.

- Thus this 3 phase Power is sent to Three-phase Transformer and then supplied to Grids.

Simulation :

- Run the simulation by Pressing Run Button  and observe the resulting signals on the various scopes.
- All the Figures show different characteristics of the simulated Hydel Power system.





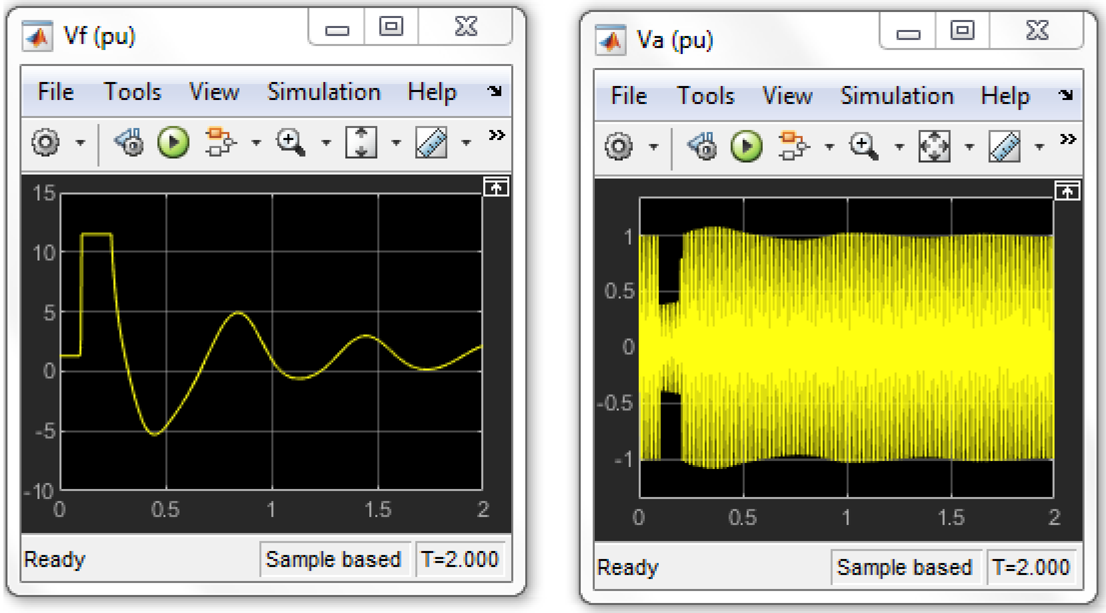


Fig 6.

Fig 6, represent the variation of stator current, Rotor speed, voltage from Excitation System and output voltage to grid & 3-phase Transformer.