POORNIMA
COLLEGE OF ENGINEERING

Department of Electrical Engineering

<u>Energy System Lab Manual</u>

Year: -4thYr. /VIII SEM

Lab Code: - 8EE4-21

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

INDEX

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

POORNIMA COLLEGE OF ENGINEERING, JAIPUR
DEPARTMENT OF ELECTRICAL ENGINEERING

VISION

To be a model of excellence in Professional Education and Research by creating electrical engineers who are prepared for lifelong engagement in the rapidly changing fields and technologies with the ability to work in team.

MISSION

- ✓ To provide a dynamic environment of technical education wherein students learn in collaboration with others to develop knowledge of basic and engineering sciences.
- ✓ To identify and strengthen current thrust areas based upon informed perception of global societal issues in the electrical and allied branches.
- ✓ To develop human potential with intellectual capability who can become a good professional, researcher and lifelong learner.

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

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DEPARTMENT OF ELECTRICAL ENGINEERING

PROGRAM EDUCATIONAL OBJECTIVES (PEO's)

PEO 1: Graduates will have the ability to formulate, analyze and apply design process using the basic knowledge of engineering and sciences to solve complex electrical engineering problems.

PEO 2: Graduates will exhibit quality of leadership, teamwork, time management, with a commitment towards addressing societal issues of equity, public and environmental safety using modern engineering tools.

PEO 3: Graduates will possess dynamic communication and have successful transition into a broad range of multi-disciplinary career options in industry, government and research as lifelong learner.

PROGRAM OUTCOMES (PO's)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineeringfundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complexengineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions**: Design solutions for complex engineering problems anddesign system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and researchmethods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

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Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modernengineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assesssocietal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms ofthe engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader indiverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

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B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

PROGRAM SPECIFIC OUTCOMES (PSO's)

PSO1: Graduate possesses the ability to apply fundamental knowledge of basic sciences, mathematics and computation to solve the problems in the field of electrical engineering for the benefit of society.

PSO2: Graduate possesses the ability to professionally communicate and ethically solve complex electrical engineering problems using modern engineering tools.

PSO3: Graduate possesses sound fundamental knowledge to be either employable or develop entrepreneurship in the emerging areas of renewable and green energy, electric and hybrid vehicles and smart grids and shall be susceptive to life- long learning.

LAB OUTCOMES

LO1: Students will be able to illustrate solar panels at various levels, solar Charge controller, PWM, MPPT with boost converter, Shadowing effect and diode based solution in Solar PV System by using large area Sun Simulator.

LO2: Students will be able to Analyze Performance of Solar Flat Plate Thermal Collector Operation with Variation in Mass Flow Rate and Level of Radiation.

LO3: Students will be able to Demonstrate wind turbine generators with DC generators, DFIG, PMSG etc.

LO4: Students will be able to demonstrate different components of Micro Grid, micro-hydel pumped storage system and Fuel Cell and its operation.

LO5: Students will be able to design and simulate hybrid wind-solar power generation along with Performance Assessment of Hybrid Power System by using Intelligent Controllers for on-grid and off-grid Hybrid Power Systems.

MAPPING OF LO WITH PO

LO	LAB OUTCOME	PO											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Students will be able to illustrate solar panels at various levels, solar Charge controller, PWM, MPPT with boost converter, Shadowing effect and diode based solution in Solar PV System by using large area Sun Simulator.	2	3	-	-	-	3	3	3	3	-	2	3
2	Students will be able to Analyze Performance of Solar Flat Plate Thermal Collector Operation with Variation in Mass Flow Rate and Level of Radiation.	2	3	-	-	-	3	3	3	3	-	2	3
3	Students will be able to Demonstrate wind turbine generators with DC generators, DFIG, PMSG etc.	2	-	-	-	-	3	3	3	3	-	2	3
4	Students will be able to demonstrate different components of Micro Grid, micro-hydel pumped storage system and Fuel Cell and its operation.	2	-	-	-	-	3	3	3	3	-	2	3
4	Students will be able to design and simulate hybrid wind-solar power generation along with Performance Assessment of Hybrid Power System by using Intelligent Controllers for on-grid and off-grid Hybrid Power Systems.	2	3	2	3	-	3	3	3	3	-	2	3

MAPPING OF LO WITH PSO

LO	LAB OUTCOME	PSO1	PSO2	PSO3
1	Students will be able to develop arithmetic programs using microcontroller kit	-	-	-
2	Students will be able to use ADC/DAC for import or export data from peripheral devices	-	-	-
3	Students will be able to interface circuit using IO devices for external communication	-	-	-
4	Students will be able to resolve issues in controller software programming	-	-	-

Dr. Mahesh Bundele
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Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

LAB RULES

DO'S:

- Enter the lab on time and leave at proper time.
- Wait for the previous class to leave before the next class enters.
- Keep the bag outside in the respective racks.
- Utilize lab hours in the corresponding.
- Before switching on the power supply, get it checked by the lecturer/Technical assistant.
- Switch off or silent your mobile before enter the lab.
- Maintaining discipline.
- Proper handling of equipment must be done.

DONT'S:

- Don't abuse the equipment.
- Don't bring any external material in the lab, except your lab record, copy and books.
- Don't bring the mobile phones in the lab. If necessary then keep them in silence mode.
- Please be considerate of those around you, especially in terms of noise level. While labs are a natural place for conversations of all types, kindly keep the volume turned down.
- Do not touch any any power supply wire or main supply.
- Do not attempt experiment without permission.
- Do not overcrowd on a table.
- Do not manipulate the experiment result.

SAFETY MEASURES

- Specific Safety Rules like Do's and Don'ts are displayed and instructed for all students.
- First aid box and fire extinguishers are kept in each laboratory.
- Insulation carpet is available in machine lab and Measurement and Instrumentation Lab.
- Well trained technical supporting staff monitor the labs at all times.
- Damaged equipment's are identified and serviced at the earliest.
- Periodical calibration of the lab equipment's are regularly done
- A clean and organized laboratories are maintained
- The use of cell phones is prohibited.
- Appropriate storage areas are available.
- In order to create more space in the laboratories, a separate section has racks to store the belongings of the students.
- Proper earthing is provided in the labs.

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LIST OF EXPERIMENT

Credit: 2
0L+0T+3P

Max. Marks: 100(IA:60, ETE:40)
End Term Exam: 3 Hours

SN	Contents
1	V-I characteristics of solar panels at various levels of insolation.
2	Experiment of solar Charge controller, PWM, MPPT with boost converter and algorithms.
3	Experiment on Shadowing effect and diode based solution in1kWpSolar PV System.
4	Study of wind turbine generators with DC generators, DFIG, PMSG etc.
5	Performance Study of Solar Flat Plate Thermal Collector Operation with Variation in Mass Flow Rate and Level of Radiation.
6	Characterization of Various PV Modules Using large area Sun Simulator.
7	Study of micro-hydel pumped storage system.
8	Experiment on Fuel Cell and its operation.
9	Study of 100 kW or higher solar PV plant.
10	Study different components of Micro Grid.
11	To design and simulate hybrid wind-solar power generation system using simulation software.
12	Experiment on Performance Assessment of Hybrid (Solar-Wind- Battery) Power System.
13	Simulation study on Intelligent Controllers for on-grid and off-grid Hybrid Power Systems.

EVALUATION SCHEME

Name Of Exam	Conducted By	Experiment Marks	Viva Marks	Total
I Mid Term	PCE	30	10	40
II Mid Term	PCE	30	10	40
End Term	RTU	30	10	40

Name Of Exam	Conducted By	Performance Marks	Attendance Marks	Total
Sessional	PCE	30	10	40

DISTRIBUTION OF LAB RECORD MARKS PER EXPERIMENT

Attendance	Record	Performance	Total
2	3	5	10

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LAB PLAN

Total number of experiment: 12

Total number of turns required: 12

NUMBER OF TURNS REQUIRED FOR

Experiment Number	Turns	Scheduled Day
Zero Lab	1	Turn 1
Exp. 1	1	Turn 2
Exp. 2	1	Turn 3
Exp. 3	1	Turn 4
Exp. 4	1	Turn 5
Exp. 5	1	Turn 6
Exp. 6	1	Turn 7
Exp. 7	1	Turn 8
Exp. 8	1	Turn 9
Exp. 9	1	Turn 10
Exp. 10	1	Turn 11
Exp. 11	1	Turn 12
Exp. 12	1	Turn 13
Exp. 13	1	Turn 14

DISTRIBUTION OF LAB HOURS

- Explanation of Experiment & Logic : 20 Minutes
- Performing the Experiment : 40 Minutes
- File Checking : 30 Minutes
- Viva/Quiz : 20 Minutes
- Solving of Queries : 10 Minutes

ROTOR PLAN

ROTOR I

1 V-I characteristics of solar panels at various levels of insolation.

2 Experiment of solar Charge controller, PWM, MPPT with boost converter and algorithms.

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

4 Study of wind turbine generators with DC generators, DFIG, PMSG etc.

5 Performance Study of Solar Flat Plate Thermal Collector Operation with Variation in Mass Flow Rate and Level of Radiation.

6 Characterization of Various PV Modules Using large area Sun Simulator.

7 Study of micro-hydel pumped storage system.

ROTOR II

8 Experiment on Fuel Cell and its operation.

9 Study of 100 kW or higher solar PV plant.

10 Study different components of Micro Grid.

11 To design and simulate hybrid wind-solar power generation system using simulation software.

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

13 Simulation study on Intelligent Controllers for on-grid and off-grid Hybrid Power Systems.

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ZERO LAB

Introduction to Lab:

a). **Relevance to Branch**: - Energy system are used to different power plant/ energy model which is a very important field for Electrical Engineers as the devices that requires solar Charge controller, PWM, MPPT, DC generators, DFIG and use of PMSG. Electrical Engineers basically deal with the power electronics to control the amount of load to be delivered to the different sections. Renewable engg with the memory elements of computer and its organization which is again very useful and relevant for electrical engineering branch.

b). **Relevance to Society**: - Looking into the present arena of faster and Efficient power plant module most of which are based on the renewable engineering, it becomes very important for Engineers to develop newer and efficient devices for the society and that can be done by including the subject in the curriculum as a basis for that .

c). **Relevance to Self**: - It helps the students to acquire knowledge of both the renewable power plants and the matlab software. It is a very important subject for Competitive exams like GATE, PSUs and many other and most important for securing marks in university exams. It is very useful in building the power projects.

d). **Relation with laboratory**: - Lab is important to get practical knowledge of what we study in theory. This Lab is related to the Power generation and renewable energy sources.

e) Pre- Requisites (Connection with previous year): -

1. Electrical Circuit Design Lab (3EE4-23)
2. Electrical Machine Lab (3EE4-07)
3. Power Electronics Lab (3EE4-06)
4. Electrical Drive Lab (6EE4-22)

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Experiment No. 1

AIM: V-I CHARACTERISTICS OF SOLAR PANELS AT VARIOUS LEVELS OF INSOLATION.

APPARATUSREQUIRED:

S.No	Name of the Apparatus	Version	Quantity
1.	MATLAB	R2014a	1

THEORY:

A material or device that is capable of converting the energy contained in photonsof light into an electrical voltage and current is said to be photovoltaic (PV). A simpleequivalent circuit model for a PV cell consists of a real diode in parallel with an ideal current source. The ideal current source delivers current in proportion to the solar fluxto which it is exposed. A more accurate model of a PV cell considers the effect of series and parallel resistance as shown in Fig.1. In a practical PV cell, there is a seriesresistance in a current path through the 3 semiconductor material, the metal grid, contacts and current collecting bus. These resistive losses are lumped together as a series resistor (Rs). Similarly a certain loss is associated with a small leakage of current through a resistive path in parallel with the intrinsic device. This can be represented by a parallel resistor (Rp). Its effect is much less conspicuous in a PV module compared to the series resistance, and it will only become noticeable when a number of PV modules are connected in parallel for a larger system.

PROCEDURE:

1. The V-I graph at various insolations on the same graph paper.
2. Show the approximate trajectory of the maximum power point as the insolation isvaried.
3. Report your conclusion about the variation of fill factor, VOC, etc. with insolaton.
4. Plot the dark characteristics.
5. Take one representative V-I curve and obtain the equivalent circuit parameters.Tabulate the equivalent circuit parameters clearly. Describe the algorithm used toobtain the parameters.
6. Draw on the same graph, the V-I characteristics obtained from experiment, andthe one calculated from the obtained equivalent circuit.

Editor Window program:

```
%% Solar Cell Power Curve
% This example shows how to generate the power-voltage curve for a
solar
% array. Understanding the power-voltage curve is important for
inverter
% design. Ideally the solar array would always be operating at peak
power
% given the irradiance level and panel temperature.
```

```
% Copyright 2013 The MathWorks, Inc.

%% Define independent variables
% Need to specify the range of irradiance levels and temperatures over
% which to plot the power curve.
irradianceVec = [200 500 1000];
temperatureVec = [20 40];

%% Load the model and simulate all combinations of irradiance and
temperature
open_system('elec_solar_characteristics')
powerMat = zeros(121,6);
index = 0; legend_info = cell(1,6);for
temperature = temperatureVec
 for irradiance = irradianceVecindex
= index+1;
sim('elec_solar_characteristics')
powerMat(:,index) = P.signals.values;
      legend_info{index} = ['T=' num2str(temperature) '^{\o}C, Ir='
num2str(irradiance) 'W/m{^2}'];
   endend
vVec = V.signals.values;

%% Plot the results
h_elec_solar_characteristics = figure;
plot(vVec,powerMat);
axis([0 450 0 2500]) % Only show positive power resultsgrid
on
xlabel('Output voltage, V')
ylabel('Output power, W')
legend(legend_info,'Location','NorthWest')

%% Determine optimal operating point as a function of irradiance and
temperature
% Extract optimum working line information for use by example model
elec_solar_performance
[Pmax,idx] = max(powerMat);
V_Pmax = vVec(idx);
% Peak power and corresponding voltage as a function of irradianceVec
and temperatureVec
powerTable = reshape(Pmax',[3,2]);
voltageTable = reshape(V_Pmax,[3,2]);
```

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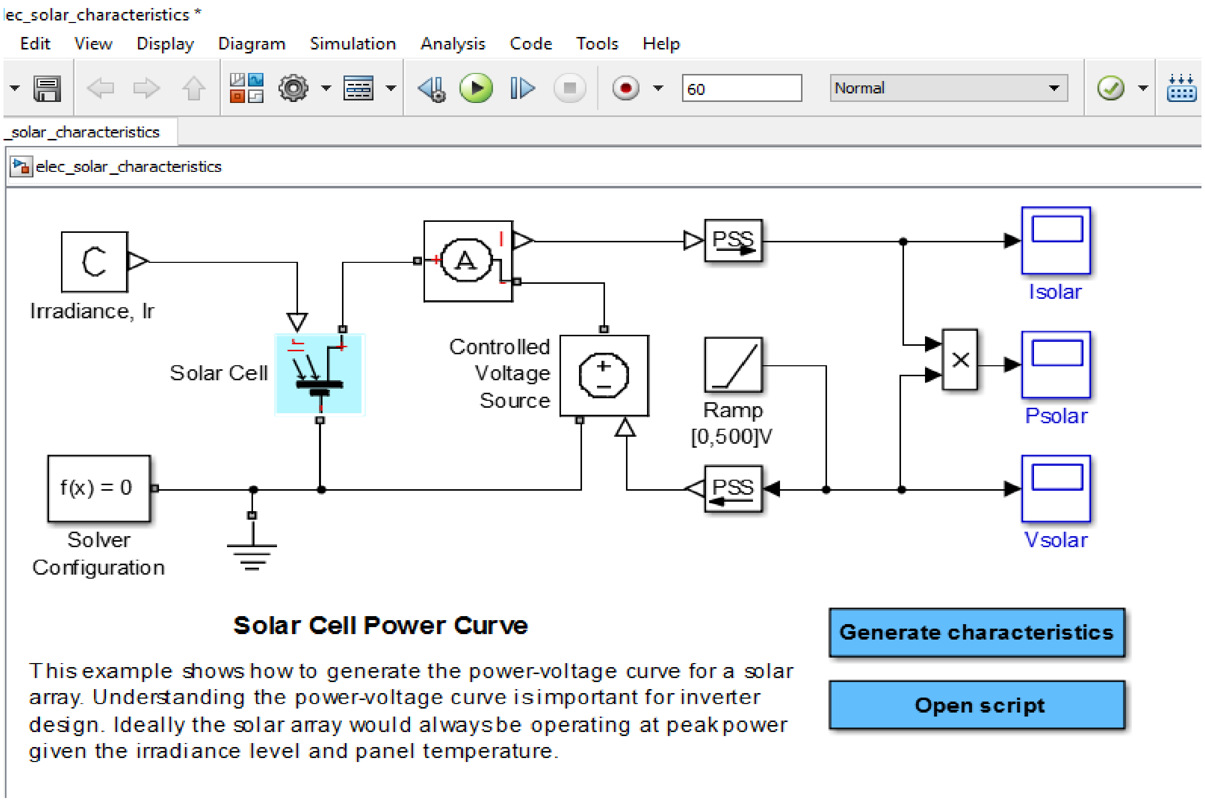
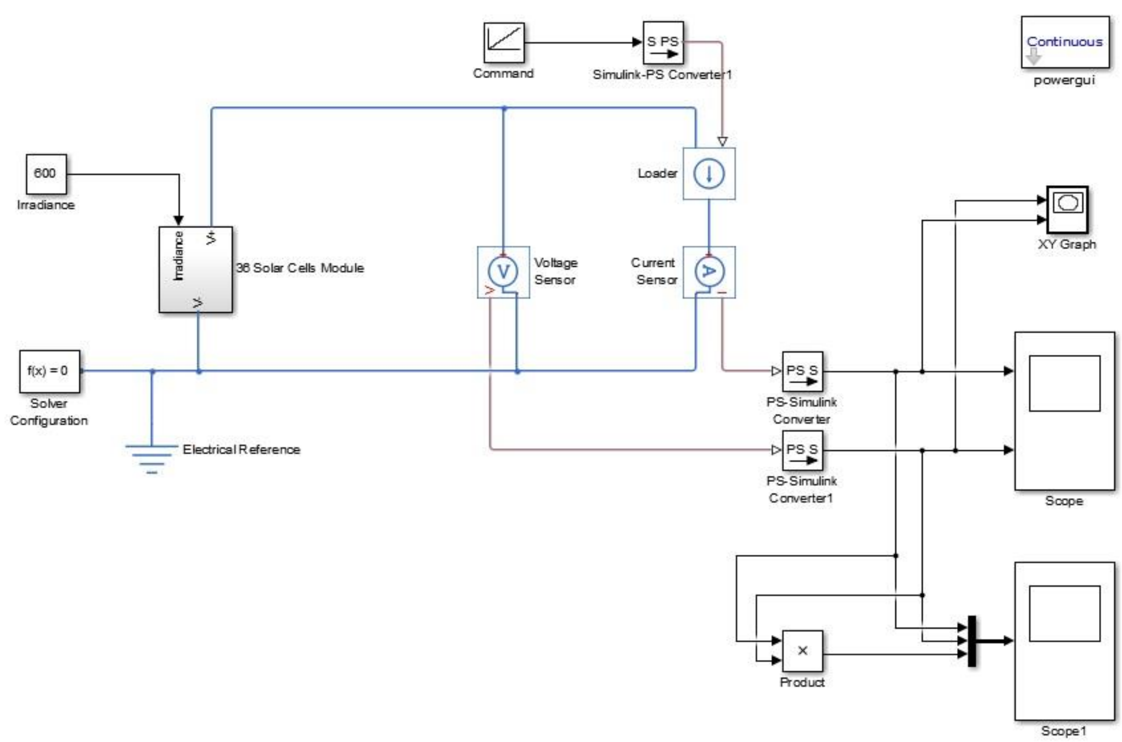
MATLAB Simulation:





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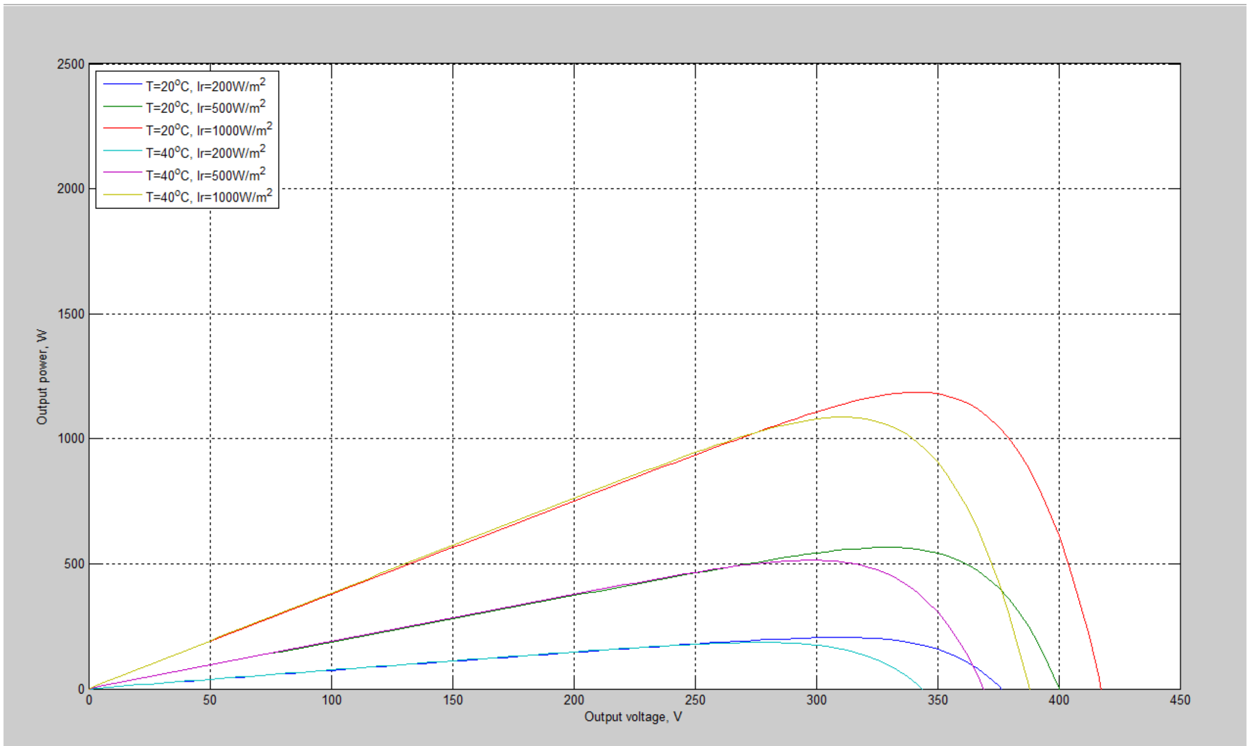
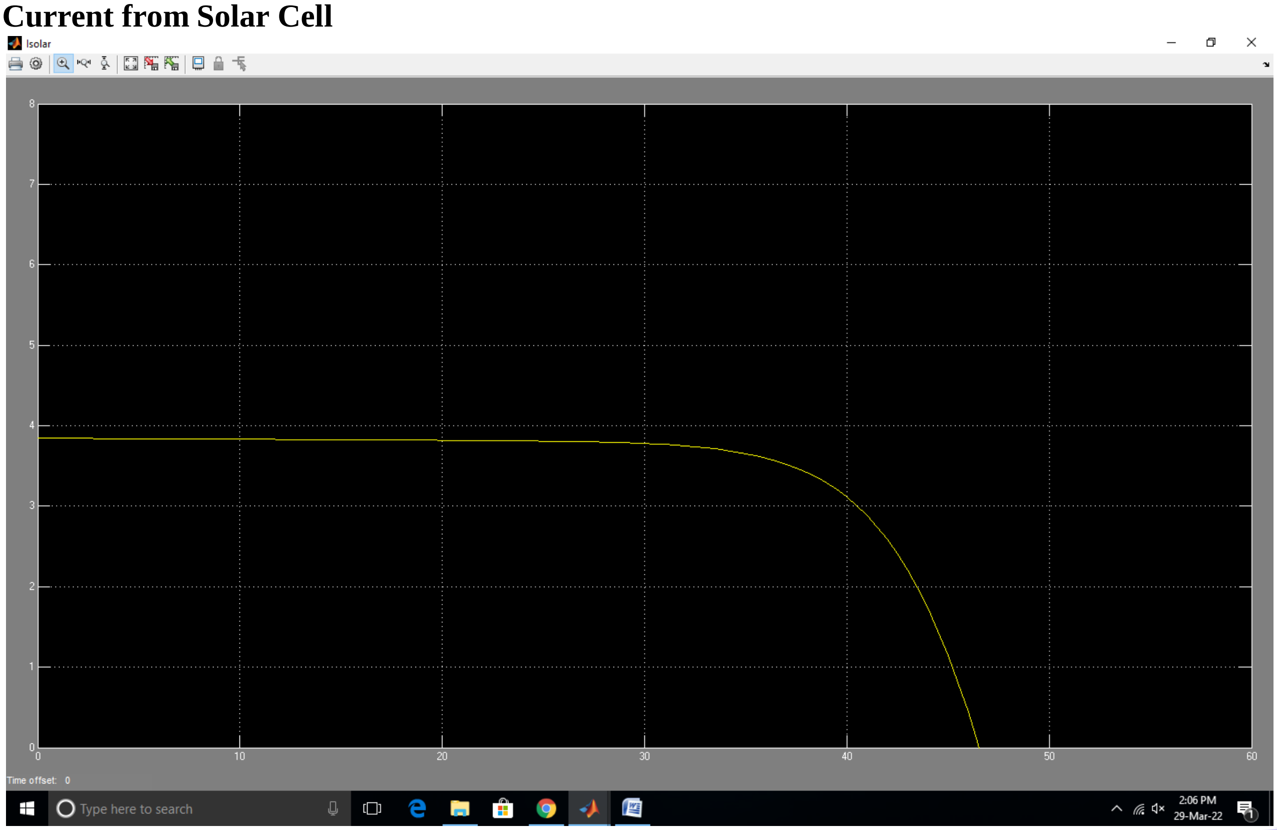
Output Variation of Power and Voltage Profile in terms of Irradiance & degree Celsius



Current from Solar Cell



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Director
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ISI-6, RIICO Institutional Area
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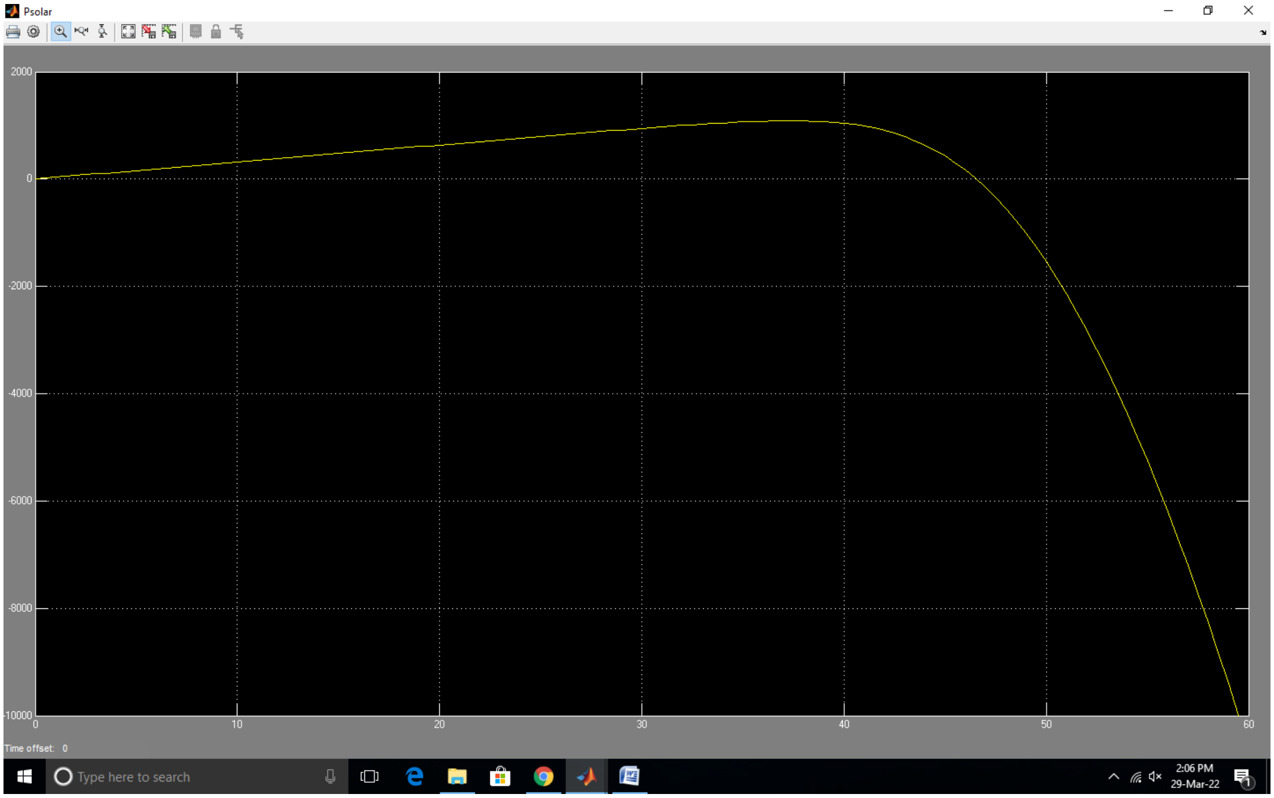
Power from Solar Cell



Voltage from Solar Cell

Result: We have successfully simulated IV Characteristics of Solar Cell on MATLAB.

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
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Poornima College of Engineering
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Experiment No. 2

AIM: EXPERIMENT OF SOLAR CHARGE CONTROLLER PWM, MPPT WITH BOOST CONVERTER ANDALGORITHMS

APPARATUS REQUIRED:

S.No	Name of the Apparatus	Version	Quantity
1.	MATLAB	R2015b	1

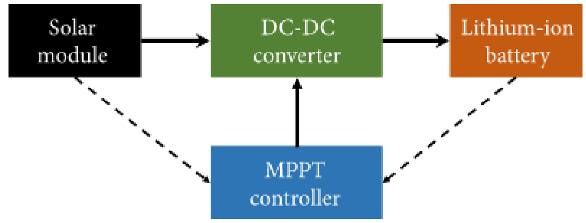
THEORY:

Solar Charge Controller (SCC) with Maximum Power Point Tracking (MPPT) is needed to extract maximum energy from photovoltaic. However, a SCC device with MPPT technology feature is expensive on the market due to the requirements for a high-power system. On the other hand, in lower power applications such as IoT sensors, solar street lights, and wireless communication nodes, these types of controllers can be produced at a lower cost. In this study, the design of a low-cost SCC was conducted using the MPPT technology for low-power solar applications. The SCC is designed based on the Arduino microcontroller, which has the role of controlling the circuit and producing PWM signals to regulate the DC-DC converter. Several tests were conducted to validate the efficiency of the MPPT algorithm. The SCC device succeeded in increasing efficiency up to 52% on the low irradiance level.

MPPT algorithms are designed so that the system can adapt to weather changes and achieve optimal power. Therefore, several algorithms can be utilized, such as open-circuit voltage, short-circuit current, incremental conductance, and P&O (Perturb and Observation) . These algorithms are integrated into the power electronic components, where their duty cycle is controlled to deliver the maximum available power to the load. The MPPT applied a buck converter and Pulse Width Modulation (PWM) signal to keep the load from the module and the load balanced, so the module's output power reaches the maximum.

MPPT Technology

Maximum Power Point Tracking or MPPT is a technology that can control a power source from photovoltaic, such as a solar module, to generate its maximum power . MPPT uses a DC-DC converter to control the solar module for charging the lithium-ion battery, as shown in Figure. This DC-DC converter then needs to operate using a certain algorithm, so the power of the solar module reaches the maximum point. Control of the DC-DC converter can be undertaken by controlling the PWM signal that drives the DC-DC converter, following various tracking algorithms, such as Perturb and Observation (P&O). For MPPT to conduct the tracking algorithm, MPPT needs a controller device or circuit that can monitor the solar module conditions, such as the voltage, current, and temperature. The controller for MPPT should have the capability to sense at least one data measurement of the solar module conditions, then control or produce the duty cycle needed by the PWM signal to drive the DC-DC converter.



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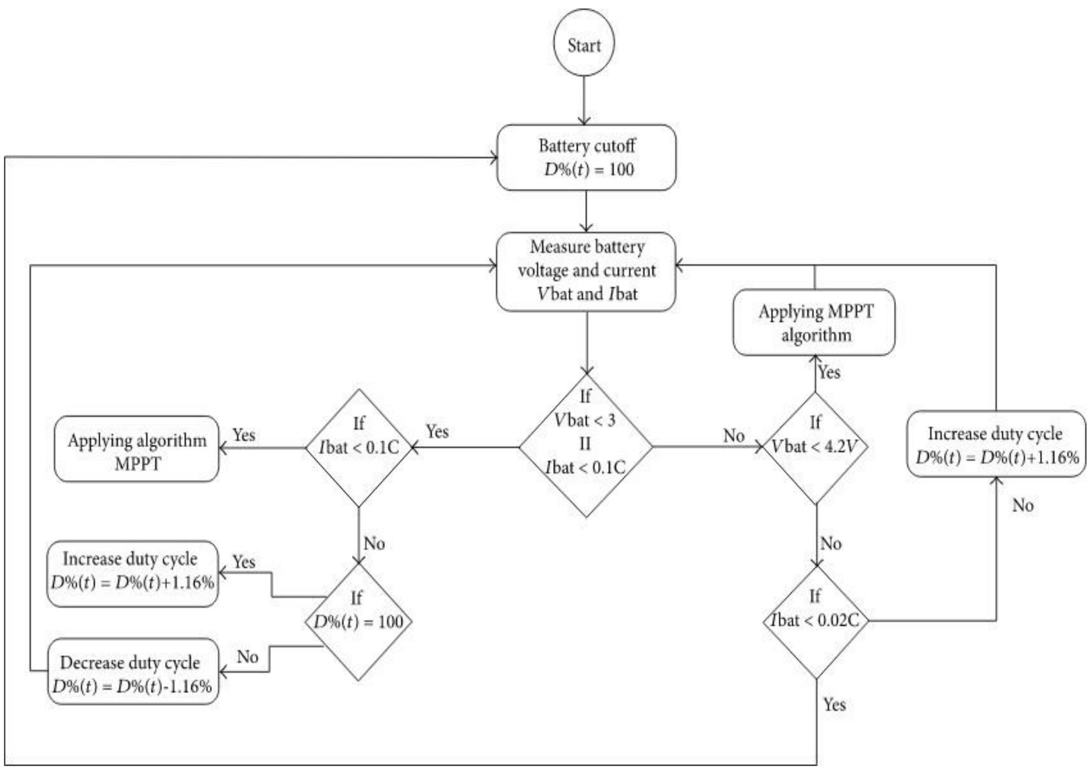
MPPT ALGORITHM

The designed MPPT algorithm was developed from basic P&O value tracking with adaptations and limitations for Arduino implementation. Figure 8 shows the flowchart of the designed MPPT algorithm. To find the maximum power point, first, the Arduino of the device must measure the solar module current voltage and current, then calculate the difference between the present power against the previous power () and the present voltage against the previous voltage (). The Arduino then decides from the difference calculation whether the present power generated is on the left side or the right side of the present condition of the maximum power point (MPP). If both the and values are below zero, the current power is on the left side of the MPP; therefore, the voltage of the solar module must be increased and vice versa. Generating a higher solar module voltage can be achieved by increasing the duty cycle value. Because the Arduino cannot limit its own duty cycle value by itself, a duty cycle tracking limit is implemented. When the device decides to increase the duty cycle value, the Arduino has to decide whether the current value is already 100%. If the condition is met, the duty cycle needs to be reduced instead of increasing the value and vice versa if the current duty cycle value is already 0%.



DC-DC Converter

A DC-DC converter consists of several types of circuit, such as buck converter, boost converter, and cuk converter. A buck converter is a circuit that is used to reduce the input voltage of the buck converter circuit so that it is lower than the input at the output side. Figure shows a basic asynchronous buck converter circuit. A buck converter usedan inductor connected series between the input and the output; a switching element connected series between the input and inductor, an output capacitor; and a diode connected parallel to the circuit ground between the switch and the inductor, an input capacitor.

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B.E., M.E., Ph.D.
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Poornima College of Engineering
ISI-6, RIICO Institutional Area
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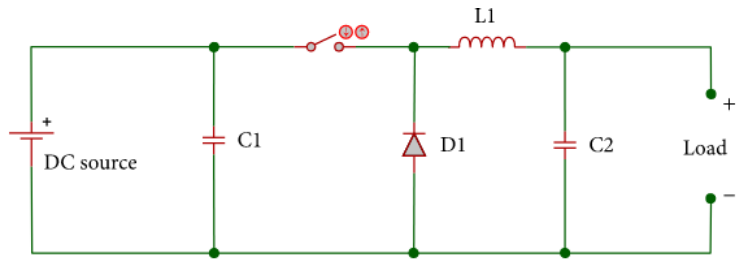
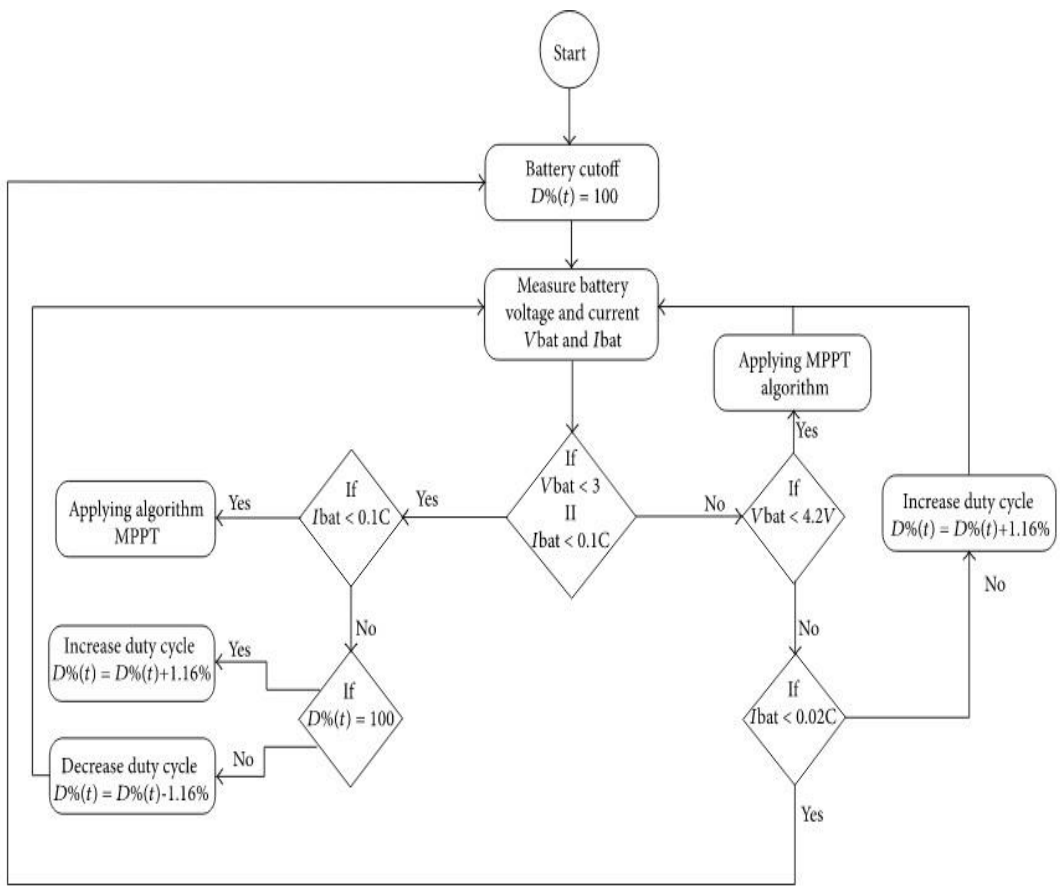


Charging Controller Algorithm

The charging controller algorithm utilized basic constant-current (CC) and constant-voltage (CV) for Li-ion battery charging. Figure shows the designed algorithm of the implemented CC-CV, with the inclusion of the MPPT algorithm and the utilized Li-ion battery specification. Before initiating any charging current, the device must cut off the current by setting the duty cycle value (D%) by 100%. Then, the Arduino measures the battery characteristic and decides the battery charging step. For increasing in Arduino, 1.16% was applied rather than 1% due to limitation on high-frequency PWM in Arduino .



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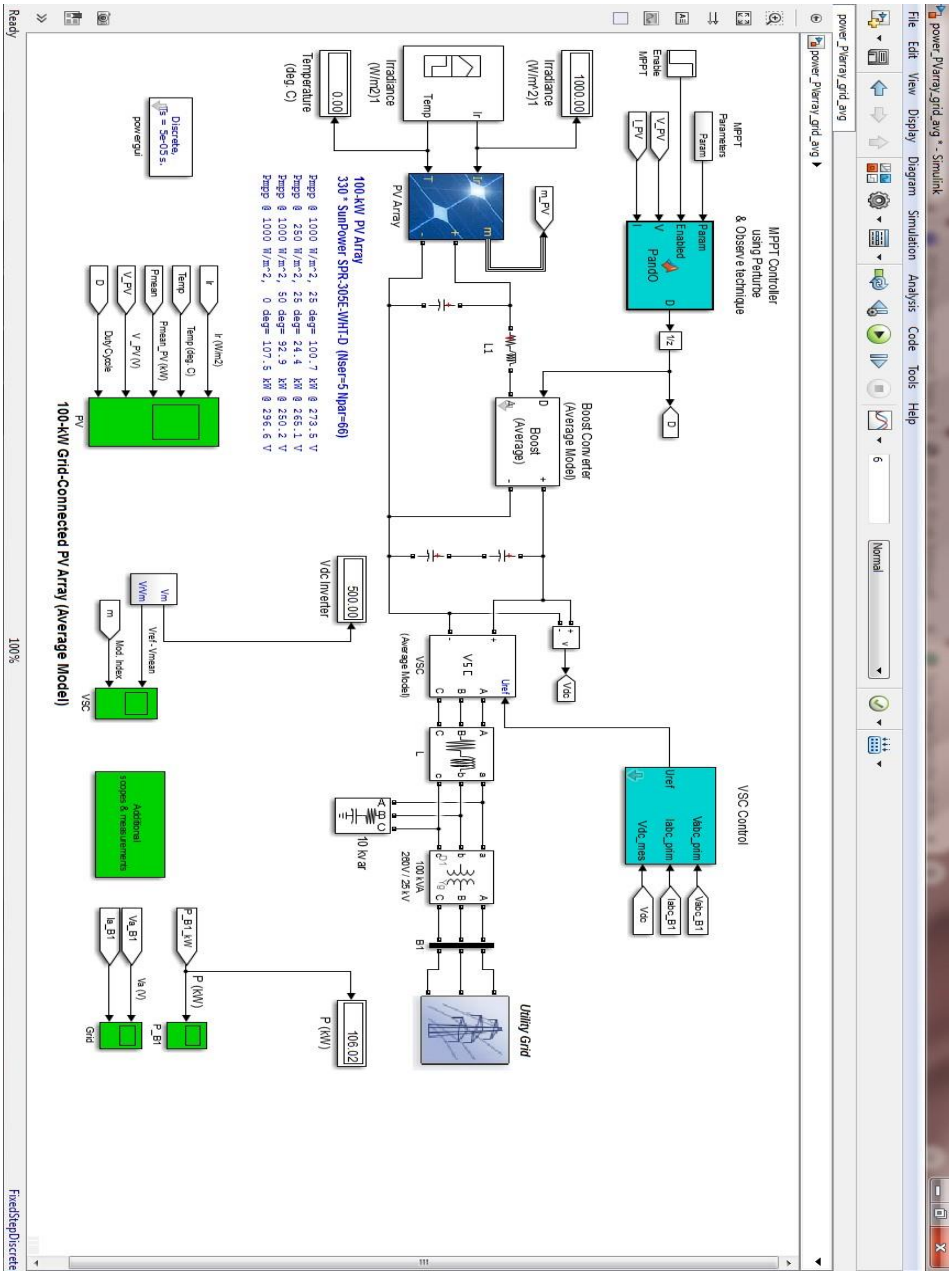

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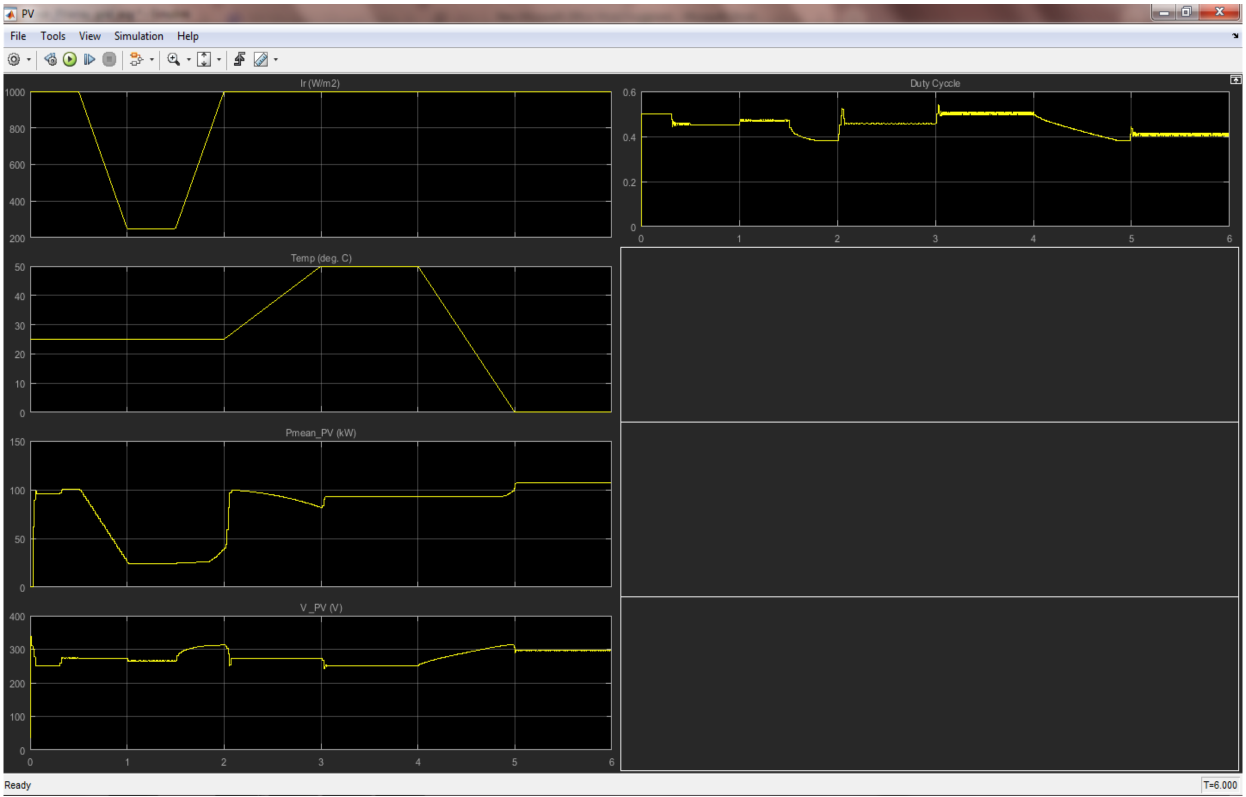

Fig: PV Array Output

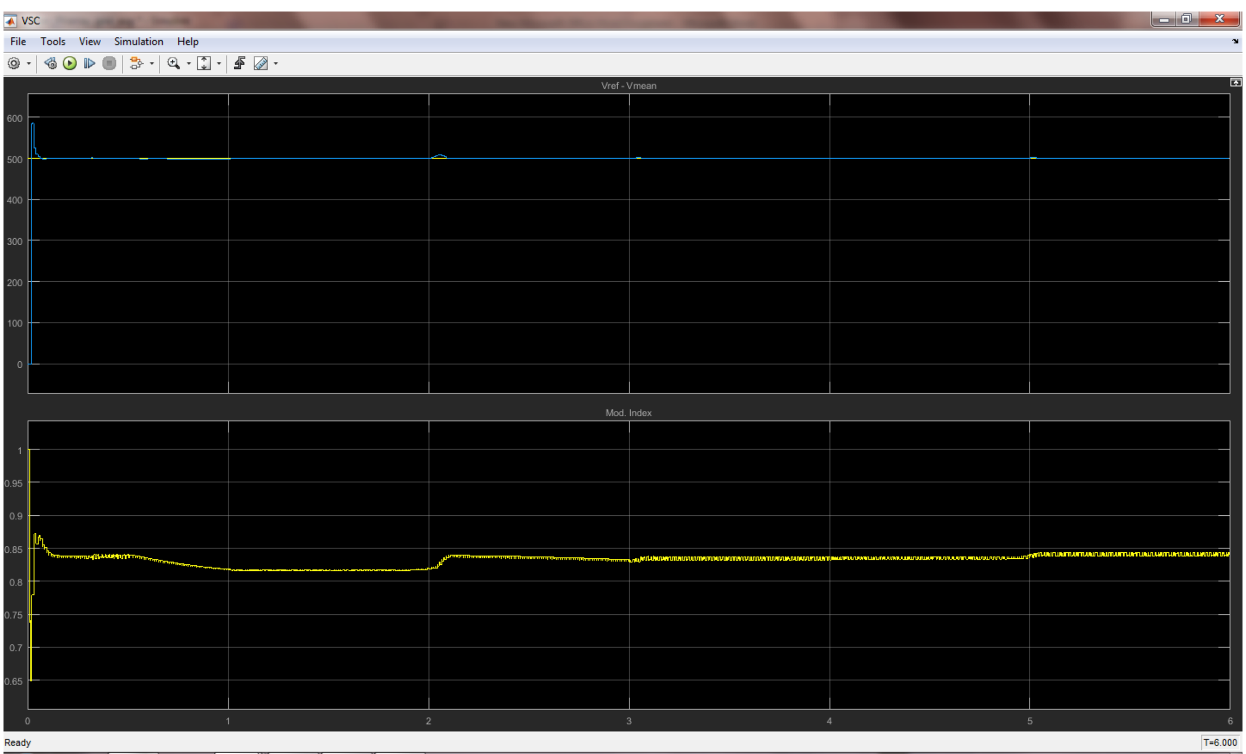

Fig: VDC inverter Output

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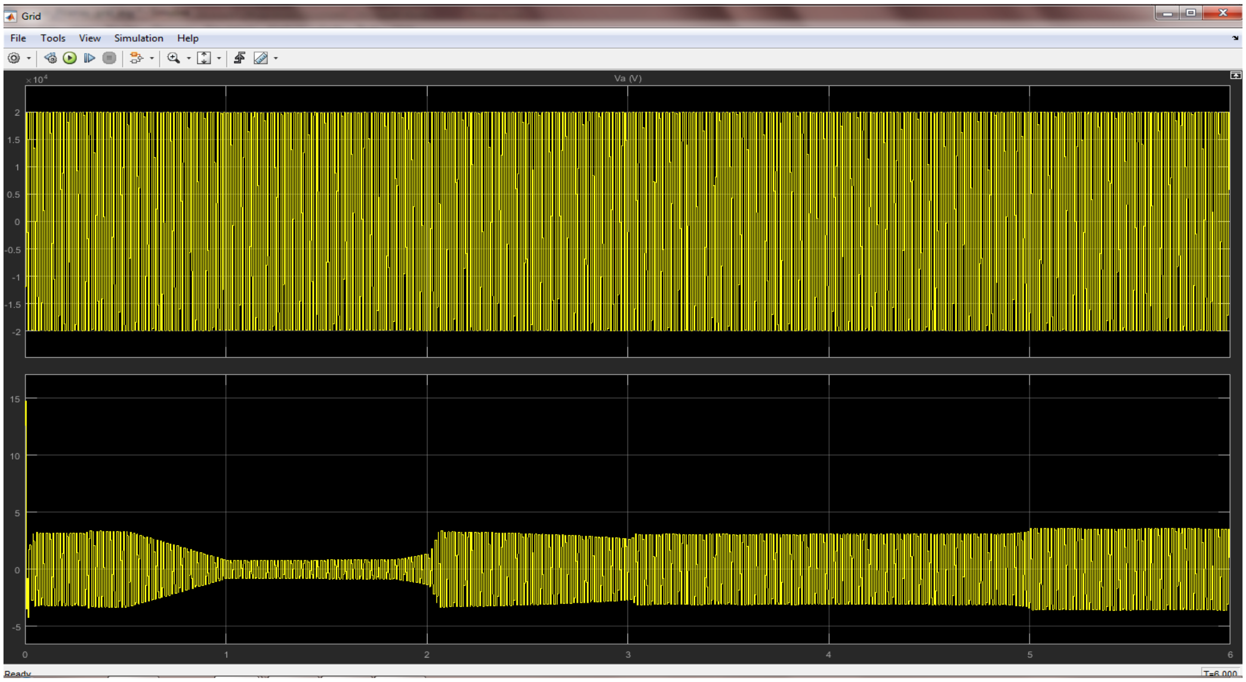


Fig: Power shared to grid in form of Volatge and Current

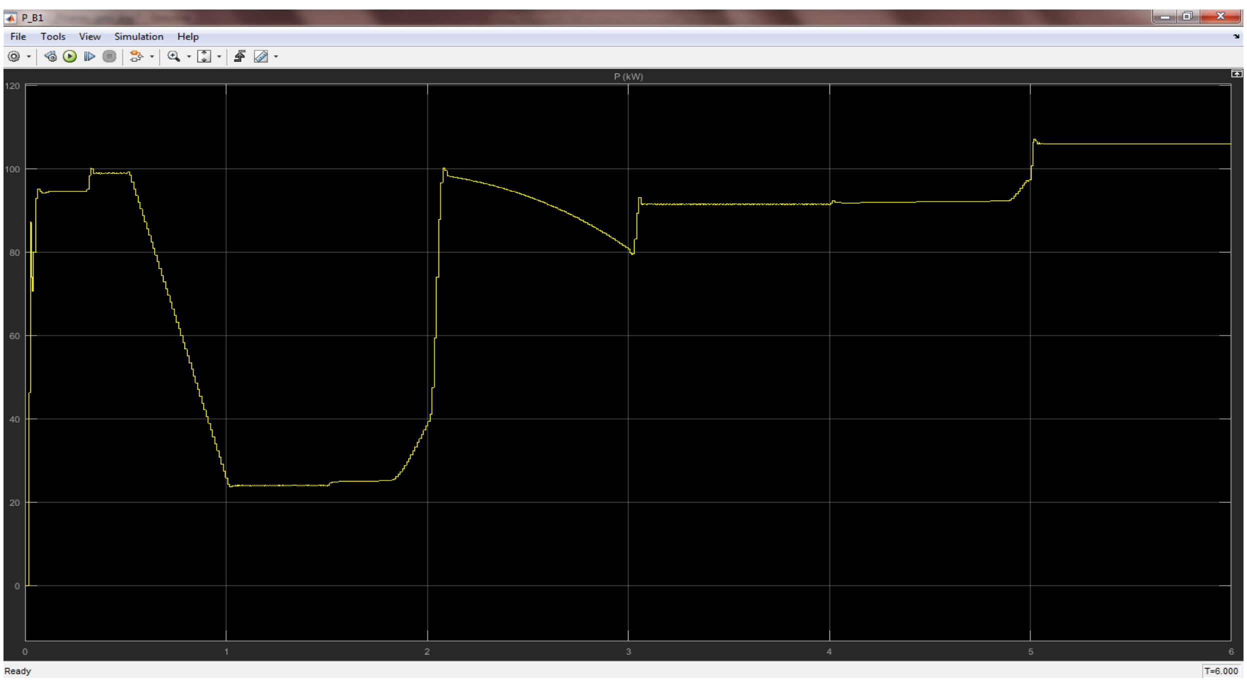


Fig: Power shared to grid

Result: We have successfully performed Experiment of Solar charge controller PWM, MPPT with boost converter and algorithms on MATLAB 2015b.

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

Experiment No. 3

AIM: EXPERIMENT ON SHADOWING EFFECT AND DIODE BASED SOLUTION IN1KWPSOLAR PV SYSTEM.

APPARATUSREQUIRED:

S.No	Name of the Apparatus	Version	Quantity
1.	MATLAB	R2015a	1

THEORY:

The sun is a hot atmosphere of gas heated by nuclear fusion reactions at its centre. Its diameter is about 1.39x109 m and is, on the average 1.5x1011m from the earth. As seen from the earth, the sun rotates on its axis about once every 4 weeks. However it does not rotate as a solid body; the equator takes about 27 days and the Polar Regions take about 30 days for each rotation. The energy produced in the interior of the solar sphere at temperatures of many millions of degrees must be transferred out to the surface and then be radiated into space. A succession of radiative and convective processes occur with successive emission, absorption and reradiation.

The shadowing effect of photovoltaics modules have a devastating impact on their performances since any shadow is able to keep down the electricity production on a PV module. Therefore in the recent years new technologies and devices have come up in the photovoltaics field in order to improve the performance of the PV modules. DC-DC optimizers as well as micro inverters are some of these new technologies. However, in order to know how these electronic products work when the shadows take place on the solar panels further investigations have to be done. When the shadows are not taking place, each system works equally well, and when a module is completely shaded in each system all of them gets the same output. However, when partially shading occurs not all of them works at the same level; the DC-DC optimizer and the micro-inverters get frequently more energy output than the string inverter system though these is not usually happening. Moreover the voltage range of the inverters and the optimizers can be a trouble that creates loses on the power output of each system.

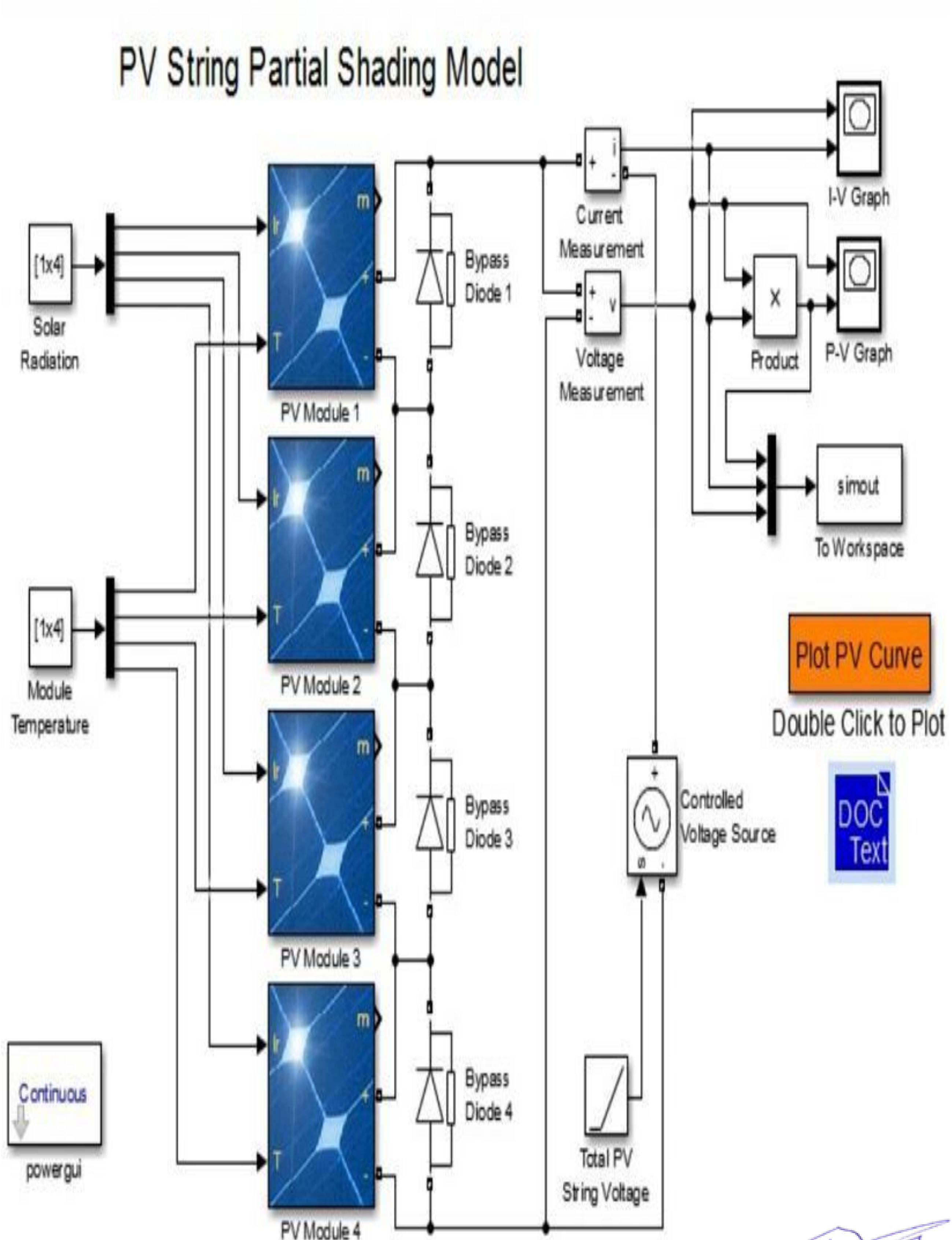
The experiment aims to study the shadowing effect on the performance in solar photovoltaic modules. First of all one modules have been analyzed in order to get a better understanding of the performance of the bypass diodes in the solar PV modules.

PROCEDURE:

1. Matlab Simulink model file is created.
2. Simulink library used to generate required components.
3. Scope is used to view results for different conditions of shadowing.
4. Plot the dark characteristics.
5. Take one representative V-I curve and obtain the equivalent circuit parameters.Tabulate the equivalent circuit parameters clearly.

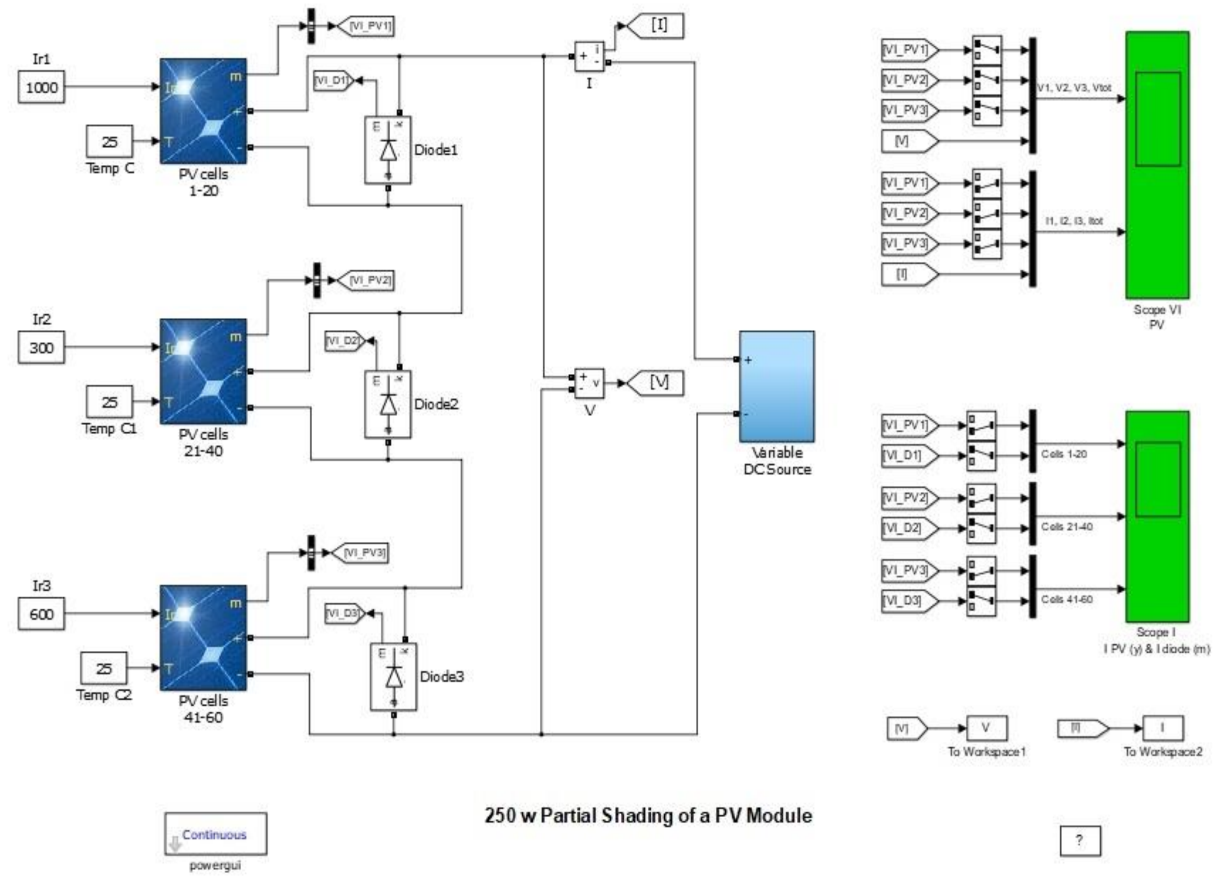
Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

CIRCUIT DIAGRAM:

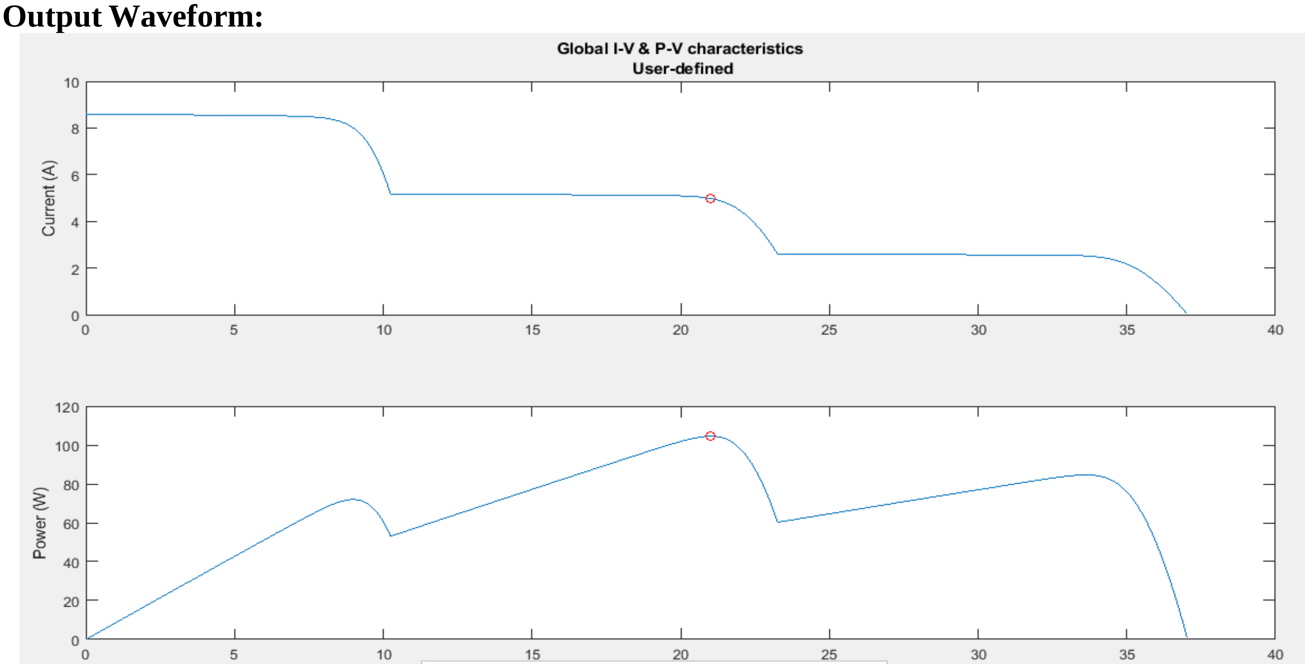


Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

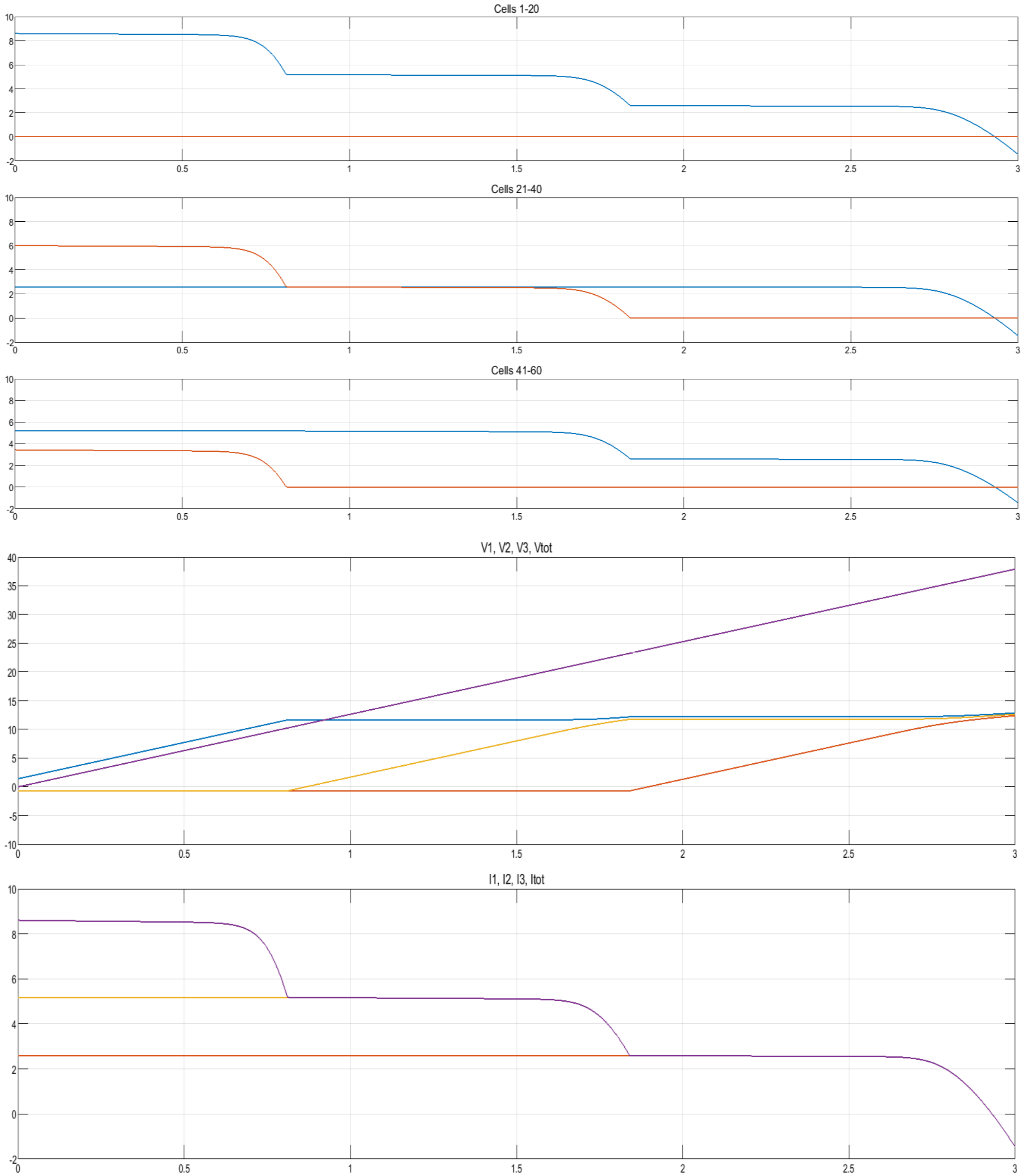
MATLAB Simulation:



Output Waveform:



Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR



Result: We have successfully simulated shadowing effect with diode based solution for different condition.

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

Experiment No. 7

AIM: STUDY OF MICRO-HYDEL PUMPED STORAGE SYSTEM.

APPARATUSREQUIRED:

S.No	Name of the Apparatus	Version	Quantity
1.	MATLAB	R2015a	1

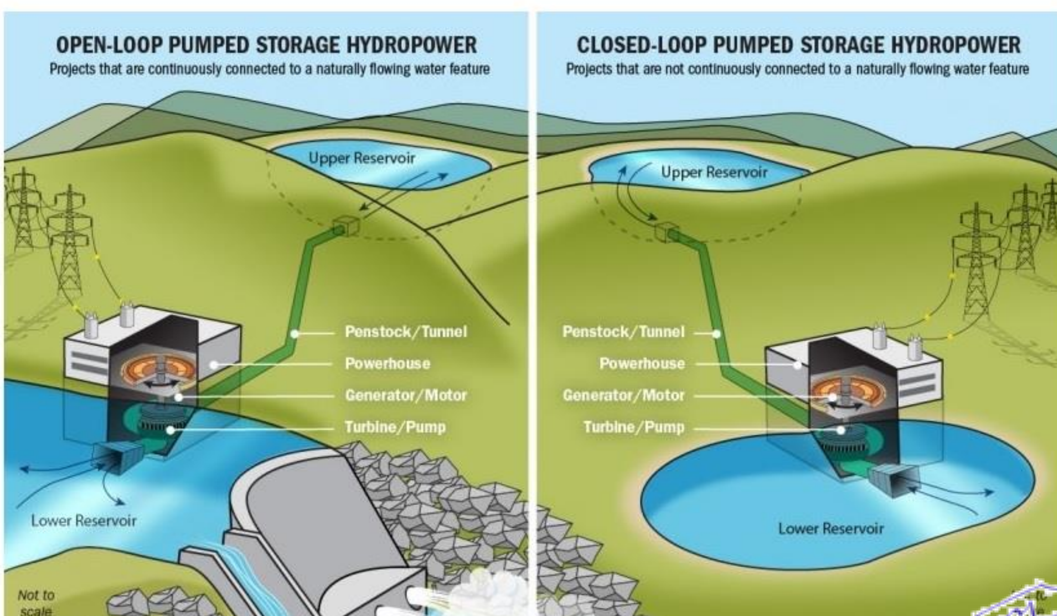
THEORY:

Pumped storage hydropower (PSH) is a type of hydroelectric energy storage. It is a configuration of two water reservoirs at different elevations that can generate power as water moves down from one to the other (discharge), passing through a turbine. The system also requires power as it pumps water back into the upper reservoir (recharge). PSH acts similarly to a giant battery, because it can store power and then release it when needed. The Department of Energy's "Pumped Storage Hydropower" video explains how pumped storage works.

The first known use cases of PSH were found in Italy and Switzerland in the 1890s, and PSH was first used in the United States in 1930. Now, PSH facilities can be found all around the world! According to the 2021 edition of the Hydropower Market Report, PSH currently accounts for 93% of all utility-scale energy storage in the United States. America currently has 43 PSH plants and has the potential to add enough new PSH plants to more than double its current PSH capacity.

OPEN-LOOP VERSUS CLOSED-LOOP PUMPED STORAGE HYDROPOWER

PSH can be characterized as open-loop or closed-loop. Open-loop PSH has an ongoing hydrologic connection to a natural body of water. With closed-loop PSH, reservoirs are not connected to an outside body of water.



(Fig 1: Open-Loop Versus Closed-Loop Pumped Storage Hydropower)

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

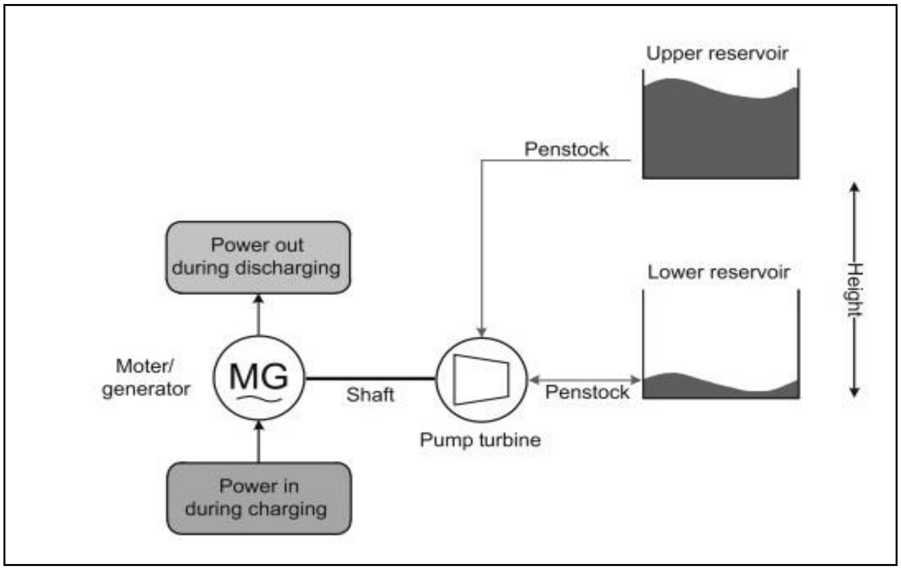
PUMPED HYDRO:

A pumped hydro energy storage system consists of two interconnected water reservoirs located at different heights such as a mountain lake and a valley lake. Penstocks connect the upper to the lower reservoir. An electrically powered pump pumps up water from the lower to the upper reservoir during the charging process and a turbine is powered by falling water during the discharging process. The amount of stored energy is proportional to the product of the total mass of water and the altitude difference between the reservoirs.

Pumped hydro energy storage is the major storage technology worldwide with more than 127 GW installed power and has been used since the early twentieth century. Such systems are used as medium-term storage systems, i.e., typically 2–8 h energy to power ratio (E2P ratio). Technically, these systems are very mature already (Table 1). Slight improvements in efficiency and costs can be achieved with advanced turbine and generator designs. The most important innovation in the last decades was the implementation of pumps with flexible operation. Older pumps can more or less only work at maximum power or they stop, whereas the newest generation of pumps is able to vary the pumping power over a wide range. This gives more flexibility and more efficiency to the pumped hydro power stations (Fig 2).

(Table 1: Pumped Hydro Storage Plants Worldwide)

Country/Town	Rated Power in MW	Duration at Rated Power in h
Germany/Waldshut	150	2.5
Germany/Tännesberg	35	3
United States/Georgetown	324	4
Poland/Porabka-Zar	500	4
Germany/Markersbach	1000	4
United Kingdom/Dinorwig	1728	5
United States/Blairstown	400	6
South Korea/Muju-gun	600	7.3
United States/Escondido	40	8
Japan/Asago	1932	8
South Korea/Sancheong-gun	400	9.6
South Africa/Jagersrust	1000	10
United States/George Washington National Forest	3030	10
Lithuania/Kruonis	900	12
United States/Shaver Lake	199	17.5
United Kingdom/Lochawe	440	22



(Fig 2: Schematic diagram of pumped hydro storage system)

The deployment potential for new pumped hydro storage systems is limited in central Europe not only by insufficient topographic sites but also by environmental problems. There are only a few new sites under construction or in the planning phase. The biggest potential for growth of storage capacity in Europe is the refitting of hydro storage plants with pump sets. Hydro storage plants are hydro power plants at seasonal water reservoirs, which so far have no pumping option and in general no lower reservoir. Typically their E2P ratio is large enough to provide power for several weeks or months. Their design goal was to collect water during the wet seasons and produce hydro power continuously throughout the year.

In order to enable these plants for energy storage they need to be equipped with pump sets. However, the biggest challenge is to find suitable spaces for lower reservoirs. Rivers cannot be used very easily as dams have to be erected and the change in water level has an ecological impact. Nonetheless, hydro storage plants can serve as sources of flexibility even without the pumping option if they can be equipped with larger turbines and are operated more dynamically to compensate for renewable energy fluctuations. Also this option has some ecological impact due to fluctuating flow rates downstream of the power plant. Due to the proximity to the Northern Sea one very favorable option for the balancing of Northern Europe's wind power is the use of the Scandinavian water storage systems. The documented storage capacity of Norwegian reservoirs alone is 84 TWh—approximately 2000 times the storage capacity of all German pumped hydro power plants. And this capacity can be used as storage capacity even without adding any additional pumps by intelligent energy management. Norway is generating today almost 100% of its electrical power from hydro power stations. If the Norwegian power market could be connected with strong grids to markets with a high share of renewable energies the following scenario would be relatively easy to implement. When there is surplus renewable energy Norway would be served by this energy excess. The pumped hydro power stations would be turned down and the water saved in the lakes. At times of low power generation from renewables Norway would be producing more power than is needed for Norwegian markets and would export the excess power. This would require only retrofits of the existing pumped hydro power stations with additional turbines and penstocks to increase the power generation capacity.

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

(Table 2: Parameters for Pumped Hydro Power)

Parameters for Pumped Hydro Power[a]	All Numbers are Indications and May Vary Significantly among Different Products and Installations	
	Today	2030[b]
Round-trip efficiency	75–82% (for new systems; existing older systems often have lower efficiency)	
Energy density	0.27 Wh l^{-1} (head 100 m) to 1.5 Wh l^{-1} (head 550 m) (taking into account only the upper water basin)	
Power density	n/a	
Cycle life	n/a	
Calendar Life	80 years	
Depth of discharge	80–100% (between predefined min and max water levels, natural lakes will have relative high min levels to assure the functioning of the eco system)	
Self-discharge	0.005–0.02%/day[c]	
Power installation cost	500–1000 € kW^{-1} (higher costs due to difficult geological conditions have been reported)	
Energy installation cost	5–20 € kWh^{-1}	
Deployment time	about 3 min[d]	
Site requirements	Two reservoirs located at different heights. Significant height difference	
Main applications	Frequency control (secondary reserve, minute reserve), Voltage control, Peak shaving, Load leveling, Standing reserve, Black start	

(Table 3: SWOT of Pumped Hydro Power)

	Pumped Hydro Power	
Internal	Strengths	Weaknesses
	• Established technology • Very long life-time • Low self-discharge • Good efficiency	• Low energy density • Geographical restriction • High investment costs • Long payback period (>30 years) • Only large units connected to the transmission grid are economical
External	Opportunities	Threats
	• Very large additional potential in Norway and Sweden, some smaller potential elsewhere • Storage costs are very competitive compared with other storage technologies	• Lengthy approval processes • High environmental standards • Increasing competition from decentralized storage systems • Flexible use of hydropower represents even more competition • High power requires connection to the transmission grid and therefore cannot solve problems in the distribution grid • Pumped Hydro in Norway: Public and political acceptance critical due to the impact of [illegible] on electricity prices.

However, as mentioned above, ecological restrictions apply. Besides that the transmission capacity would have to be increased significantly. Apart from the technical and ecological challenges in the case of Scandinavia another aspect has to be considered. Due to the low-cost power generation from almost 100% hydro power Norway has relatively low electricity prices compared with other European countries. Therefore, a strong energy-intensive metallurgical industry has been established and electricity usage in the private sector, e.g., for space heating is very common. The utilization of storage capacities in Norway as a flexibility source for Central European renewable energy generation would imply, according to today's energy market designs, an integration of the Norwegian electricity market into the European electricity market. While the Norwegian power supply industry would strongly benefit from the additional markets, this would increase the electricity prices in Norway, conflicting with the interests of existing industries and private end users (Tables 2 and 3).

PROCEDURE:

1. Run the motor-pump system.
2. Open the turbine inlet valve. Vary the load and obtain the load current versus power output characteristics.
3. Again fill the tank and keep the motor-pump system running. Open the valve in four stages. In each stage, obtain the hydraulic power input from head and flow rater readings and electrical power from wattmeter. For each flow rate, obtain the maximum electrical power and draw the efficiency against flow rate.
4. Starting from an empty tank, fill it up fully. Keep the turbine valve closed. Note down the electrical energy spent in the pumping process. Open the valve; keep the resistance fixed close to the maximum power point. Note down the power against time using a stop watch. From the area under the curve, obtain the energy recovered. Calculate the full cycle efficiency of the pumped storage scheme.

RESULT: We have successfully Study of Micro-Hydel pumped storage system

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

Experiment No. 8

AIM: EXPERIMENT ON FUEL CELL AND ITS OPERATION.

APPARATUSREQUIRED:

S.No	Name of the Apparatus	Version	Quantity
1.	Fuel Cell		1
2.	Voltmeter	1-400V	1
3	Ammeter	1-100A	1

INTRODUCTION:

The generation of clean, efficient and environmentally friendly energy is a major challenge for science and engineering. Carbon dioxide levels are 40 % higher than they were in the 19th century, at the beginning of the industrial revolution, and most of the increase has taken place since 1970. During the last 40 years the global energy consumption has accelerated, and the rise in CO2 is largely due to the combustion of fossil fuels. There are growing concerns regarding the increasing **greenhouse gas emissions** from fossil fuels, as well as the **diminishing fuel reserves**, and therefore scientists are looking towards fuel cell technology for future power. Fuel cells have a wide range of potential applications, including portable device and transport applications.

A fuel cell, like a battery, is an electrochemical cell, which converts chemical energy into electricity, via a chemical **redox** reaction. Fuel cells convert the chemical energy associated with the combustion of a fuel gas directly into electrical work, which is much more efficient and environmentally clean than the process of combustion itself. A spontaneous redox reaction produces a potential difference between the two electrodes. The electrode at which the reduction occurs becomes the cathode, which is positively charged, and the oxidation occurs at the anode, which is negatively charged. Electrons flow from anode to cathode.

Fuel cells are known as one of the most efficient energy conversion devices. Proton exchange membrane (PEM) fuel cells have advantages such as low operating temperature, high power density, rapid startup, as well as excellent reliability and durability over other types of fuel cells. PEM fuel cells are widely recognized being suitable for wide applications as power sources for automobiles and small to medium scale portable and stationary backup power suppliers.

THEORY

Electrolysis of Water

Electrolysis is the process of chemical decomposition of a substance (liquid or solid) using an electric current. For instance, to electrolyze water, we can use a system made up of two tubes, connected at their bases, where the electrodes are located. This is called the Hofmann apparatus (fig. 1).

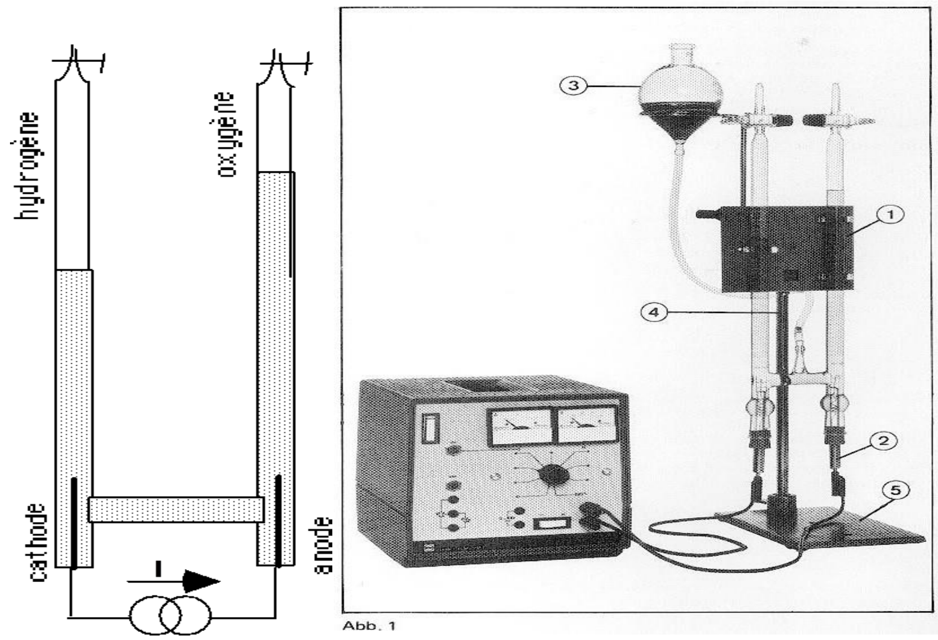


Fig 1: Hofmann apparatus, used for electrolysis.

Chemical reactions at the electrodes

Cathode: $2\,H_2O + 2\,e^- \rightarrow H_2 + 2\,OH^-$

Anode: $2\,OH^- \rightarrow 1/2\,O_2 + H_2O + 2\,e^-$

Faraday's law: The mass m of matter freed from the electrodes is proportional to the electrical charge Q that has passed through the electrolyte, to the molar mass M of the substance, and is inversely proportional to "v", the number of valences broken in the electrolyte (number of electrons):

$$m = \frac{1}{F} \cdot Q \cdot \frac{M}{\nu}$$

where F = 96 485 C/mol is the Faraday constant.

where n is determined from the ideal gas law: $PV = nRT$

Fuel cell

The fuel cell is an apparatus allowing the inverse reaction of the electrolysis: a controlled oxidation of hydrogen, producing electricity and water simultaneously. A fuel cell is made of two electrodes (cathode and anode) separated by an electrolyte that can be liquid (potassium hydroxide KOH, phosphoric acid) or solid (conducting polymer, doped ceramic e.g. ZrO2 doped with Y2O3). The electrodes are generally made of a porous metal, allowing a rather fast diffusion of the gas, all the while stopping the inverse diffusion of the electrolyte if it's liquid. The adsorption of the reacting gas should preferentially be done to the combustible product, in order to preserve the catalyst. If we look at the periodic table, we notice that elements such as Ni, Ag, Pt, Pd, … are electronegative with respect to hydrogen and electropositive with respect to oxygen. They can therefore be used for both electrodes (cathode and anode), since they are capable of ionizing both gases.

Liquid Electrolyte Fuel Cell (KOH)

<u>Chemical reactions at the electrodes:</u>

cathode: $1/2\ O_2 + H_2O + 2\ e^- \rightarrow 2\ OH^-$

the OH^- ions move from the cathode to the anode through the electrolyte (KOH)anode:

$H_2 + 2\ OH^- \rightarrow 2\ H_2O + 2\ e^-$

electrons freed at the anode go back to the cathode through the outer circuit.

Solid PEM Electrolyte Fuel Cell (Proton Exchange Membrane):

<u>Chemical reactions at the electrodes:</u>

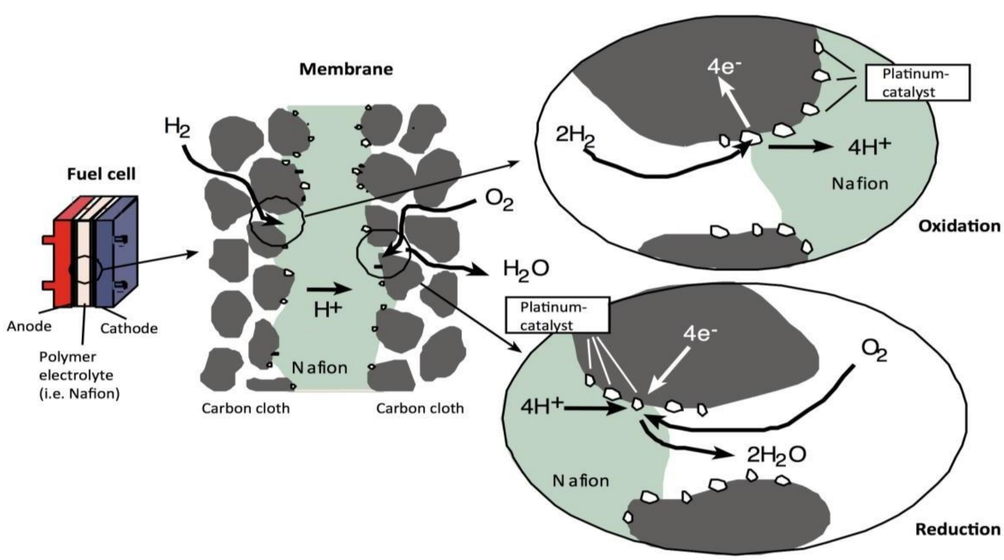
anode: $H_2 \rightarrow 2\ H^+ + 2\ e^-$

the H^+ ions move from the anode to the cathodecathode:

$1/2\ O_2 + 2\ H^+ + 2\ e^- \rightarrow H_2O$

A single cell (fig. 2) consists of two gas flow plates, one for hydrogen and one for oxygen, separated by a membrane electrode assembly, abbreviated MEA. The flow plates contain channels to ensure that the gases are in contact with as much of the MEA as possible. The MEA consists of two porous carbon-cloth electrodes bonded a polymer electrolyte membrane (50– 175 μm thick). This material, the electrolyte, allows the conduction of hydrogen protons from one side of the membrane through to the other. At the same time, it prevents oxygen molecules from flowing in the reverse direction.

On the electrodes are Nano-sized particles of platinum. The platinum acts as a catalyst for the redox reaction to take place. Initially the hydrogen molecules are chemically adsorbed onto the platinum surface, forming hydrogen-platinum bonds. Platinum is unique in that it has the ideal bonding strength to both break the hydrogen molecule bond, to form the hydrogen-platinum bonds, while being able to release the hydrogen, allowing the redox reaction to proceed.



(Fig 2: Cross-section of a polymer electrolyte membrane electrode assembly, illustrating the processes taking place during the fuel-cell reactions.)

Fuel cells also have losses, due to the internal membrane permeability as well as due to polarization phenomena that generate a voltage drop within the fuel cell. That means that it is impossible to convert100% of the gases into electrical energy.

The Faraday efficiency η_F of a fuel cell can be calculated as the ratio between the amount of moles of electrons produced and the amount of moles of gas consumed. Or, shown in another way:

$$\eta_F = \frac{\text{Mass of fuel reacted in cell}}{\text{Mass of fuel input in cell}} = \frac{V_{H_2}\,(\text{calculated})}{V_{H_2}\,(\text{consumed})}$$

The volume that theoretically reacted in the cell V_{H_2} (calculated) is obtained from the mean current and measurement time using the Faraday's law and the ideal gas equation.

The energy efficiency η_E could be defined as the ratio between the electrical energy (E_{el}) produced and the energy of consumed hydrogen ($E_{Hydrogen}$):

$$\eta_E = \frac{E_{el}}{E_{H_2}}$$

The latter is calculated from the formation energy of water H_{H_2O} = 285.84 kJ/mol:

$$E_{H_2} = n \cdot H_{H_2O}$$

using again the ideal gas equation to calculate n from the V_{H_2} (consumed).

CELL FABRICATION AND EXPERIMENTAL WORK

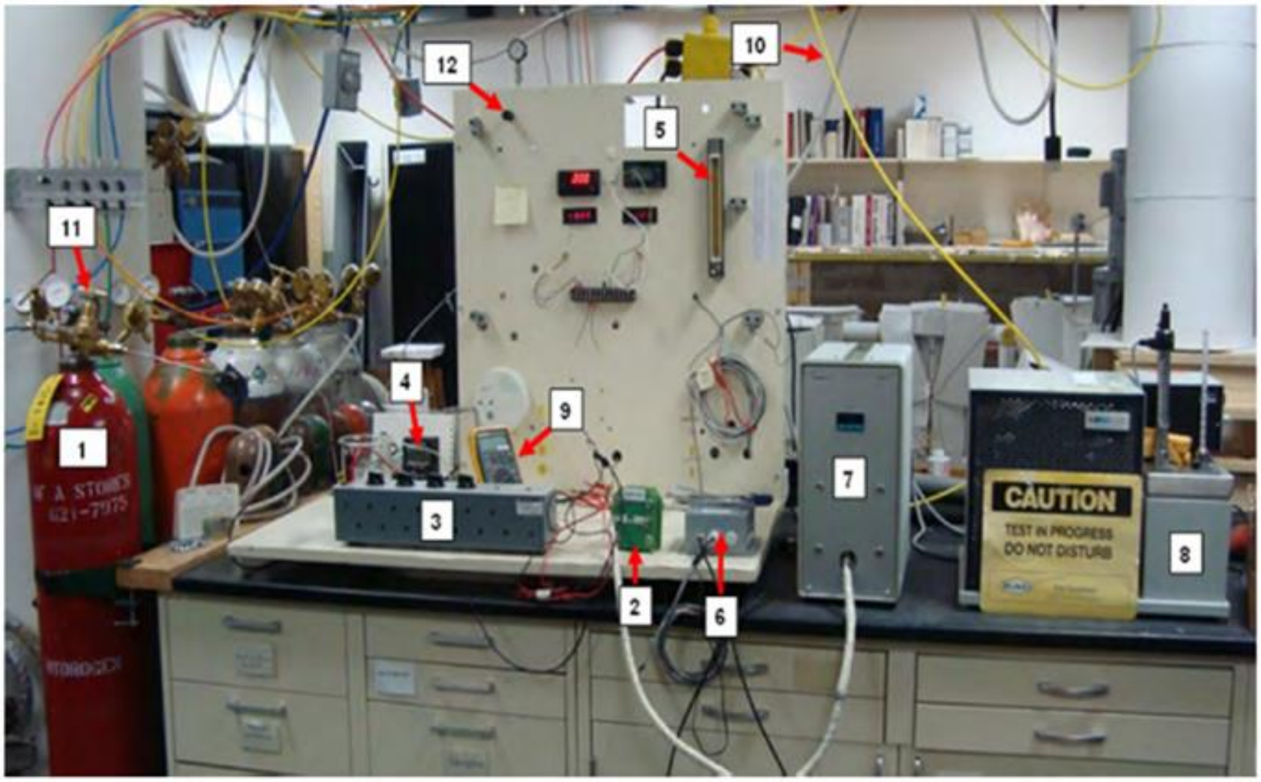
The experimental tests have been conducted in Energy and Fuel Cell Lab at the University of Arizona. The same type of membrane electrode assemblies (MEAs) from one manufacturer was used for all the tests, which include a membrane of Nafion 115 with platinum loadings of 0.4 mg/cm2. The MEA and gas diffusion layers were pre-laminated at factory with an effective area of 23.5 cm2. The gas diffusion layers are made of carbon fiber cloth.

Fuel Cell Assembling

The anode and cathode graphite plates, with flow channels fabricated, are assembled together with MEA. Two plastic end-plates are used to sandwich the fuel cell to maintain good electrical contact between all components. Since the electrical contact resistant between the graphite plates and the gas diffusion layers depends on pressure applied on the contacting surfaces, all the assembly of the fuel cells should have the same compression to ensure that study and comparison of the fuel cell performance for other factors is based on the same contact resistance. A torque meter was used to indicate the same torque on the bolts when assembling a fuel cell.

Experimental Setup

The front panel of the experimental setup is shown in Figure 4. Key components in the setup are marked in the figure, which include: a hydrogen tank and pressure control valve, mass flow controllers for hydrogen, flow meter for air, air supply tubes with pressure regulation, humidity and temperature measurement equipment, humidifier to air and hydrogen, a single fuel cell, a load/resistance box, and a voltmeter.



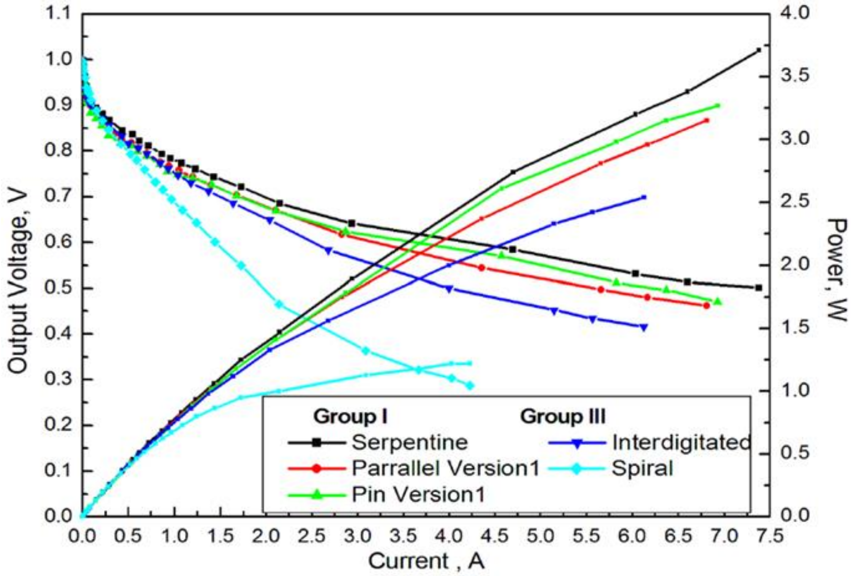
(Fig 3: Experimental Setup of fuel-cell reactions.)

RESULT:-

According to the authors' former observation for the flow arrangements (concurrent or counter current flow) in fuel cells, counter current flow of hydrogen versus air/oxygen showed better performance. Therefore, all PEM fuel cells tested in this work were conducted with counter current flow arrangement for hydrogen and air. The supplies of hydrogen and oxygen were more than that needed for the tested current densities.

Effect of Flow Field Designs

The performance of fuel cells due to the different designs of the flow channels is to be compared. In the tests, the hydrogen and air flow rates were set at constant of 189 and 1274 sccm, respectively, and the humidifiers of hydrogen and airflow have a dew point of 30°C. Figure 5 gives a comparison of the performance of single fuel cells having serpentine, parallel V1, pin V1, inter digitated, and spiral designs of flow fields. Figure 6 shows a comparison of the performance of fuel cells having serpentine, parallel V2, pin V2, inter digitated, and spiral designs of flow fields.



(Fig 4: Comparison of cell output performance between group I and group III flow field designs)

RESULT: We have successfully Study of Micro-Hydel pumped storage system

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

Experiment No. 9

AIM: STUDY OF 100 KW OR HIGHER SOLAR PV PLANT.

APPARATUSREQUIRED:

S.No	Name of the Apparatus	Version	Quantity
1.	Number of Modules	400	1
2.	PV Technology	Polycrystalline 250Wp	1
3.	Module Manufacturer	PV Power Tech ECO	1
4.	Series Connected	20/20/20	1
5.	Parallel Connected	3/3/4	1
6.	Plant Rated Power	100 kWp	1
7.	Area	648.4 m^2	
8.	Tilt	23.4^0	1
9.	Tracking System	Without Tracking System	1
10.	Number of Inverters (PCU)	2	1
11.	Inverter Manufacturer	KACO POWADOR 60.0 TL3 (UPF)	1
12.	Pin Assignment of the Input	1/1/1	1
13.	Number of MPPTs	3	1

THEORY:

The energy plays a pivotal role in our daily activities. The degree of development of a country is measured by the amount of utilization of energy by human beings. Energy demand is increasing day by day due to increase in population, urbanization and industrialization. The world's fossil fuel supply will be depleted in a few hundred years. The rate of energy consumption increasing, supply is depleting resulting in inflation and energy shortage. This is called energy crisis. Hence alternative or renewable sources of energy have to be developed to meet future energy requirements. The principle of solar power plants is quite simple. They consists of a field of solar photovoltaic modules connected them in series and parallel and connected to one or more inverters.

BASIC BLOCK DIAGRAM:

The basic block diagram of the 100 kW solar plant is shown in Fig 1. This solar plant is mainly consists of

- 400 Solar Panels
- DC String Array and Combiner Box
- Two Inverters (PCU)
- AC Distribution Box
- Plant AC Energy Meter
- Data Acquisition System

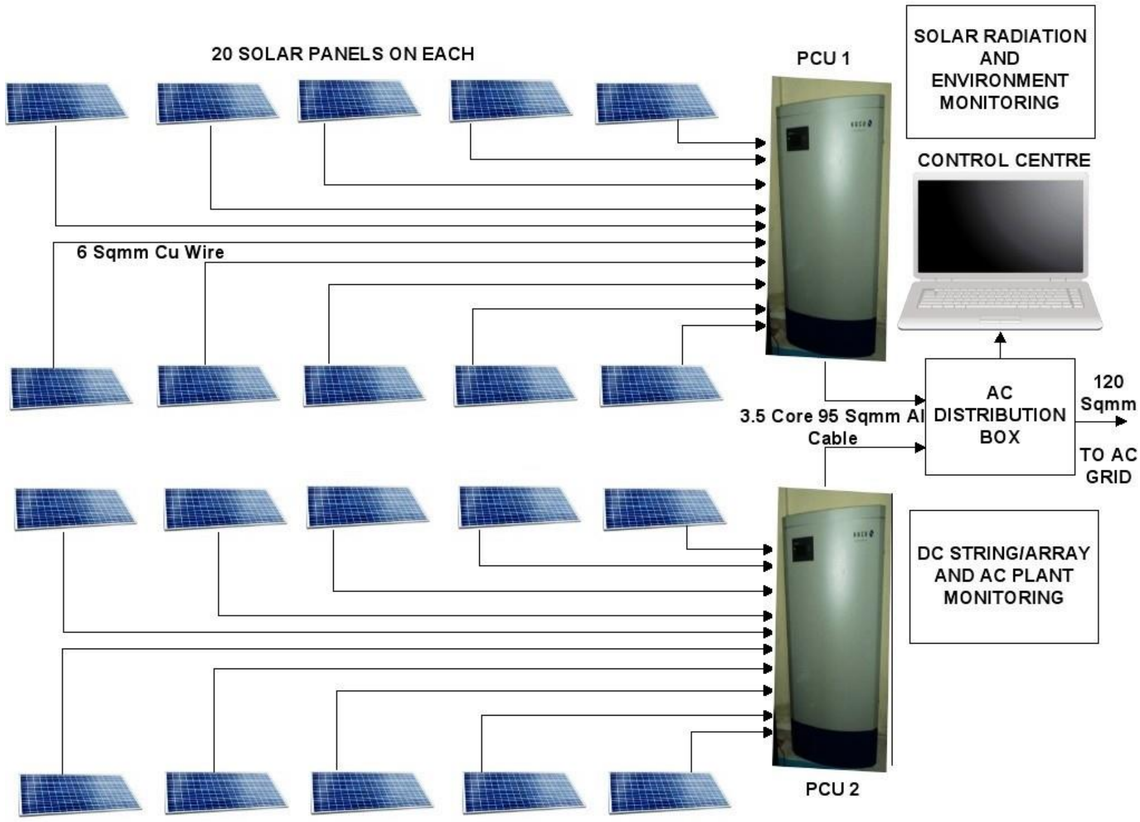


Fig. 1: Schematic Diagram of 100 kW Solar Power Plant

PV Array:

The total solar PV array installed capacity is 100kW. Individual PV module rating is of 250 watt. The PV array consists of framed multi-crystalline. A suitable number of solar PV modules are connected in series string and a suitable number of series strings are connected in parallel to formulate a series parallel array. Maximum DC output voltage of the array is nearly 600 V. Conversion efficiency of the plant is approximately 15.5%. The front surface of the module consists of impact resistant low iron and high transmission toughened glass.

Fig. 2: PV Array on the rooftop

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

For each of the solar panel the corresponding data available are as below

V_{OC}	37 Volt
I_{SC}	8.55 Amps
V_{MP}	30.95 Volt
I_{MP}	8.08 Amps
Power Thermal Coeff.	-1.036 Watt/^{0}C

PCU:

There are two PCUs used to convey the DC power produced by SPV modules into AC power and adjust the voltage and frequency levels to the local grid connection. Those PCUs are provided with the Maximum Power Point Tracking (MPPT) features so that maximum possible power can be obtained from the PV module. There are 3 MPPTs are there and those are connected in asymmetrical manner (3/3/4). PCUs are capable of disconnection automatically in the event of grid failure. The PCUs have internal protection against sustained faults and lightening in DC and mains AC grid circuit. The sine wave output of the inverters is suitable to connect to AC LT voltage grid. The internal connections in a PCU are shown in Fig 3.

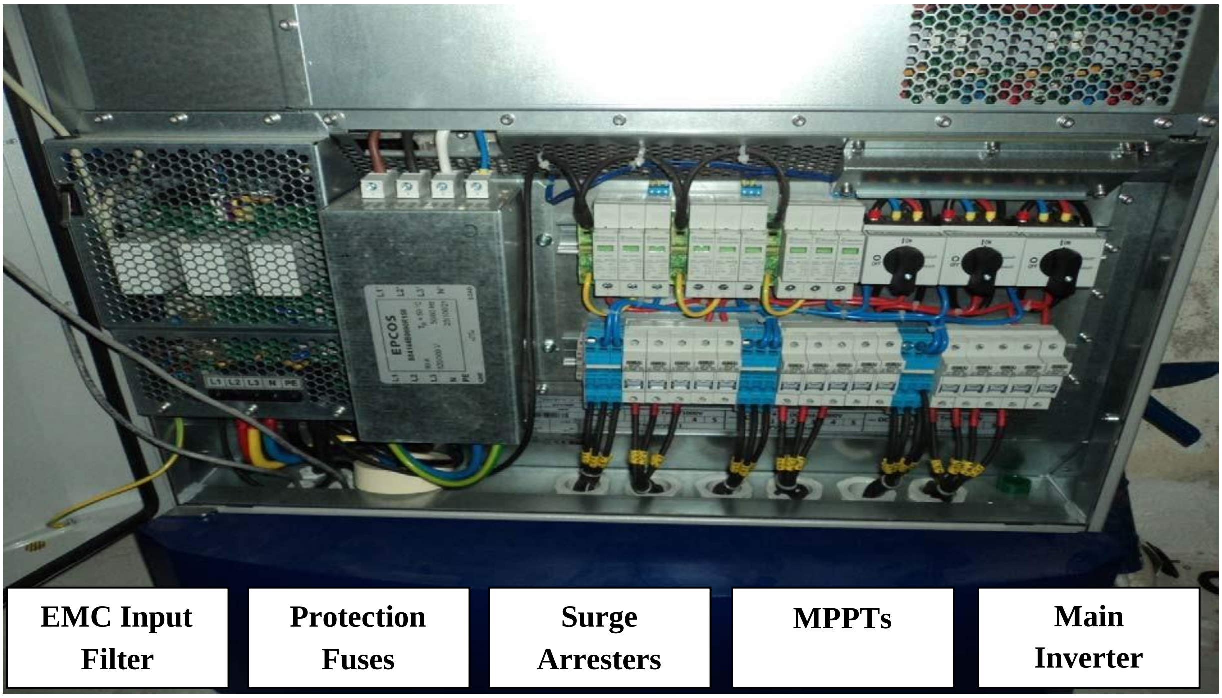


Fig. 3: Inside View of PCU

From the figure 3 it is cleared that there are total 3 MPPTs (Sky colored) to which total 10 (in 3+3+4 fashion) cables are connected. Above the MPPTs there are three surge arresters (white colored). Between the three MPPTs there are three solar photovoltaic system protection fuses (1000 V, 32 amps, manufactured by SIBA). At the left there is an EMC input filter (90 amps 520/300 V) made by EPCOS. The top most enclosed one is the main inverter.

AC Distribution Box:

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

Solar AC Distribution Board is the panel used between solar Inverter and Load to provide overload and short circuit protection. Normally these panels have one power input controlled by MCB, MCCB or Fuse multiple load feeders that use energy meter to measure total load consumption. All the components are assembled in a suitable powder coated metal enclosure. The basic block diagram is shown in Fig 4.

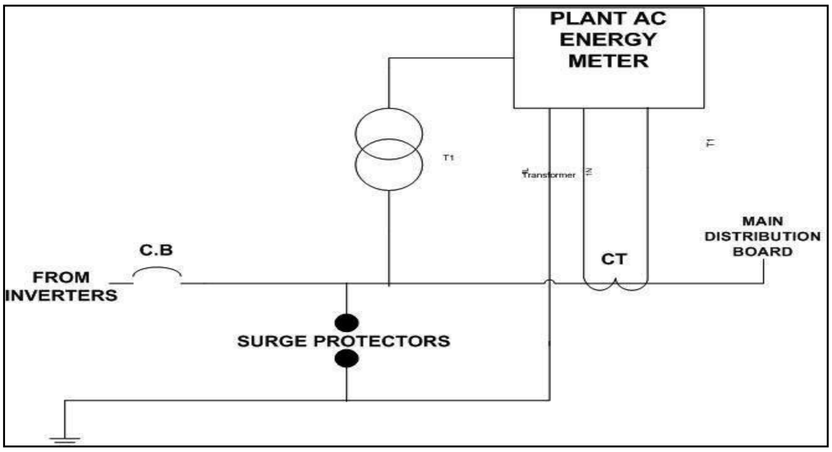


Fig. 4: Schematic Diagram of ACDB

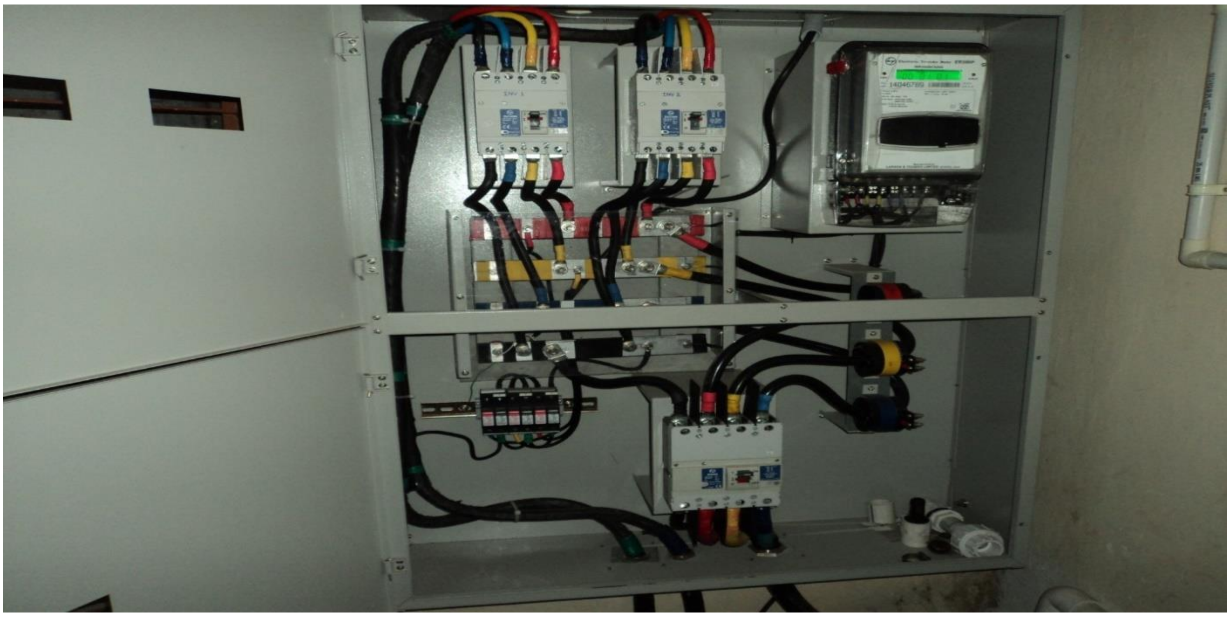


Fig. 5: AC Distribution Box

As seen from the fig. 5 the leftmost two large cables are coming out from the two PCU units and connected to the two MCCB. The outputs of the MCCB are connected to the common bus (Red, Yellow, Blue, Neutral (Black)). Below the common bus the black colored device is a surge protector for protection purpose. At the right there are three CTs connected to each phase to measure the phase current. Those are directly connected to the common bus. Above the CTs a Trivector Energy Meter is used to measure the energy supplied. Cables from main distribution board are connected to the common bus through another MCCB and the above mentioned CTs.

The cable connections from AC distribution board to the LT grid are shown Fig.6.

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

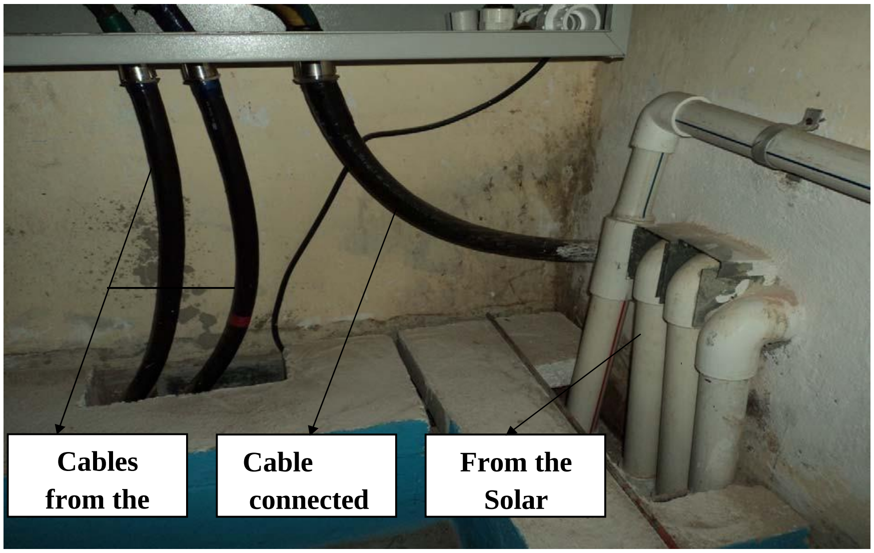


Fig. 6: Incoming and Outgoing Cables of ACDB

Solar Radiation & Environment Monitoring:

For this purpose a reference cell is used. Solar reference cell is a precision instrument for the determination of solar irradiance levels. The sensor is a mono-crystalline silicon solar cell. The back of the solar cell is attached to the device in such a way that a good heat transfer to the device housing is guaranteed. Below the solar cell a RTD temperature sensor is mounted to allow monitoring of PV cell temperature a shown in Fig. 8. The device is not shunted allowing the whole IV-curve to be measured. Each reference solar cell is delivered with a calibration report showing the IV-curve plot and the following parameters: ISC, VOC, IMPP, VMPP, Fill Factor and Efficiency. Solar radiation and environment monitoring equipments are connected to the reference cell as shown in Fig.7

Fig. 7: Reference Solar Cell

Fig. 8: Temperature Sensor

By this arrangement global and diffuse solar radiation in the plane of array can be monitored on continuous basis.

Data Acquisition System:

A data blogger is used for computerized monitoring of string and array DC voltage, Current and Power, Inverter AC output voltage and Current, AC Power (Active, Reactive, and Apparent), Power Factor. There is a provision for remote monitoring and data downloading is also incorporated. The data can be recorded in a common work sheet chronologically date wise. The data file is MS Excel compatible. The data can be represented in both tabular and graphical form.

The online data can be obtained from the following links

i. 10.23.2.6 For PCU 2
ii. 10.23.2.5 For PCU 1
iii. 10.23.2.4 For System performance

Connection to the Substation:

From the ACDB the solar plant is connected to the Substation-2 (11 kV/430V) The substation connection is shown in Fig 9.

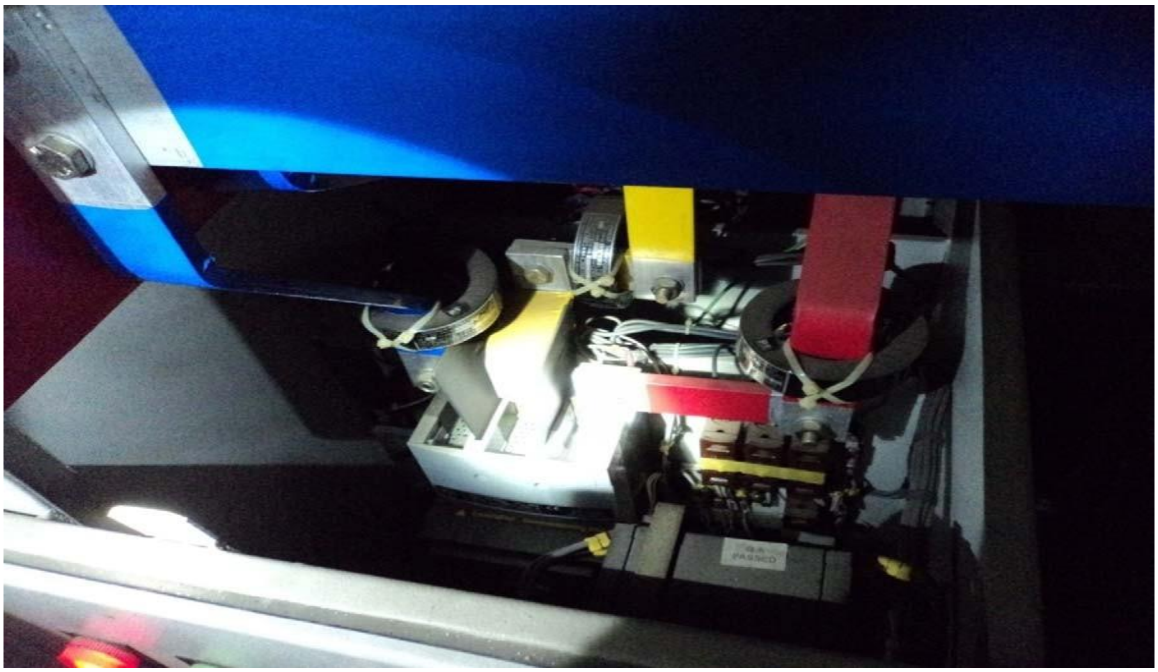


Fig. 9: Connection to the Substatio

RESULT: We have successfully Study of 100 KW solar PV plant

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

Experiment No. 10

AIM: STUDY DIFFERENT COMPONENTS OF MICRO GRID

APPARATUSREQUIRED:

S.No	Name of the Apparatus	Version	Quantity
1.	MATLAB	R2015a	1

THEORY:
Definition of Microgrid:

A microgrid has multiple distributed sources and local load centers with low voltage distribution network with or without backup storage components. It can work with or without collaboration of main grid to feed the local load demand. Two way power can flow when main grid is connected with it. For control and management of all components and power flow in microgrid, single or multiple intelligent control unit(s) are there. Minimization of toxic gasses emission from thermal generation and maximization of profit (if taking part in energy market), are also taken as objectives of intelligent controller of micro grid.

So, from above definition, we can say that microgrid:
1. Have distributed sources
2. Works inside or outside energy market
3. Have intelligent control and management unit(s).

A microgrid is a local energy system which incorporates three key components; Generation, Storage and Demand all within a bounded and controlled network. It may or may not be connected to the grid.

BASIC STRUCTURE AND ELEMENTS IN MICROGRID:

As stated in start that microgrid is home for a lot of components according to requirements of stakeholders (consumer, investor, market). All components join together to form structure of microgrid. From the definition, we can conclude that basic elements in microgrid are:

- Distributed Generating units
- Load Centers
- Distribution network
- Control Unit(s)
- Electric Power Storage (optional)

The distributed generation units could be conventional, non-conventional (renewable or alternate sources) or combination of both. Main objective of these generating units is to meet the demand of local load centers. Load centers can also have own generation, partially dependent to the supply or total demand is fulfilled by the generating units through distribution network.

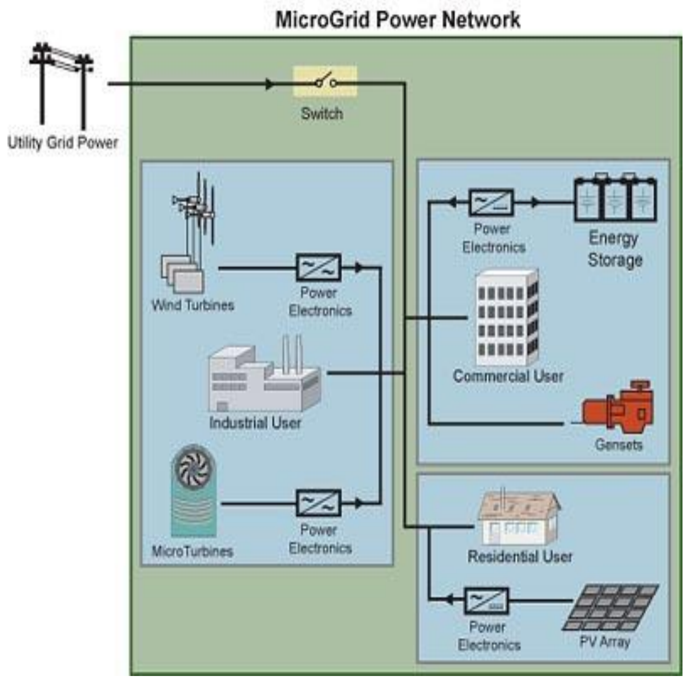


Fig. 1: Microgrid Components

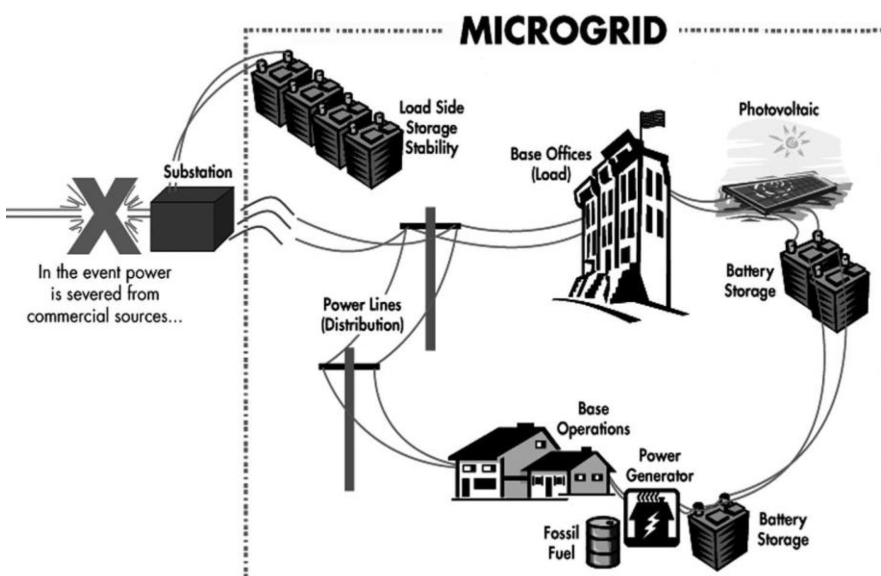


Fig. 2: Typical Microgrid Components

CONTROL IN MICROGRID:

Control unit is one of major component of microgrid. The flow of power from generation to the load centers should be monitored, controlled and managed properly. Even before, the generation of electric power must have controller to maintain power quality (voltage, frequency and sin wave within limit). Synchronization and control of single type of generation in microgrid is relatively easy and less complex. And this can be controlled by single central controller. But microgrid can have multiple type of generation (by its nature) at single place to feed the single load center. So, the control of such diverse type of generation becomes very complex and difficult to handle by single central controller. So, basically two main classes are there for microgrid controller:

- Centralized Controller
- Distributed Controller
- Hybrid Controller

Centralized Controller of Microgrid:

In the centralized scheme of Microgrid, single controller is whole responsible for controlling all the generators, power flow, power quality, meeting the load demand and/or selling/buying power to/from the market. For this purpose, commonly used controller is *supervisory control and data acquisition (SCADA)* centralized control unit. It takes input of all kind and control and manage accordingly.This controller works fine for simple systems but when complexity increases, due to increase in number of components, tasks and constraints to handle, the communication and computation burden also increases exponentially. Also, if the central control unit fails, whole system is destined to collapse.

Distributed Control Structure of Microgrid:

In distributed control of microgrid, each component have its local controller and responsible for control of that specific component locally, according to all the constraints. Controller of generators maintains the power quality and main objective remain the same i.e. meeting the load demand collectively. In this scheme, communication burden is reduced on single controller and computational time is reduced and system works efficiently. The cost of whole system may increase due to multiple control units.

Hybrid Control Structure of Microgrid:

The combination of both central controller and distributed control is also purposed in many research articles. Researches tried to combine the positive aspects of both types of controllers to form a hybrid controller. These controllers reduces the communication and computation burden on single controller by somewhat decentralizing the controller (not completely).

STORAGE IN MICROGRID:

Microgrid can have storage as backup while operating in stand-alone mode of operation. When there is renewable source of power, excess power from renewable (after the load demand is fulfilled), can be stored in batteries. This can then be used as backup when needed.

STRUCTURE OF MICROGRID:

From a brief introduction of components of microgrid, a visualization of microgrid can be viewed as following figure: This figure has multiple load centers (commercial and residential) and multiple type of generation (conventional and non-conventional). The microgrid has distributed sources and local controllers also whole microgrid is monitored by centralized control unit. There is also a battery bank for storage of excess renewable power. This is stand-alone operation of a microgrid.

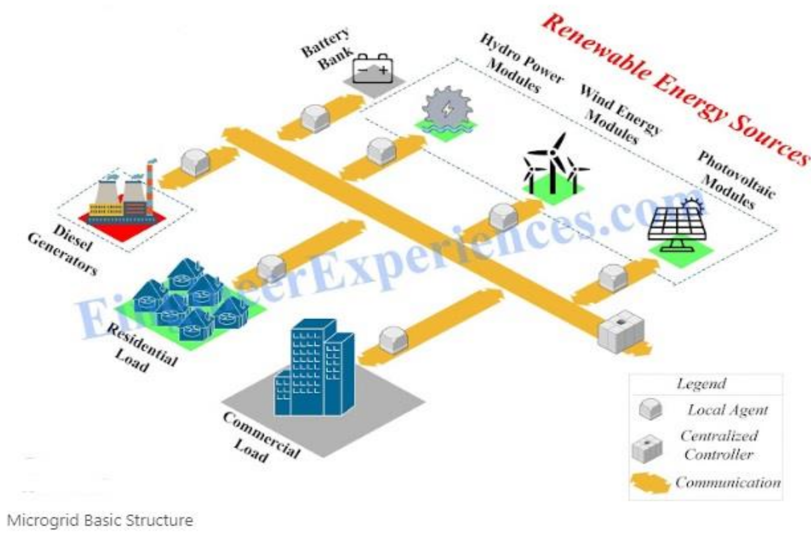
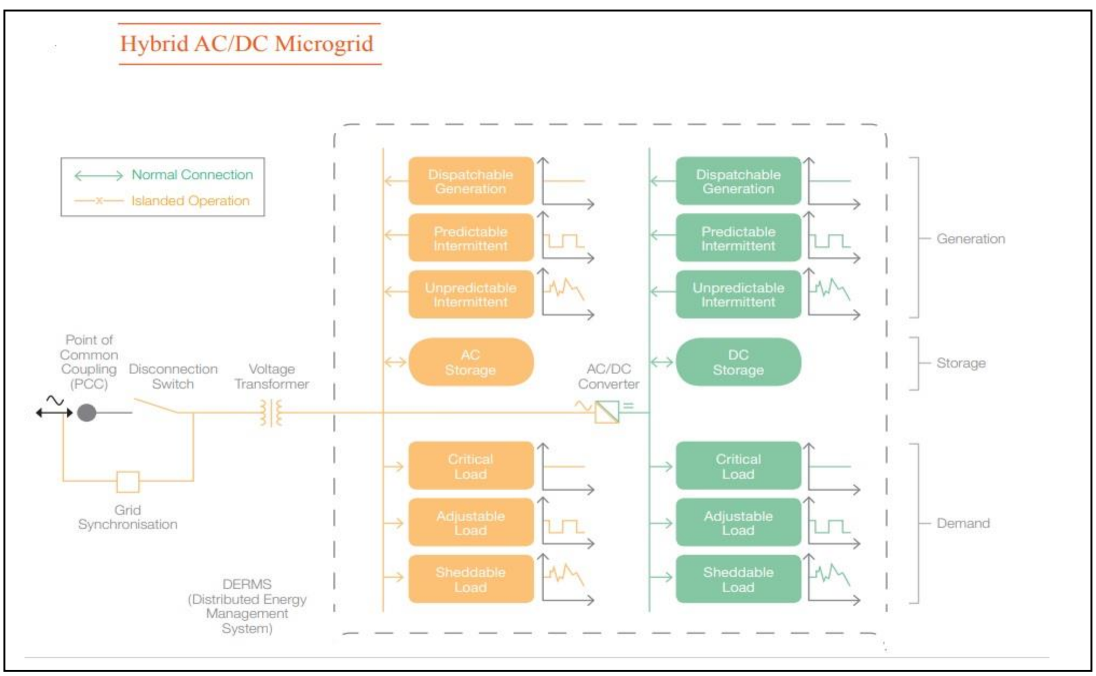


Fig. 3: Microgrid Basic Structure

MODE OF OPERATION OF MICROGRID:

Microgrid can work with the main power supply from the utility to feed the load and provide power to the main grid when it has excess power. It can work as island of load units and generation when other parts of whole power system is under maintenance or have bug in it. Control unit is also responsible of successful connection and disconnection of microgrid from main grid.



(Fig 2: Hybrid AC/DC Microgrid)

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

BALANCING SUPPLY AND DEMAND

Microgrids have the ability to maintain a balance between available supply and desirable load demand through careful marriage of supply and demand combined with intelligent control of any imbalance. Microgrids can be configured in a number of ways based on the required reliability, sustainability and affordability emphasis together with consideration of the local grid characteristics and availability. The ability of a Microgrid to maintain a supply/demand balance is a key attribute.

Microgrid energy supply comprises a number of categories ranging from readily controlled to intermittent and not controllable. This range includes dispatch able generation such as diesel generators or fuel cells at one end, through predictable intermittent supply such as PV or micro-hydro and on to less predictable intermittent supply from wind generation at the other end of the scale.

Microgrid energy load has a range of controllability characteristics ranging from critical loads such as data systems or life support machinery at one end of the scale, to adjustable loads such as heating/ cooling, lighting or grid dispatch at the other. The extent to which the loads can be modulated as well as the time period over which they can be changed are key characteristics. Some loads may also be temporarily curtailed where necessary.

Microgrid energy storage provides a critical supply fallback as well as a means to 'time-shift' own generation to match load demands

RESULT: We have successfully Study of Microgrid components system

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

Experiment No. 12

AIM: EXPERIMENT ON PERFORMANCE ASSESSMENT OF HYBRID (SOLAR-WIND- BATTERY) POWER SYSTEM

APPARATUSREQUIRED:

	Name of the apparatus	Range	Type	Quantity
1	PV array			
2	Wind turbine			
3	Hybrid charge collector			
4	Battery bank			
5	Inverter			
6	Load			

THEORY:

PV Array Performance Model

The PV module performance depends on weather conditions, especially solar radiation and PV module temperature. PV modules represent the fundamental power conversion unit of a PV system. It is mandatory to connect PV modules in series and in parallel in order to scale up the voltage and current to tailor the PV array output.
If a matrix of $N_s \times N_p$ PV modules is considered, the maximum power output of the PV system can be calculated by

$$P_{PV} = N_p . N_s . P_{module} . \eta_{MPPT} . \eta_{oth}$$

Where,
η_{MPPT} is efficiency of the maximum power point tracking,
(constant value of 95% is assumed)
η_{oth} is the factor representing the other losses caused by cable resistance and accumulative dust.

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR

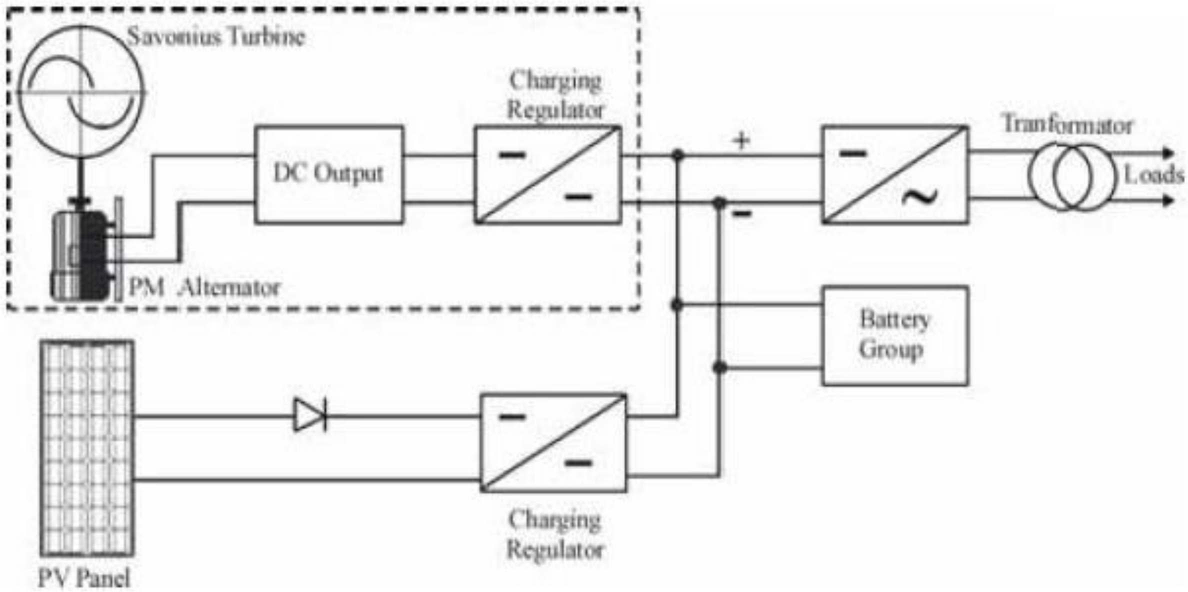


Fig. 1: Combined solar and wind system model

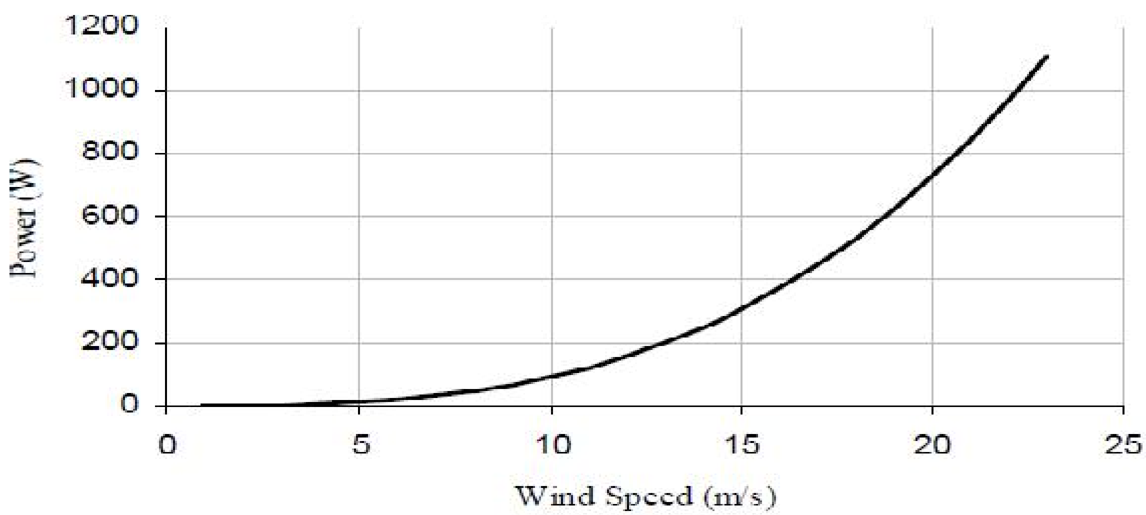


Fig. 2: Power curve of the savonius wind turbine

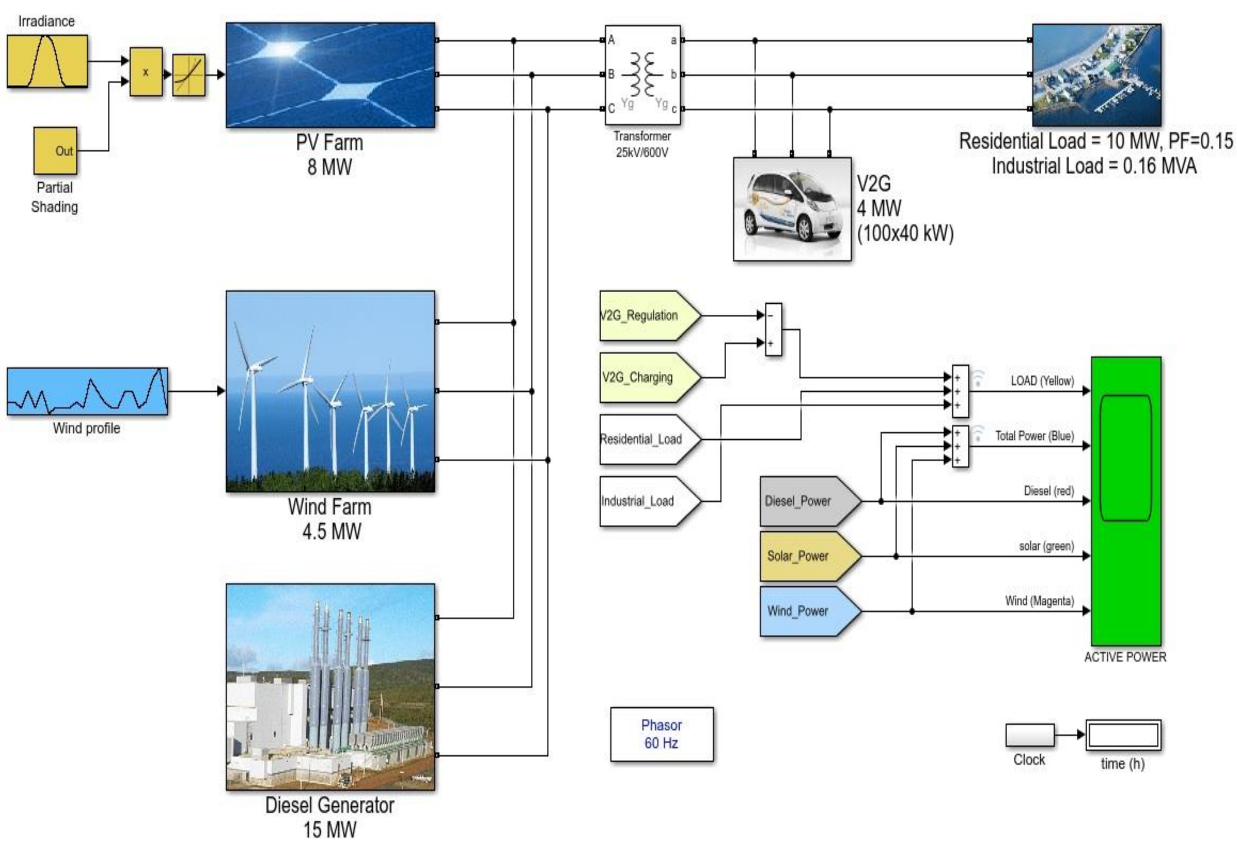
Wind Turbine Performance Model

A wind turbine turns wind energy into electricity using the aerodynamic force from the rotor blades, which work like an airplane wing or helicopter rotor blade. When wind flows across the blade, the air pressure on one side of the blade decreases. The difference in air pressure across the two sides of the blade creates both lift and drag. The force of the lift is stronger than the drag and this causes the rotor to spin. Power from Wind Turbine Generator. The wind fan may rotate in clockwise or anti clockwise direction.

So the power generated from wind generator may be positive or negative, in order to get the positive power polarity corrector is connected to the wind turbine. This converts the AC power into DC power. Wind power may not be constant so a regulator circuit is connected and this regulated power is given to charge the battery

If the average wind speed reaches 10 m/s and above, SWT can produce electricity at the rated power. In the case of wind speed lower than 10m/s, electricity production is less than the rated power.

MODEL:



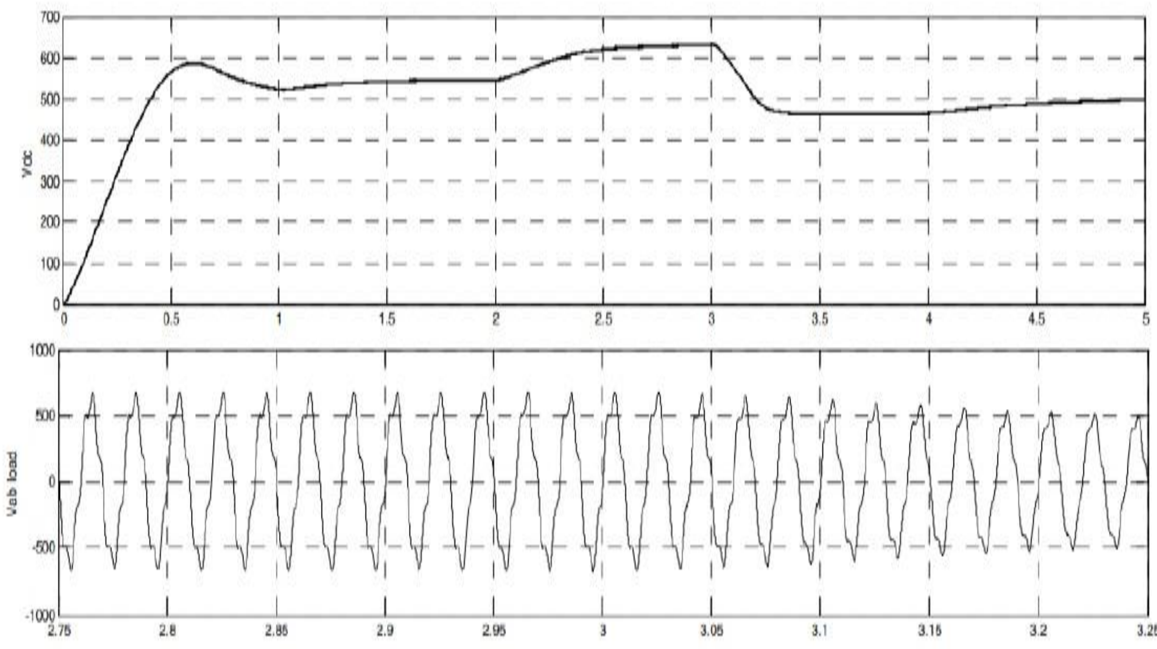
PROCEDURE:

1. Matlab Simulink model file is created.
2. Simulink library used to generate required components.
3. Scope is used to view results for different conditions of shadowing.

OUTPUT WAVEFORM:

Perhaps the hybrid power system, which consists of two non-conventional energy sources, the combination of solar photovoltaic and wind turbine system and providing single phase AC load. The above figure represents the voltage waveform of wind turbine and solar photovoltaic system based on the MPPT technique.

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR



RESULT: Thus the Performance of Hybrid (Solar-Wind) Power System was observed

Dr. Mahesh Bundele
B.E., M.E., Ph.D.
Director
Poornima College of Engineering
ISI-6, RIICO Institutional Area
Sitapura, JAIPUR