Indian Institute of Technology, Kanpur

Department of Sustainable Energy Engineering

Lab Manual

Microgrid

Course : PG/SEE605

Name :

Roll No.:

Group :

List of Experiments:

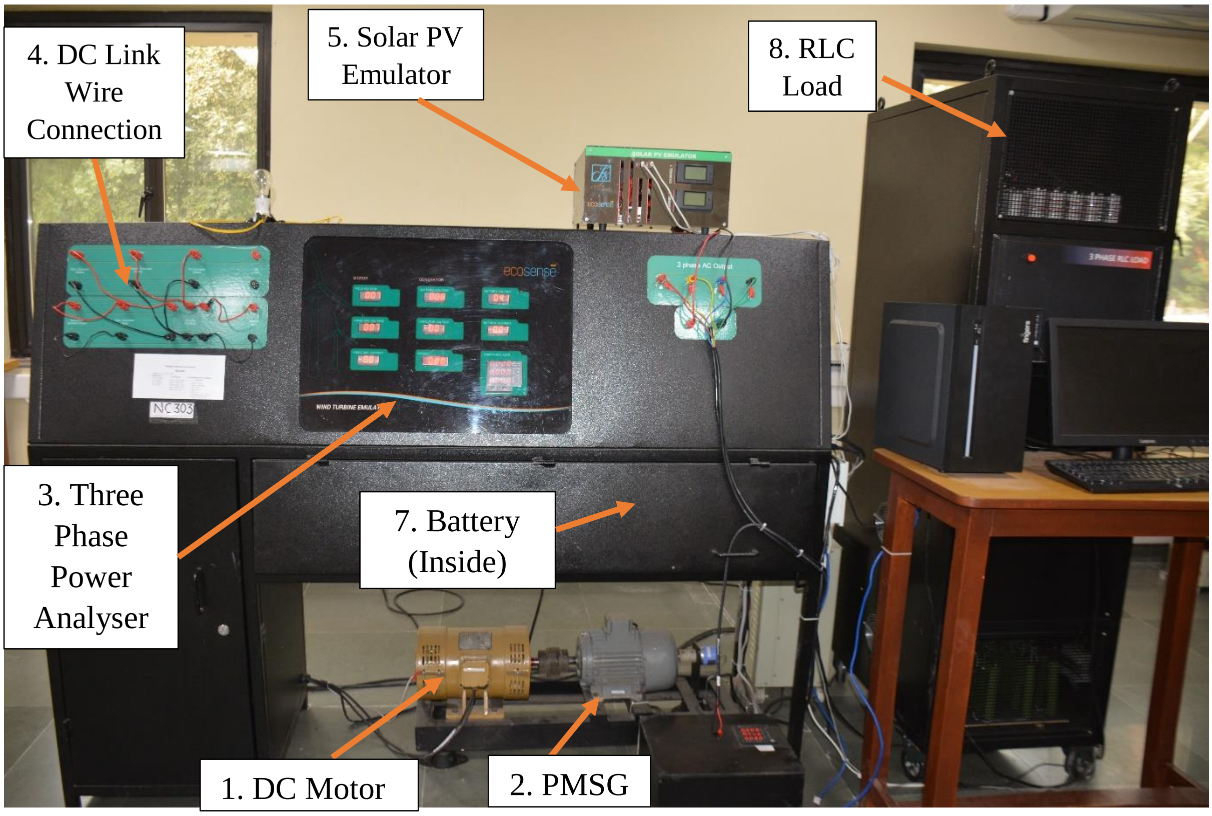
1. To operate the RLC load with only R, only L and only C Load and other load combinations and observe inverter parameters with only grid supply.
2. To study power flow analysis in grid connected mode and determine the cases of overall import of power from the utility grid to the microgrid or overall export of power from the microgrid to the utility grid (ON-Grid case).
3. To operate microgrid in ON-Grid connected mode and find the efficiency of different power electronic devices associated with the microgrid set up.
4.

4.1. To operate Wind turbine Emulator (WTE), Solar Photovoltaic Emulator (PVE), Battery, and RLC load in maximum Power point Tracking (MPPT) and OFF MPPT mode in OFF-grid connection.

4.2. To observe whether maximum power condition in OFF MPPT mode is same as MPPT mode.

4.3. To visualise power surplus and deficit conditions by varying the resistive load.

Description of Set-up:



1. **DC Motor:**
   A DC motor of rating 2hp (1.5kW) with Armature and field voltage 220V rectifier fed, runs at 0-1500 RPM based controlled input, is used for artificial rotation of wind turbine.

2. **Permanent Magnet Synchronous Generator (PMSG):**
   An AC 3phase Permanent Magnet Generator with power rating of 1kW, rated Vac = 405V, and other specifications are Speed 1500 Rpm, Ampere 1.5A, 4 Pole, Star (Y) Connection, Rated Torque 6 NM, is used for wind energy generation.
3. **Three Phase Power Analyser:**
   It shows data for the motor: field & Armature Voltages, Armature Current; Generator: Rectified Voltage, Capacitor Voltage and speed of generator rotation; Battery: Voltage, Current; and Load, losses in kW, kVAR and kVA.
4. **DC Link Wire Connection:**
   It is used to configure the inverter, rectifiers, bidirectional converters, and DC Loads.
5. **Solar PV Emulator:**

- It acts as replica of solar PV with power rating options 1KW and 2KW. The voltage and current rating can be altered as per our requirement through software control. The emulated solar PV have features to study different types of solar PV performance characteristics.

6. **Solar PV Panel:**
   A solar PV Panel with power rating 400W, V_{oc} 47.45V, V_{mp} 41.64V and I_{mp} 9.89A is used.
7. **Battery:** A Li-ion battery of rating 72V, 30Ah is used in this setup. We can set battery charging-discharging conditions through software.
8. **RLC Load:** A variable RLC load is used as a load on the Microgrid.

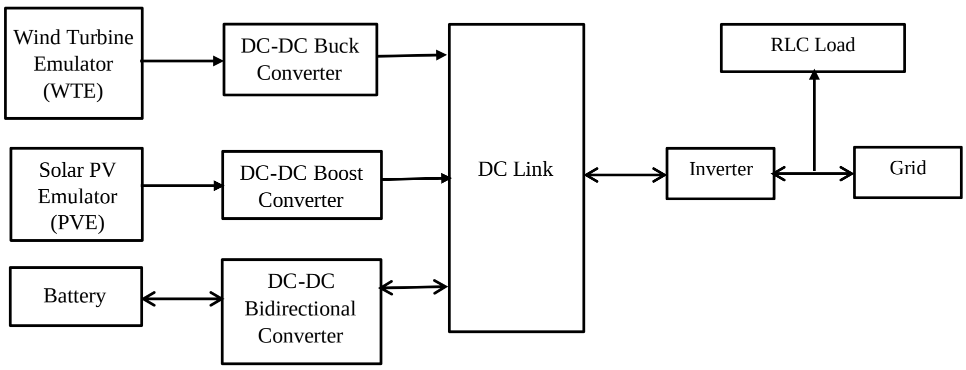


Fig: Block Diagram of DC Link Wire Connection

<u>**Overview**</u> **–**

- WTE-PVE hybrid microgrid setup combines an emulated wind turbine, solar PV panel, and PV Emulator, Battery and 3 phase RLC load.
- We can operate the grid in 2 modes of operation, i.e., ON-grid and OFF-grid (stand-alone) mode, and analyse the power consumed or delivered by different components of the system and power losses.
- The emulated solar PV and wind turbine have features to study different types of solar PV and wind turbines performance characteristics.
- We can set battery charging-discharging conditions, wind power output with variable wind speed, different shading conditions, and solar intensity and draw further inferences.

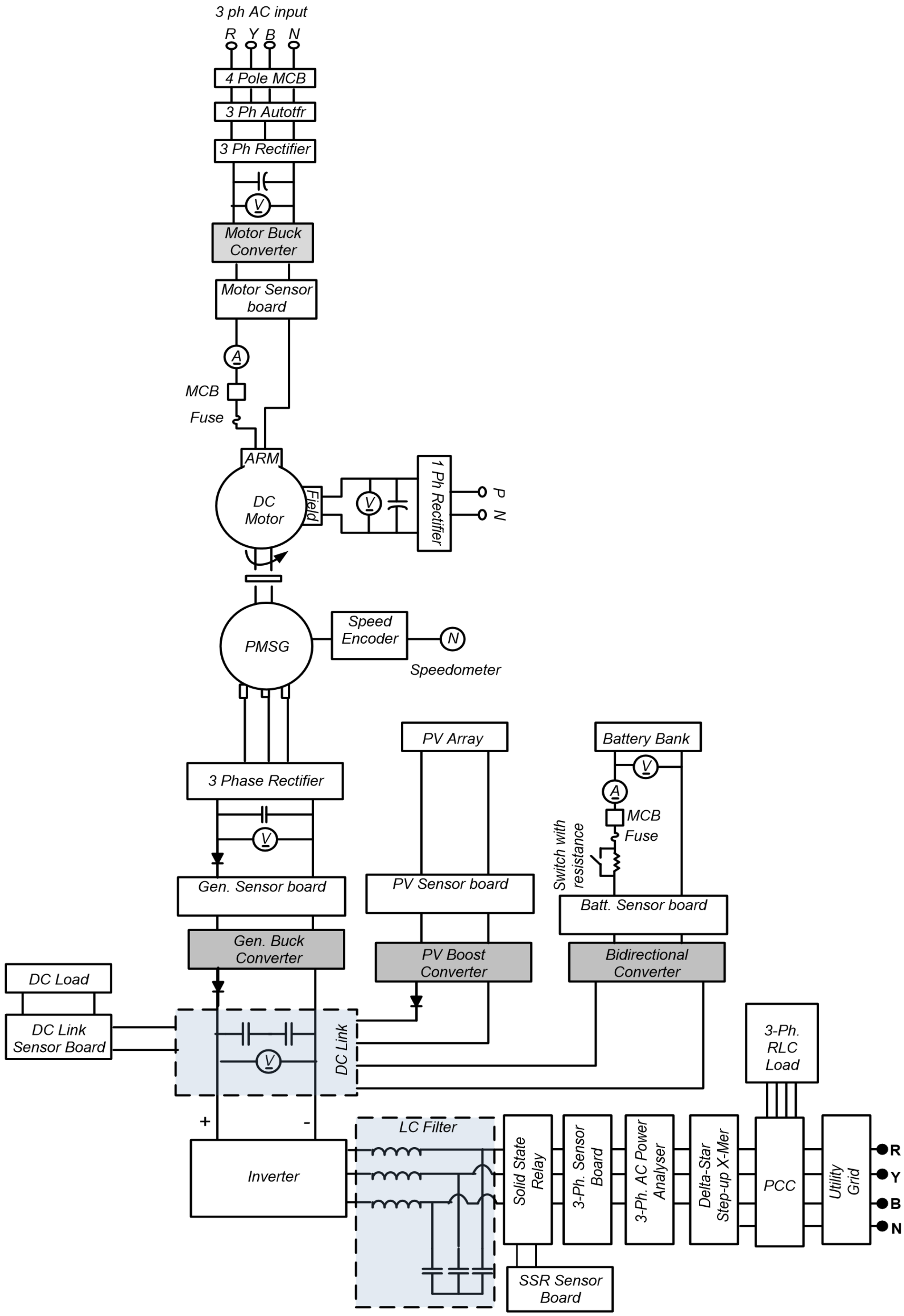


Fig: Line Diagram of overall Microgrid Circuit

Initial Exercise:

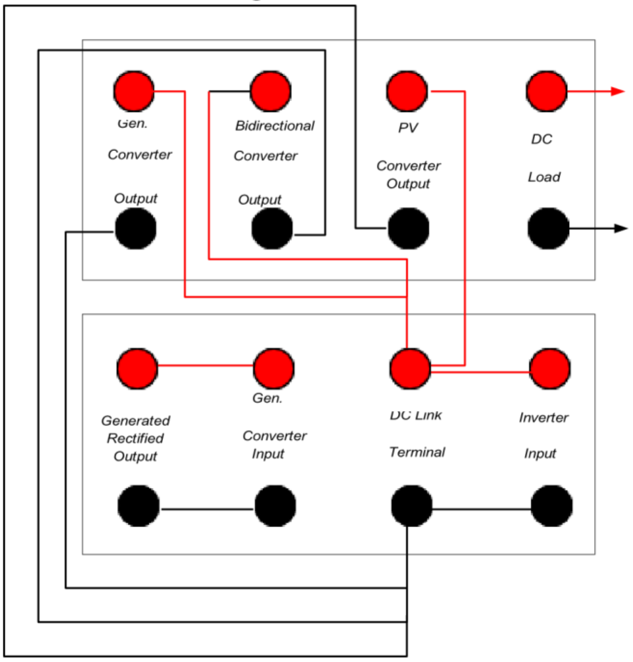
Study the following questions before the lab schedule.

Answer the following questions in short:

a) What do you understand by a microgrid?
b) What is an electricity grid?
c) What are the different types of DC-DC and AC-DC converters?
d) What is the voltage source of the inverter? And what is its function?
e) What is active power, reactive power, and apparent power?
f) What are the different types of loads?
g) What are the losses associated with power electronics devices?

Initial-check-ups

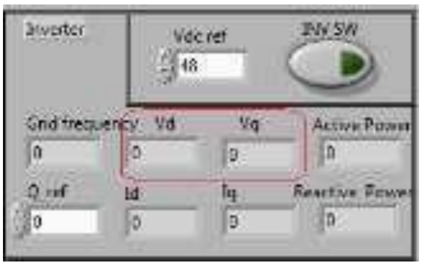
1. Battery MCB (Miniature circuit Breaker) and Battery Switch both are in OFF Position.
2. Armature and Field voltage Auto-transformers are in OFF position.
3. Grid and grid side autotransformer are in OFF position.
4. PV Array is in OFF position.
5. Check the following Connections:



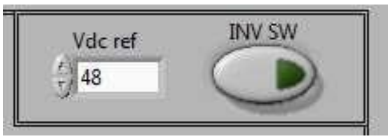
6. Verify that PV Input terminal is connected to PV array, three phase AC output of the system is connected to grid via autotransformer through grid side MCB.
7. Verify that no load is connected at DC Load terminal.

Inverter-setup -

1. Switch ON the Main supply (single phase and three phase) of the system.
2. Switch ON the MCB of the grid on the right side of the system.
3. Apply the grid voltage using the grid auto transformer till its maximum value, i.e., **270 V**.
4. Switch ON battery MCB first.
5. Switch ON the battery switch.
6. Switch ON Three Phase Supply MCB and Armature DC MCB on the system's left side.
7. Set Field Voltage to **220 V** using Field Auto-transformer.
8. Set the Armature Voltage to **220 V** using the Armature Auto-transformer.
9. Now go to folder "IIT Kanpur (Microgrid)" and open "MicroGrid(IIT-Kanpur) (type: LabVIEW Project)" file and open "Wind_PV_Hybrid(ON-Grid).vi" file. This is the main software for control.
10. Run the application software using the run button at the top.
11. Check the Phase Voltage of Grid, check the Vd at Software; Vd = Phase Voltage of Grid*1.414 and Vq≈0.
12. If Vd≠ Phase Voltage of Grid*1.414 and Vq≠0, Change the Phase Sequence of 3 Phase AC Output and Repeat Steps 11 and 12.



13. Input the Vdc Ref =120 and Switch ON the Inverter using Inverter Switch ON software to set the capacitor voltage, observe that capacitor voltage will rise to Vdc Ref.
14. Now wait for Inverter LED to switch ON. It will take 20-30 s for synchronisation with grid.



Sign convention used in this experiment –

1. Power drawn from grid is shown as negative and power delivered to grid is shown as positive in the power analyser.
2. Current drawn by battery is shown as negative and current out from battery is shown as positive in the power analyser.

<u>LabVIEW Software Control</u> -

<u>1.</u> <u>ON-Grid</u>

1.1 <u>Operating wind turbine emulator in MPPT mode</u>

1.1.1. Turning ON WTE in MPPT mode

a) Go to the wind turbine emulator tab and click on manual (static) mode.

b) Turn ON the "WTE ON" button and then click on the "Static" button.

c) Now give the desired wind speed.

1.1.2. Turning OFF WTE in MPPT mode

a) Gradually decrease wind speed to its starting position.

b) Now turn OFF the "Static" button and then turn OFF the "WTE ON" button.

1.2. <u>Operating wind turbine emulator in OFF MPPT mode</u>

1.2.1 Turning ON WTE in OFF MPPT mode

a) Turn ON the "Gen_Buck_Duty_Manual" button.

b) Turn ON the "WTE ON" button and then click on the "Static" button.

c) Now give the desired wind speed but do not work on high speed (above 7m/s). After that, give duty.

1.2.2 Turning OFF WTE in OFF MPPT mode

a) Gradually decrease wind speed and duty simultaneously.

b) Turn OFF the "Static" button, then turn OFF the "WTE ON" button.

c) Turn OFF the "Gen_Buck_Duty_Manual " button.

1.3. <u>Operating PV emulator in MPPT mode</u> –

1.3.1 Turning ON PVE in MPPT mode –

a) First, switch ON PV Emulator from the socket and then switch ON the button from the back side of the PV Emulator.

b) Now go to folder "IIT Kanpur (Microgrid)/PV Emulator/Program 2KW" and open the 'Application (type: application)' file.

c) Change the COM value in the communication box. The first value will be for channel 1, and the second value will be for channel 2. For channel 1, set the COM value as COM5, and for channel 2, set the COM value as COM4.

d) Now run the software using the run button at the top.

e) Set V_{OC} = 45 V and I_{SC} = 2A, and click the ON/OFF button. After this solar PV Emulator starts running.

f) Now go to the main software, open the 'PV Control' tab, and click the 'PV MPPT' button.

1.3.2 Turning OFF PVE MPPT mode –

a) Turn OFF the 'PV MPPT' button from the main software.

1.4 Operating PVE in OFF MPPT mode

1.4.1 Turning ON PVE

a) Follow the same steps as in MPPT mode till step f.

b) Now go to the main software, open the 'PV Control' tab, and click the 'PV manual' button.

c) Give the duty to the Boost converter by gradually varying the "PV Duty" scale.

1.4.2 Turning OFF PVE

a) Gradually decrease PV duty to its initial position.

b) Turn OFF the 'PV manual' button.

c) Turn OFF the "ON/OFF" button from other software and click on the red button to pause the software.

1.5 Operating battery

a) First, go to the battery control tab and switch ON the "BID SW" button.

b) For charging the battery, give charging Ibref current.

c) For discharging of the battery, give discharging Ibref current.

d) To turn OFF the battery, decrease the current to zero and switch OFF the "BID SW" button.

1.6 Operating RLC Load

a) Open "RLC Load.vi" file same as you opened the "Wind_PV_Hybrid(ON-Grid).vi" file in inverter setup.

b) Select COM 3 in dropdown of the "Arduino COM" port.

c) Select COM 15 at dropdown of "Three phase power analyser COM" port.

d) Run the Application and wait for 3-4 seconds so that software can detect the device name as "Arduino".

e) Select the desired loads from R, L and C and switch on individual switches to get the output.

2. OFF-Grid

2.1 OFF-Grid set-up –

a) First, turn OFF all the sources, i.e., WTE, PVE, and battery.

b) Turn OFF the inverter and wait for the capacitor voltage of 3 phase power analyzer comes down to 80 V, and then click the stop button in the software on the left side of the screen.

c) Verify that grid auto-transformer is at zero and grid MCB is at OFF position.

d) Switch ON battery MCB first and then battery switch.

e) Connect a DC load at DC load terminal to reduce capacitor settling time.

f) Now open "Wind_PV_Hybrid(OFF-Grid)(Open-Cycle).vi" file.

g) Run the software, set DC Link Volt Ref to 120 V, and turn ON the "BID SW" switch.

h) Now set the MI value to 0.5 and turn ON the "Inverter SW" switch, and after 5-8 seconds, again set the MI value to 0.9.

2.2 Operating WTE –

a) Same as ON-Grid whether it is MPPT mode or OFF MPPT mode.

2.3 Operating PVE –

a) Same as ON-Grid whether it is MPPT mode or OFF MPPT mode.

2.4 Operating battery –

a) There is no control over the battery in OFF-Grid mode. However, it can be controlled by generating power from sources and energy consumption in RLC load; hence, the resulting power will start to affect the battery in a charging/discharging manner.

Safety and precautions before doing any experiment

- This equipment carries **High Current.** So do not unnecessary touch any Circuit/wiring.
- Do not touch any inner circuits.
- Do not change USB connections from ports.
- Always check that no wires are tangling in motor or generator.
- Always perform **Initial-check-ups** before switching ON the setup.
- Do not connect any load at the DC load before switching ON the battery.
- For switching ON the system, perform **Inverter-setup** and wait for battery current to come to zero again.
- For doing any experiment, always check that inverter is ON and set at 120V.
- Always keep an eye on V_{gen} of PMSG shown in the software, it must not cross the value of 500V. If it crosses anytime then switch OFF the wind turbine emulator immediately.

Experiment 1

<u>Objective:</u>

To operate the RLC load with only R, only L and only C Load and other load combinations and observe inverter parameters with only grid supply.

<u>Procedure:</u>

1. Keep WTE and PVE OFF and keep battery current 0 from software control panel. Turn OFF battery from software.
2. Run the load in ON-grid mode. (Refer steps from software control section)
3. Enter different values of R, L, and C load.
4. The power drawl is displayed on RLC power analyser.
5. Refer the units and get active, reactive and apparent power values.

Observation:

S.No.	R (P) (W)	L (Q_l) (Var)	C (Q_c) (Var)	Active Power (W) (P)	Reactive Power (Var) (Q)	Apparent Power (VA) (S)	Calculated Apparent Power (S^1) (VA)	Error $\lvert S-S^1 \rvert$ (VA)
1	100	0	0					
2	0	100	0					
3	0	0	100					
4	100	100	0					
5	100	0	100					
6	0	100	100					
7	100	50	100					
8	100	100	50					
9	100	100	50					
10	100	100	100					

(R, L, C are value power set in software and Active, reactive and apparent power are shown in power displayed on RLC power analyser) P: active power commanded from software.

Q: Equivalent reactive power of capacitive and inductive power commanded from software

$$Q=Q_L- Q_c$$

Result & Analysis:

1. Does the purely resistive load have reactive losses? Why?
2. Why is resistive loss non-zero (positive or negative) in
    a. Purely capacitive case
    b. Purely inductive case
3. Do the resistive loss increase with increase in loading condition? Why?
4. What is ideal value of reactive power when the capacitive and inductive loads are equal? Is there any deviation observed in experimental case? If yes, WHY?
5. Why is there a difference between calculated apparent power and experimentally observed apparent power?
6. Why the command of certain loading condition in software do not match with the actual reactive or active power drawn?
7. Why the reactive power is positive in case of capacitive load and negative in case of inductive load?
8. What is approximate R, L, C power value where reactive power on load analyser is 0? Why is it so?

Experiment 2

Objective:

To study power flow analysis in grid connected mode and determine the cases of overall import of power from the utility grid to the microgrid or overall export of power from the microgrid to the utility grid (ON-Grid case).

Procedure:

1. Perform inverter set-up.
2. Now run the solar PV emulator in MPPT mode while V_{OC} = 45V, I_{SC} = 2A, and take the reading of power shown in the software in the PV section.
   Note: Refer steps to operate WTE from software control section.
3. Run wind turbine emulator in MPPT mode and keep wind speed = 6.5 m/s and take the reading of power shown in the software in the PMSG section.
4. Now, take the reading of power (W) shown in 3 phase power analyzer.
5. Turn ON the battery and increase the "charging reference current" for charging of battery or increase the "discharging reference current" for discharging the battery and note down the following table.

Observation 1: Power flow during charging of the battery.

S.NO	P_W (W)	P_s (W)	P_{load} (W)	P1 (W)	Ib_{ref} (A)	I_{batt} (A)	V_{batt} (V)	P_{batt} (W)	P_a (W)	P_{grid} (W)
1	150	84	20		-0.2					
2	150	84	20		-0.4					
3	150	84	20		-0.6					
4	150	84	20		-0.8					
5	150	84	20		-1					
6	150	84	20		-1.2					
7	150	84	20		-1.4					
8	150	84	20		-1.6					
9	150	84	20		-1.8					
10	150	84	20		-2					
11	150	84	20		-2.2					

P_w = Power generated from WTE.

P_s = Power generated from solar PV emulator.

P_1 = Power generated by WTE and PVE (lesser than actual generation due to some converter and inverter losses)

*Take P_1 as Power shown in the power analyzer before switching on the battery.

P_{load} = Active power drawn by the resistive load.

Ib_{ref} = Battery reference current given from software.

I_{batt} = Battery current shown in power analyzer.

V_{batt} = Battery voltage shown in power analyzer.

P_a = Power shown in power analyzer after giving Ib_{ref}. It is total power consumed or delivered by combination of WTE, PVE and battery.

P_{grid} = Power fed by microgrid to the utility grid or power consumed by microgrid to the Utility Grid.

$P_{batt} = I_{batt} \times V_{batt}$	$P_{grid} = P_a - P_{load}$

Analysis:

1. Why the battery current is negative?
2. Why the power export decreases with increase in battery charging current?

Observations:

1. What is the significance of power shown on load power analyser?
2. Separate the total import or export cases on different Ib_{ref} reference cases?
3. Why and how the import or export of power changes with increase in battery charging rate?
4. If a load of 100W is added to the same system and operate the same condition, what are the changes that we can observe?
5. Do the battery acts as load or source in this case?

Observation 2: Power flow during discharging of the battery.

S.NO	P_W (W)	P_S (W)	P_{load} (W)	P_1 (W)	I_{bref} (A)	I_{batt} (A)	V_{batt} (V)	P_{batt} (W)	Pa (W)	P_{grid} (W)
1	150	84	200	162	0					
2	150	84	200	162	0.5					
3	150	84	200	162	0.6					
4	150	84	200	162	0.7					
5	150	84	200	162	1					
6	150	84	200	162	1.5					

P_w = Power generated from WTE.

P_s = Power generated from solar PV emulator.

P_1 = Power shown in the power analyzer before switching ON the battery.

P_{load} = Active power drawn by the resistive load.

Ib_{ref} = Battery reference current given from software.

I_{batt} = Battery current shown in power analyzer.

V_{batt} = Battery voltage shown in power analyzer.

P_a = Power shown in power analyzer after giving Ib_{ref}.

P_{grid} = Power fed by microgrid to the utility grid or power consumed by microgrid to the utility-Grid.

$\mathbf{P_{batt} = I_s \times Vb_{att}}$	$\mathbf{P_{grid} = P_a - P_{load}}$

Result & Analysis:

1. How the import of power changes with increase in battery charging current. Why?
2. How the export of power changes with increase in: battery discharging current? Why?

Experiment 3

Objective:

To operate microgrid in ON-Grid connected mode and find the efficiency of different power electronic devices associated with the microgrid set up.

1. Efficiency of Bidirectional converter connected to battery and inverter efficiency

Procedure:

1. Do the initial inverter set up for ON-Grid operation (off RLC load).
2. Switch on the battery from battery control tab on software.
3. Vary the charging Ib_{ref} and note following table.
4. After taking readings turn OFF the battery.

Observation table 1:

S.No	Ib_{ref} (A)	I_{batt} (A)	V_{batt} (V)	P_{batt} (W)	I_{dc} (A)	V_{dc} (V)	P_{dc} (W)	P_{1_loss} (W)	Effi-ciency 1	P_a (W)	P_{2_loss} (W)	Effi-ciency 2
1	-1											
2	-1.5											
3	-2.00											

Ib_{ref} = Battery reference current given from software.
I_{batt} = Battery current shown in power analyzer.
V_{batt} = Battery voltage shown in power analyzer.
Vdc=Voltage at DC link.
I_{dc}= Current through DC link to/from inverter.
P_{dc}=Power at DC link.
P_a = Power shown in power analyzer after giving Ib_{ref}.
P_{1_loss}= power loss in bidirectional converter.
Efficiency_1 = efficiency of bidirectional converter
Efficiency_2 = Efficiency of inverter

$P_{batt} = I_{batt} \times V_{batt}$	$P_{1\_loss} = P_{dc} - P_{batt}$
$P_{2\_loss} = P_a - P_{dc}$	$\text{Efficiency\_1} = \frac{P_{batt}}{P_{dc}}$
$\text{Efficiency\_2} = \frac{P_{dc}}{P_a}$	

2. Efficiency of Boost converter connected to PVE

Procedure:

1. Switch on PVE and turn on PV from PV control tab on software.
2. Vary the PV duty and note following table.
3. After taking readings turn OFF the PVE.

Observation table 2:

S.NO	PV duty	P_{pv} (W)	I_{dc} (A)	V_{dc} (V)	P_{dc} (W)	P_{loss} (W)	Efficiency
1	0.6						
2	0.65						
3	0.7						

V_{dc} = Voltage at DC link
I_{dc} = Current through DC link to/from inverter
P_{dc} = Power at DC link
P_{pv} = PV power generated
P_{loss} = Power loss in bidirectional converter.
Efficiency = Efficiency of boost converter

$\mathbf{P_{loss} = P_{pv} - P_{dc}}$	**Efficiency_1 =** $\frac{P_{dc}}{P_{pv}}$

3. Efficiency of Buck converter connected to WTE

Procedure:

1. Switch on WTE in MPPT mode.
2. Take reading of P_gen from software and other readings as well and then vary wind speed.
3. After taking readings turn OFF the WTE.

Observation table 3:

S.NO	Wind speed(m/s)	P_gen (W)	I_{dc} (A)	V_{dc} (V)	P_{dc} (W)	P_{loss} (W)	Efficiency
1	5						
2	5.5						
3	6						

V_{dc}=Voltage at DC link
I_{dc}= Current through DC link to/from inverter
P_{dc}=Power at DC link
P_{gen}=WTE power generated
P1_loss= power loss in bidirectional converter.
Efficiency=efficiency of buck

$P_{loss}= P_{gen}-P_{dc}$	**Converter Efficiency_1=** $\frac{Pdc}{P_{gen}}$

Result & Analysis:

1. What are different kinds of convertors in this set-up and explain their role?
2. Why the converter efficiency increases with increase in power generation in WTE and PVE?
3. In battery case what is effect of increase in battery current to converter efficiency? Why is it so?

Experiment 4

Objective:

- To operate WTE, PVE, battery, and RLC load in MPPT and OFF MPPT mode in OFF-grid connection.
- To observe whether maximum power condition in OFF MPPT mode is same as MPPT mode.
- To visualise power surplus and deficit conditions by varying the resistive load.

Operating PVE and WTE separately in OFF MPPT mode

1. Procedure for PVE only:

1. Follow steps to operate microgrid in OFF grid mode as given in software control section.
2. Turn off the WTE.
3. Run the PV emulator in OFF MPPT mode.
4. Set V_{oc} = 45V and I_{sc} = 2A.
5. Now give the duty as shown in table below and note down the readings.
6. Turn OFF the PV emulator.

Observation table 1:

S.No	PV duty	I_{batt} (A)	P_{pv} (W)
1	0.2		
2	0.3		
3	0.4		
4	0.5		
5	0.6		
6	0.63		
7	0.67		
8	0.7		
9	0.75		

I_{batt} = Battery current shown in power analyzer.

Ppv = PV power generated

Result & Analysis 1:

1. Why is there increase power to a maximum value and then decrement with increase in PV duty?
2. Why is duty varied in smaller points between 0.6 and 0.7?
3. Why the battery current varies with increase in PV duty till the maximum power point?

2. Procedure for WTE only:

1. Turn ON only WTE in OFF MPPT mode. (Steps are given in software control panel)
2. Set the wind speed at 6 m/s.
3. Start giving duty as shown in table below and note down the readings.

Observation table 2:

S.No	Gen buck duty	I_{batt} (A)	P_{gen} (W)
1	0.05		
2	0.1		
3	0.15		
4	0.2		
5	0.25		
6	0.3		
7	0.31		
8	0.33		
9	0.37		

I_{batt} = Battery current shown in power analyser.
P_{gen} = Power generated by WTE.

Result & Analysis 2:

1. **1.** Why the battery current is negative?
2. **2.** Why the wind speed in this case kept constant?
3. **3.** In different wind speed case will the buck duty be where maximum power generator be same or different?

3. Operating PVE and WTE simultaneously in MPPT mode Procedure:

1. Run WTE in MPPT mode by following the steps shown earlier and set the wind speed at 6 m/s.
2. Run the PV emulator in OFF MPPT mode by following the steps shown earlier and set V_{oc} = 45V and I_{sc} = 2A.
3. Now note down the duty you get for WTE and PVE in MPPT mode.
4. Now vary the resistive load as shown in table and note down the readings.

WTE Gen buck duty = ________
PVE boost duty = ____________
Rating of DC load = __________

Observation table 3:

S.NO	Pw (W)	Ps (W)	Pload (W)	Ibatt (A)	Vbatt (V)	Pbatt (W)	Pa (W)
1	0	0	0				
2	0	84	0				
3	105	84	0				
4	105	84	20				
5	105	84	40				
6	105	84	60				
7	105	84	80				
8	105	84	100				
9	105	84	120				

P_w = Power generated from WTE.
P_s = Power generated from solar PV emulator.
P_{load} = Active power drawn by the resistive load.
I_{batt} = Battery current shown in power analyzer.
V_{batt} = Battery voltage shown in power analyzer.
P_a = Power shown in power analyzer.

$\mathbf{P_{batt} = I_{batt} \times V_{batt}}$

Result & Analysis 3:

1. What is the relation between battery current and load power? Why is it so?
2. How is the balancing of energy surcharge and deficit done in an OFF MPPT set up?
3. When no generation operated how the load power is fulfilled?
4. Consider the case where power generation is in surplus. Battery is fully charged, and load is constant. In this case how the load balancing be done?