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Design of a Low Voltage DC microgrid based on renewable energy to be applied in communities where grid connection is not available

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Outline

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1 Introduction

2 DC network topologies

3 System description and modelling

4 Case study

5 Conclusions

Introduction

Context

- Electrification process is being developed in communities without access to electricity
- No AC connection is available
- The installation must be affordable, simple and reliable
- Small isolated microgrids are constructed based on:
  - Solar photovoltaic (PV) generation
  - Energy storage – batteries
  - Households loads

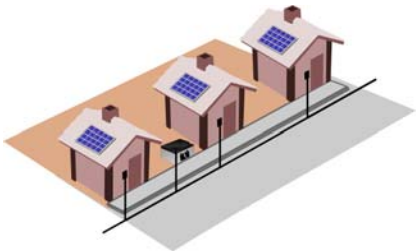
Photo: ME SOLshare (IEEE Spectrum)

- Interconnection using Low Voltage DC
  - Direct connection between the different elements

Introduction

Motivation of the study

- **General objectives**
  - Develop a tool to design a generic LVDC microgrid through a technical-economical analysis to reduce the cost of energy of the installation
  - Understand the particularities of this type of installations (typical network layouts, voltages, cables used, protections, etc.)
  - Collaborate with companies that are currently building this type of installations.
- **Specific objective of this work**
  - Compare the usual network layout used in these installations with alternative network topologies including converters

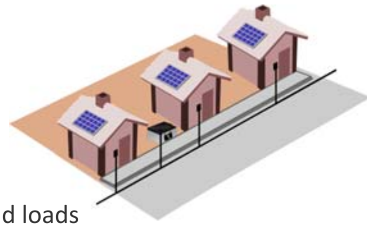


Outline

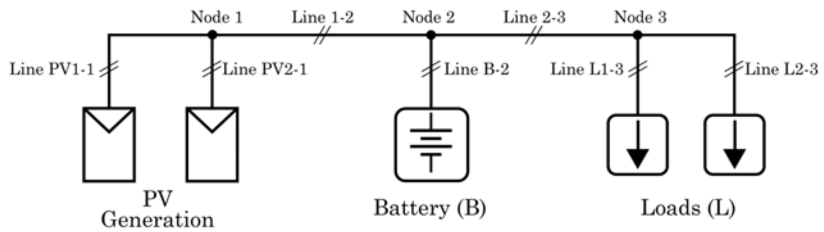
Converter-less topology

Usual network topology (based on existing projects)

- Converter-less network:
  - PV generation
  - Battery
  - Loads
  - No converter
  - Interconnected in DC (12 or 24 V)
  - Independent connection of generation and loads



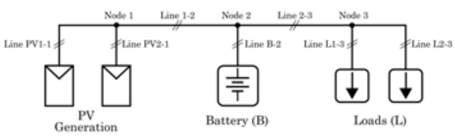
Network scheme



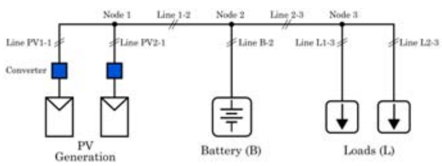
Network topologies

Scope of work – Four alternatives compared through a power flow analysis

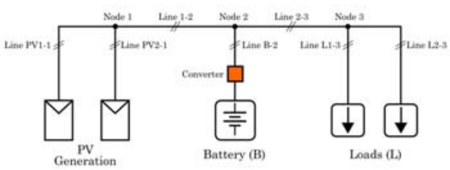
Configuration 1
Converter-less topology



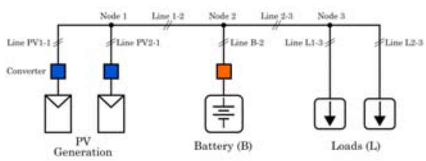
Configuration 2
Converters connected to each PV



Configuration 3
Central battery DC/DC converter



Configuration 4
Converters connected to PVs and battery



Outline

Alternatives comparison

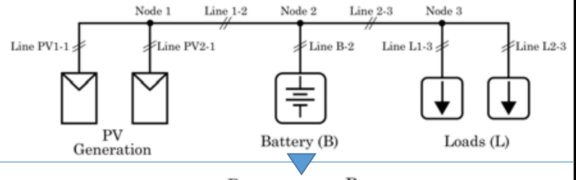
Comparison method description

- Steps to compare the different alternatives
  - Obtain a steady-state model for each alternative including
    - PV model
    - Cables
    - Simple model of the battery
    - Simple model of the system loads
  - Define the different scenarios to study the performance:
    - **Full/Low** PV irradiance: 1000 W/m^2 (Day) – 0 W/m^2 (Night)
    - **Full/Low** load: 50 W – 0 W
  - Define the **battery voltage**
  - Define converters operation mode (whenever they are present):
    - PV converter – MPPT
    - Battery converter – Voltage control
  - **Solve and compare** the system power flow

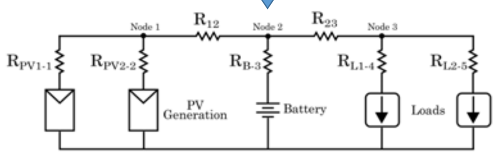
Steady-state model

Modelling a converter-less network

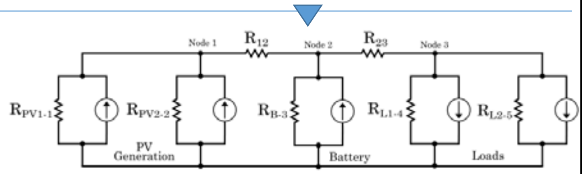
- Initial system



- Model the cables as resistances



- Model PV and Loads using the Norton equivalent
- V/I PV characteristic curve used



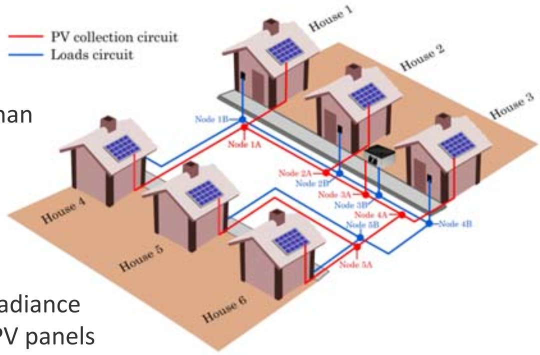
Outline

Case study

Six house system

The presented network topologies will be compared based on the following system:

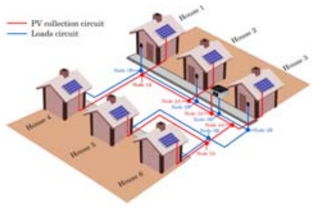
- 6 houses
- PV Generation in each house
- House load profile:
  - Consumption no higher than 50 W and 4 hours a day
- Location: Dhaka (Bangladesh)
- DC grid voltage – 12 V



Assumptions:

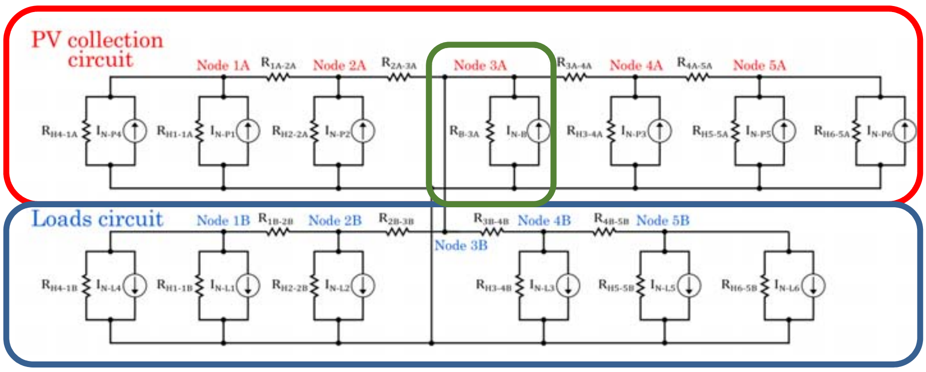
- PV panels receive the same irradiance
- Same temperature for all the PV panels
- Equal demand for all houses
- Cable sections are considered equal for all connections

Case study



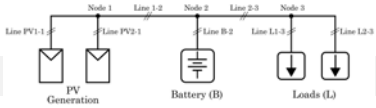
Model of the system – Converter-less approach

The presented network topologies will be compared based on the following system:



Case study

Converter-less approach

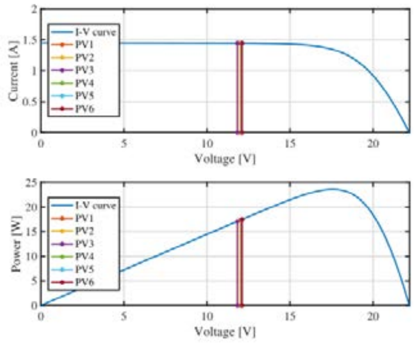


- Power flow Results

POWER FLOW RESULTS - NO CONVERTERS

Parameter Name	$G = 1000$ W/m^2 $P_L = 50$ W		$G = 0$ W/m^2 $P_L = 50$ W		$G = 1000$ W/m^2 $P_L = 0$ W	
	Sum	Mean	Sum	Mean	Sum	Mean
P_{pv}	104.06 W	17.34 W	0 W	0 W	108.24 W	18.04 W
P_{load}	-300 W	-50 W	-300 W	-50 W	0 W	0 W
P_{bat}	240.7 W	240.7 W	350.66 W	350.66 W	-103.43 W	-103.43 W
Max V_{drop}	12.61 %	-	13.02 %	-	3.54 %	-
I_{max}	20.06 A	-	29.22 A	-	8.619 A	-
P_{loss}	44.76 W	-	50.66 W	-	4.34 W	-

Graphical example
Case Full load/Full irradiance
PV panels conditions

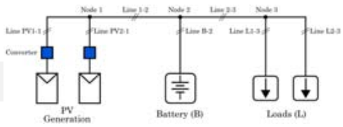


Discussion:

- Full irradiance – Full load (1st col)
  - Panels - 75 % production [104 W]
- Full irradiance – No load (3rd col)
  - Panels - 75% production [108 W]
- Loads connected (1st and 2nd col)
  - Losses are approx. 50 W

Case study

Converters connected at the PV output

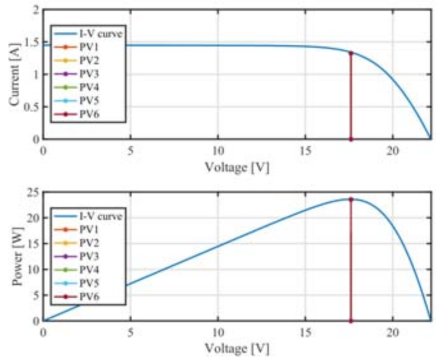


- Power flow Results

POWER FLOW RESULTS - PV CONVERTERS

Parameter Name	$G = 1000$ W/m^2 $P_L = 50$ W		$G = 1000$ W/m^2 $P_L = 0$ W	
	Sum	Mean	Sum	Mean
P_{pv}	141.57 W	23.60 W	141.57 W	23.60 W
P_{load}	-300 W	-50 W	0 W	0 W
P_{bat}	203.22 W	203.22 W	-134.32 W	-134.32 W
Max V_{drop}	12.47 %	-	4.54 %	-
I_{max}	16.94 A	-	11.19 A	-
P_{loss}	44.79 W	-	7.25 W	-

Graphical example
Case Full load/Full irradiance
PV panels conditions

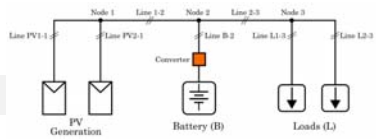


Discussion:

- PV power production improvement (MPP operation mode) [increase from 104 to 140 W]
- Losses are still high [≈50 W]
- No load scenarios, equal to the previous case.

Case study

Converter connected to the battery

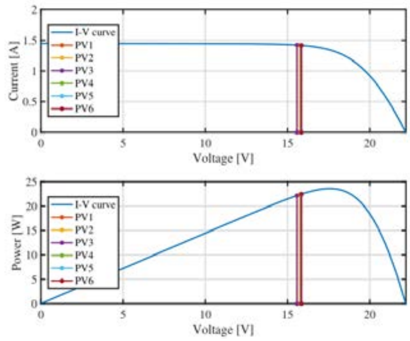


- Power flow Results

POWER FLOW RESULTS - BATTERY CONVERTER

Parameter Name	$G = 1000$ W/m^2 $P_L = 50$ W		$G = 0$ W/m^2 $P_L = 50$ W		$G = 1000$ W/m^2 $P_L = 0$ W	
	Sum	Mean	Sum	Mean	Sum	Mean
P_{pv}	134.15 W	22.36 W	0 W	0 W	131.33 W	21.88 W
P_{load}	-300 W	-50 W	-300 W	-50 W	0 W	0 W
P_{bat}	189.06 W	189.06 W	325.01 W	325.01 W	-127.00 W	-127.00 W
Max V_{drop}	6.77 %	-	6.77 %	-	2.84 %	-
I_{max}	12.11 A	-	20.64 A	-	8.55 A	-
P_{loss}	23.21 W	-	25.02 W	-	4.26 W	-
V_{bat-dc}	15.61 V	-	15.75 V	-	14.85 V	-

Graphical example
Case Full load/Full irradiance
PV panels conditions

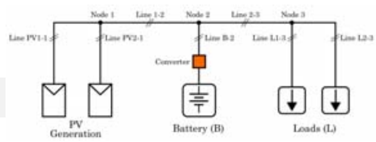


Discussion:

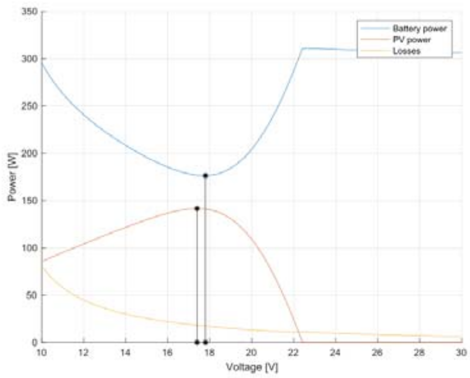
- Objective: minimize the power exchanged by the battery
- Full irradiance – Panels producing close to the MPP (141 W) - [1st col: 134 W]
- System losses are reduced compared to the previous cases [≈23 W]

Case study

Converter connected to the battery



- Power flow Results

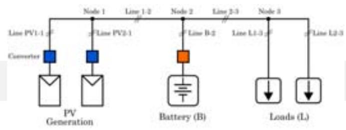


Discussion:

- The MPP of the PV is not the optimal operation point from the overall system perspective
- The optimal point is where the battery exchanges the minimum power

Case study

Converters at PV output and battery



- Power flow Results

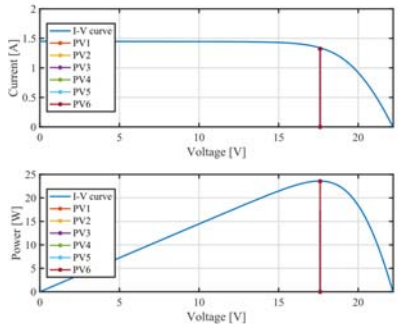
POWER FLOW RESULTS - PV AND BATTERY CONVERTERS

Parameter Name	$G = 1000$ W/m^2 $P_L = 50$ W		$G = 1000$ W/m^2 $P_L = 0$ W	
	Sum	Mean	Sum	Mean
P_{pv}	141.57 W	23.60 W	141.57 W	23.60 W
P_{load}	-300 W	-50 W	0 W	0 W
P_{bat}	181.77 W	181.77 W	-136.65 W	-136.65 W
Max V_{drop}	6.77 %	-	3.05 %	-
I_{max}	11.65 A	-	9.21 A	-
P_{loss}	23.34 W	-	4.92 W	-
V_{bat-dc}	15.60 V	-	14.84 V	-

Discussion:

- No load results equivalent to the ones in the central battery approach.
- Operational improvement in terms of losses and production
  - PV at MPP [141 W]
  - Losses [23 W]

Graphical example
Case Full load/Full irradiance
PV panels conditions

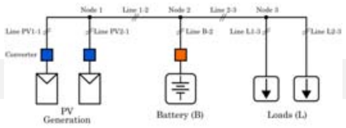


Discussion

Summary of the analysis

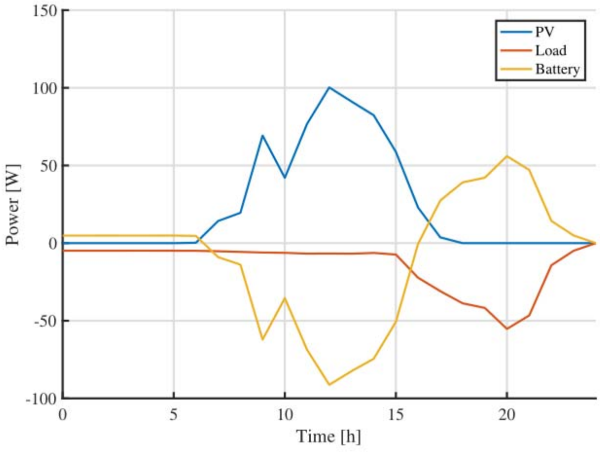
- **Configuration 1 – Converter-less topology**
  - It is able to able to extract a 75% of the nominal power of the PV panels. However, losses are relatively high.
  - Reduced initial investment cost
- **Configuration 2– Converters connected to the PV panels output**
  - It can maximize the power extraction from the PV panels. Losses are also relatively high.
  - 'Moderate' investment cost
- **Configuration 3 – Converter at the output of the battery**
  - It operates the PV panels close to the MPP while reducing importantly the system losses.
  - 'Moderate' increase of the initial investment cost
- **Configuration 4 - Converters connected to the PV panels and battery**
  - It is the most efficient one, maximizing the PV production and reducing the system losses.
  - Important increase of the initial investment cost

Additional studies



Converters at PV output and battery

- Daily evolution of the system



Outline

Conclusions

Conclusions and future work

- Systems with a central battery converter might be interesting an interesting alternative, as they can improve the overall power extraction from the PV generation system installed, reducing the system losses while maintaining the simplicity of the entire system
- An additional technical-economic analysis must be carried out, combined with this analysis, in order to see which of the alternatives is the most interesting for each community.
- Also, the steady-state analysis should be complemented with a dynamic analysis in order to assess the system transients and design the converter controllers.
- Transfer the developed design tools to companies working in the sector

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Thank you for your attention

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