International Solar Alliance
Expert Training Course

Ensuring quality in off-grid rural electrification projects

In partnership with the Clean Energy Solutions Center (CESC)

Jorge Ortiz González - November 2019

Supporters of this Expert Training Series

INTERNATIONAL SOLAR ALLIANCE

CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY
An Initiative of the Clean Energy Ministerial

CARBON TRUST

Expert Trainer: Jorge Ortiz González

Brief Profile:

- Solar mini-grid engineer at Trama Tecnoambiental, an international consulting and engineering company specialized in distributed generation through renewable energies in rural contexts.
- Previous experience as a solar PV engineer in commercial and utility-scale applications in The Netherlands.
- 7+ years of experience in solar PV energy, including Silicon cell research, PV panel manufacturing and PV system design and installation.

Overview of Training Course Modules

This Training is part of Module 7, and focuses on the issue of quality assurance in off-grid solar projects

Quality Assurance

- IEC
  - TC 82 (PV), JWG 1 (off-grid PV)
  - Specific standards for each component
- Lighting Global
  - Standards for PicoPV and SHS products
  - IEC TS 62257-9-5:2018
- NREL/Global LEAP
  - QAF for mini-grids

Index

- Phase 1: Design
- Phase 2: Component selection
- Phase 3: Logistics
- Phase 4: Installation
- Phase 5: Commissioning
- Phase 6: Training
- Phase 7: Operation and Maintenance

Phase 1

DESIGN

Sizing

- Software-based sizing process

Inputs

- Demand profile (current and future)
- Costs
- RE resource
- Other inputs

Software

+

Optimization objective

Outputs

- Indicators
- Graphs

Sizing

Optimization objective

Critical to avoid under- or over-sizing the plants, resulting in mismatch between demand and generation

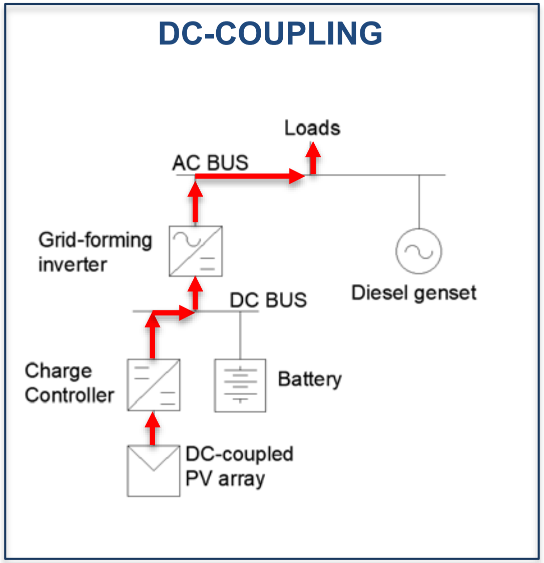
Examples:

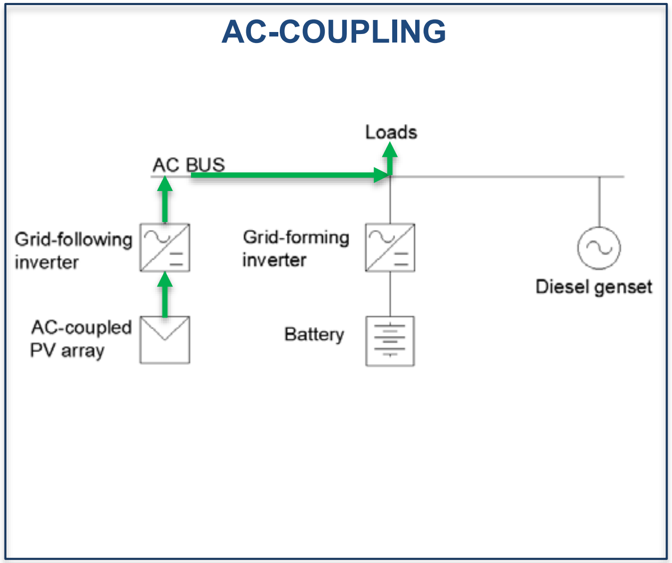
1. Economic indicators:
   - Minimize LCOE
   - Minimize CAPEX
   - Minimize OPEX
2. Technical indicators:
   - Maximize resilience
   - Maximize autonomy
   - Maximize RE fraction
3. Environmental indicators:
   - Minimize CO_2 emissions

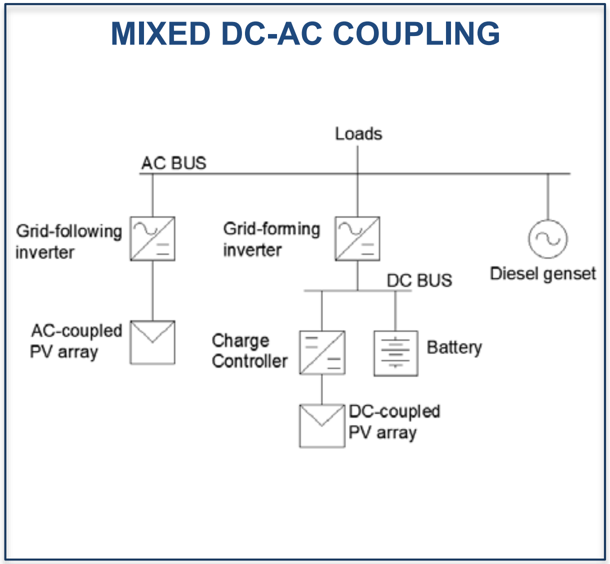
What can it depend on?

1. Financing mechanisms
2. Tariffs
3. Other regulations
4. Demand uncertainty
5. Location

Electrical architecture



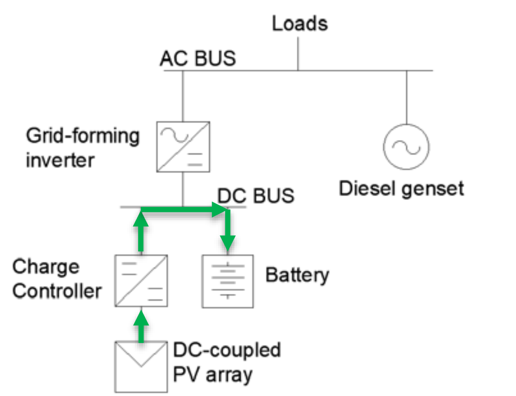




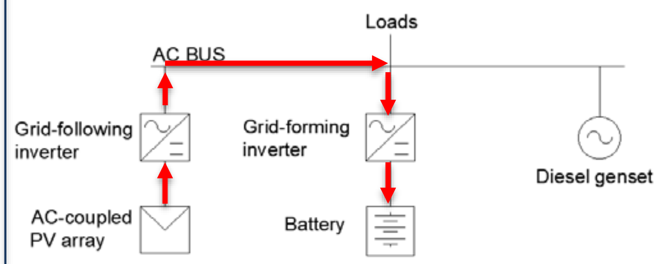
- When selecting the electrical architecture, consider:
  - Load profile
  - Costs
  - Reliability and robustness

Electrical architecture

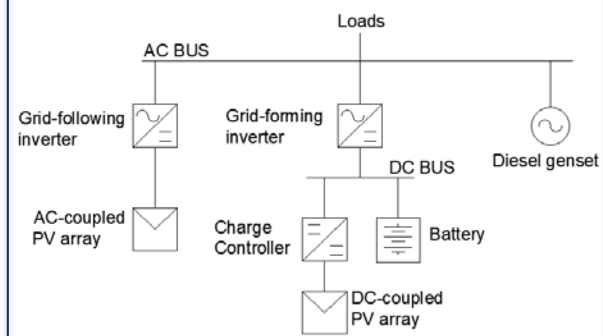
DC-COUPLING



AC-COUPLING



MIXED DC-AC COUPLING



- When selecting the electrical architecture, consider:
  - Load profile
  - Costs
  - Reliability and robustness

Phase 2

COMPONENT SELECTION

PV modules

- Normative references:
  - IEC 61215
  - IEC 61730-1, IEC 61730-2
  - IEC 61701 and IEC 62716 - depending on the environment

- Suggested best practices:
  - Crystalline silicon-based PV modules (poly-Si and mono-Si) are the most mature technology nowadays in terms of reliability and cost per Wp.
  - All the PV modules within the same string must be of the same brand, model and production lot, having the same electrical characteristics (Pmp, Isc, Imp, Voc, Vmp).
  - Positive tolerance preferred, together with an efficiency >15%

Batteries

- Normative references:
  - IEC 61427
  - Lithium: IEC 62619, IEC 62133-2, IEC 61960, UN38.3
- Suggested best practices:
  - High charging and discharging efficiency
  - Resistance in cycling (>1500 cycles up to SoC ≈ 20%)
  - Minimum self-discharge (<4%/month)
  - Consider influence of temperature
  - Max 3 batteries in parallel

Lead-acid or Li?

- Budget
- Temperature
- Recyclability
- # of cycles
- Energy density (per kg or per m3)
- Efficiency

Batteries

- Normative references:
  - IEC 61427
  - Lithium: IEC 62619, IEC 62133-2, IEC 61960, UN38.3
- Suggested best practices:
  - High charging and discharging efficiency
  - Resistance in cycling (>1500 cycles up to SoC ≈ 20%)
  - Minimum self-discharge (<4%/month)
  - Consider influence of temperature
  - Max 3 batteries in parallel

Lead-acid

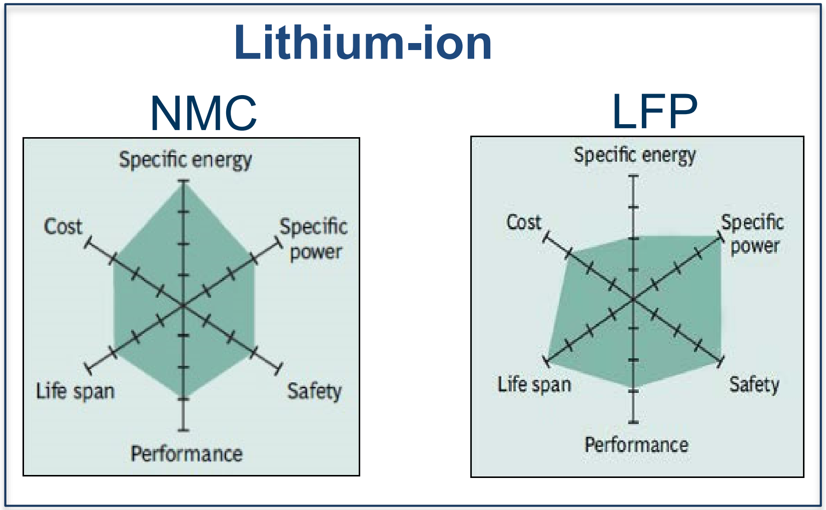
OPzS or OPzV?

- Maintenance, local know-how
- Local availability of dist. water
- Budget
- Logistic requirements
- Area available

Batteries

- Normative references:
  - IEC 61427
  - Lithium: IEC 62619, IEC 62133, IEC 61960, UN38.3

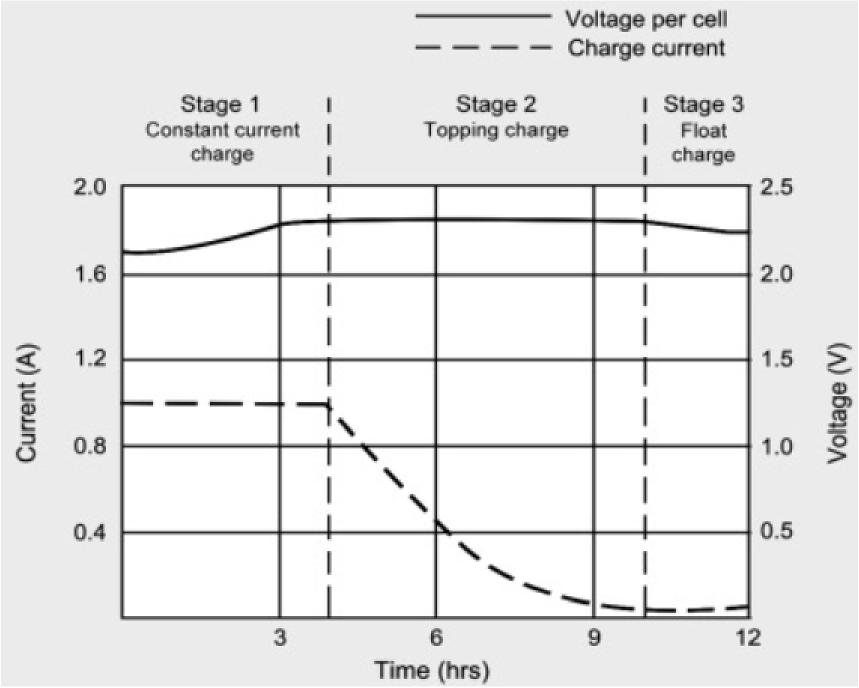
- Suggested best practices:
  - High charging and discharging efficiency
  - Resistance in cycling (>1500 cycles up to SoC ≈ 20%)
  - Minimum self-discharge (<4%/month)
  - Consider influence of temperature
  - Max 3 batteries in parallel



Batteryuniversity.com

Charge controller

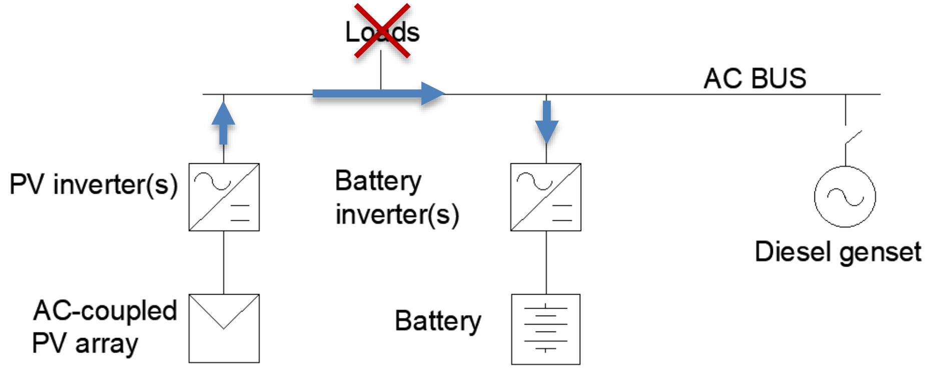
- Normative references:
  - IEC 62109, IEC 62509
  - UL1741
- Suggested best practices:
  - For minigrid-sized systems, use MPPT controllers
  - Regulation phases according to battery technology
  - Temperature-dependent charging thresholds
  - SoC embedded calculation with temperature compensation



Batteryuniversity.com

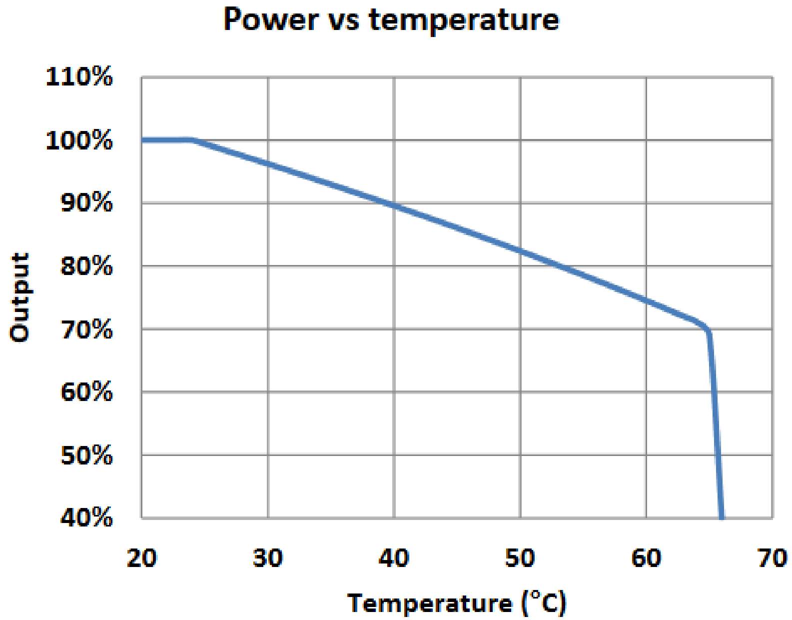
PV inverters

- Normative references:
  - IEC 62109, IEC 62477
- Suggested best practices:
  - String inverters with MPP tracking
  - Ask for temperature derating curve
  - Ensure compatibility with battery inverter (communication, control)
  - $kW_p/kW_{ac} > 1$
  - Ensure that the ratio between the PV inverter power and battery inverter power is within manufacturer´s limits



Battery inverters

- Normative references:
  - IEC 62109, IEC 61000
- Suggested best practices:
  - Ask for temperature derating curve
  - Note overload capability (30min, 5min)
  - Active power regulation
  - Compatible communication bus with all other components
  - Modularity
  - Keep in mind the reliability of the existing grid



Derating curve of Victron Quattro

Typical warranties

Component	Warranty (years)
PV modules	10 (product), 25 (performance)
Charge controller	5
PV inverter	5
Battery inverter	2-5
Battery	1-2 (Pb), 5-10 (Li)

Phase 3

LOGISTICS

Process

- Inspection of goods
- Certifications by independent party
- Container optimization
- Transport insurances
- Shipping documents
- Custom release
- Inland transport to remote locations.

Transport

Source: Trama Tecnoambiental

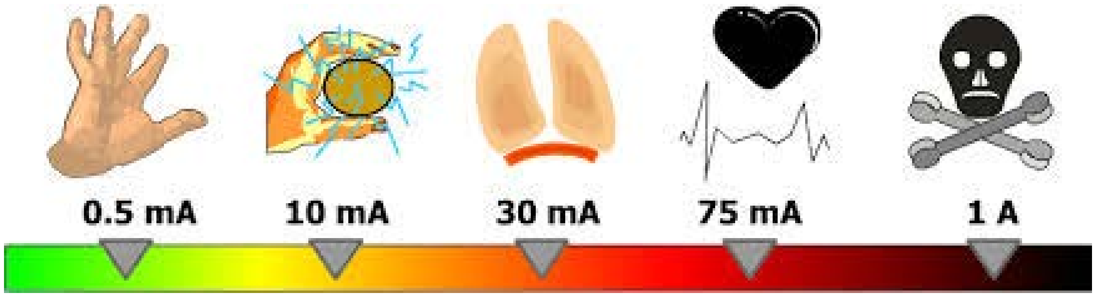
Phase 4

INSTALLATION

General

- Consider added value options

Protection of people



IEC ELV (Extra Low Voltage) definition:

AC: 50V

DC: 120V

Best practices

- Follow international standards to ensure safety of personnel and components, inter alia:
  - IEC 60364, Low-voltage electrical installations. Part 7-712 deals with PV systems.
  - IEC 61557, Electrical safety in low voltage distribution systems up to 1000 Vac and 1500 Vdc.
  - IEC 62548, PV arrays – design requirements.
  - IEC 62485 – safety requirements for secondary batteries and battery installations
- Consider local environment (high temperatures, corrosion, rainy seasons, hurricanes..)
- Ensure proper ventilation if OPzS batteries are used.

Phase 5

COMMISSIONING

Objectives

- Check the process to ensure that the system installation meets the requirements set forth in the implementation contract between the developer and the implementer
- Test the process to ensure that the system operates according to the functional part of the implementation contract
- Once the parties come to agreement, transfer the responsibility of the system

- Relevant standards:
  - **IEC 62446-1.** Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection
  - **IEC TS 62257-6**. Recommendations for renewable energy and hybrid systems for rural electrification - Part 6: Acceptance, operation, maintenance and replacement

Steps

	Step	Description
0	Preparation	Check that all non-operational contractual requirements are met: Documentation, manuals, spare parts, drawings, procedures, warranty contracts, etc.
1	Evaluation of the conformity of the installed system with the accepted design	Check that the equipment complies to the contractual accepted design and that any differences are explained
2	Evaluation of qualification of the installation	Check that the system is ready to be operated
3	Preliminary tests	Test that the system components operate correctly
4	Performance testing	Check all the operating performance parameters of the whole system
5	Agreement	Transfer of responsibility

Commissioning reports

- Code-compliant test descriptions and example reports can be found in:
  - IEC 62446-1
  - IEC TS 62257-7 to IEC TS 62257-10

Model PV array test report

PV array test report	Initial verification Periodic verification
Installation address	Reference
	Date
Description of work under test	Inspector
	Test instruments

String		1	2	3	4		n
Array	Module						
	Quantity						
Array parameters (as specified)	Voc (stc)						
	Isc (stc)						
String over-current protective device	Type						
	Rating (A)						
	DC rating (V)						
	Capacity (kA)						
Wiring	Type						
	Phase (mm²)						
	Earth (mm²)						
String test	Voc (V)						
	Isc (A)						
	Irradiance						
Polarity check							
Array insulation resistance	Test voltage (V)						
	Pos – Earth (MΩ)						
	Neg – Earth (MΩ)						
Earth continuity (where fitted)							
Switchgear functioning correctly							
Inverter make / model							
Inverter serial number							
Inverter functions correctly							
Loss of mains test							

Phase 6

TRAINING

Community involvement and training

- Critical step in order to ensure long-term project sustainability
- Continuous process

Consumer education

- Financial obligations:
  - Written policy concerning the disconnection of consumers in case of non-payment shall be clearly defined
- Safety
- Efficient use of energy

ENERGY STAR

- Combine with women empowerment

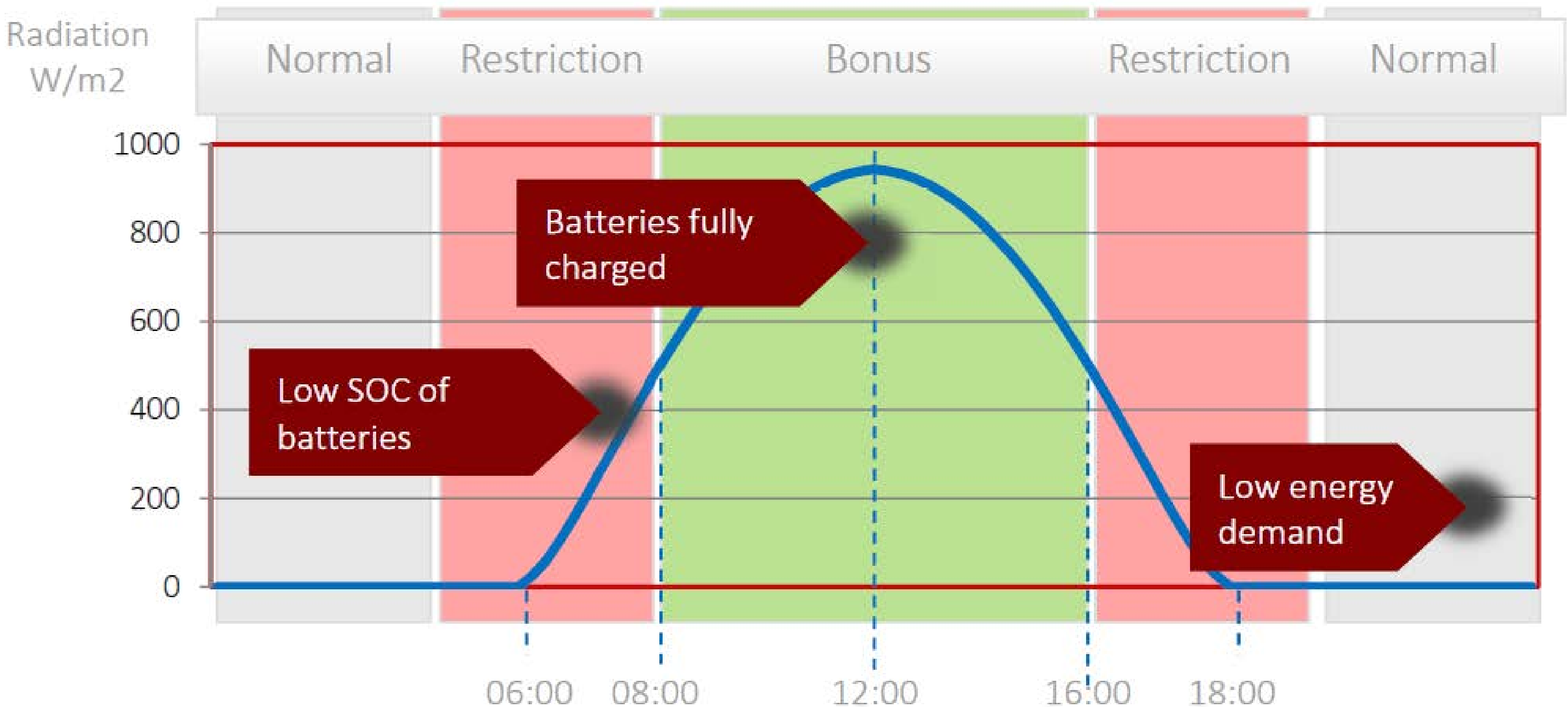
barefoot college

SOLAR SISTER

Grameen Shakti

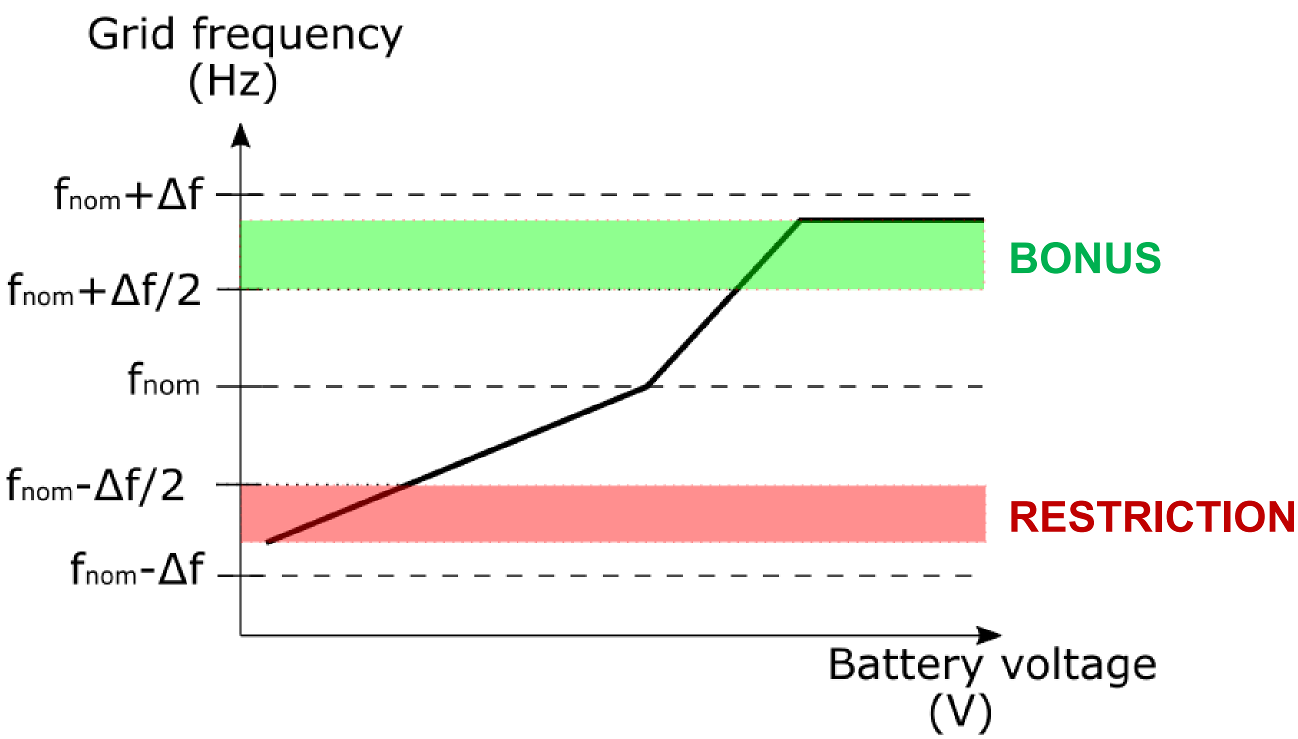
Demand-side management

- Give incentives to users to shift their demand to follow energy production times



Demand-side management

- Real-time communication by detecting frequency changes:
  - Smart meters can detect the mini-grid´s frequency
  - A price signal can be transmitted by modifying the frequency of the inverter



Phase 7

O&M

Objectives

- **Operation**:
  - Manage and monitor
  - Respond to abnormal system operation (corrective actions, troubleshooting)
  - Guarantee safety
  - Perform analysis
- **Maintenance**:
  - Preventive maintenance
  - Corrective maintenance
  - Conduct periodic tests and inspections

PREVENTIVE

CORRECTIVE

References

- **IEC TS 62257-6:** maintenance and replacement recommendations for small renewable energy and hybrid systems for rural electrification
- **IEC 62446-2:** maintenance of PV systems
- **IEC 61724:** PV system performance monitoring and evaluation
- **NREL QAF for minigrids**:
  - Levels of service framework
  - Accountability and performance reporting framework

Table ES-1. Summary of Level of Service

Issue	Base Level of Service	Standard Level of Service	High Level of Service
AC Power Quality Phenomena			
Voltage imbalance	<10%	<5%	<2%
Transients	No protection	Surge protection	Surge protection
Short voltage duration variations	<5/day	<1/day	<1/week
Long voltage duration variations	<10/day	<5/day	<1/day
Frequency variations	48 Hz < f <52 Hz	49 Hz < f <51 Hz	49.5 Hz < f <50.5 Hz
DC Power Quality Phenomena			
Resistive voltage drop	<10%	<5%	<2%
Percent ripple	50% peak to peak (pk-pk)	20% pk-pk	10% pk-pk
DC ripple & switching noise	Unfiltered	Transient noise minimized	Ripple noise also minimized
Transients	No protection	Surge protection	Surge protection
Faults allowed per day	<5 per day	<2 per day	<1/day
Power Reliability			
Unplanned-SAIFI_{xx}[1,3]	<52 per year	<12 per year	<2 per year
Unplanned-SAIDI_{xx}[1,3]	<876 hours (90% reliability)	<438 hours (95% reliability)	<1.5 hours (99.99% reliability
Planned-SAIFI_{xx}[1,2]	No requirement but should be defined	No requirement but should be defined	<2 per year
Planned-SAIDI_{xx}[1,2]	No requirement but should be defined	No requirement but should be defined	<30 minutes - 100% reliability

Quality Assurance Framework for Mini-Grids, NREL, 2016.

(some) Possible issues

Example of maintenance schedule

- **CONSTANT TASKS:**

TYPE	LEVEL O&M	DESCRIPTION
0 - General	Basic	Existence and availability of O&M checklist
0 - General	Basic	Existence and availability of O&M plan
0 - General	Basic	Availability and update of O&M logbooks
0 - General	Professional	Existence and availability of “as-built” plans
0 - General	Professional	Existence and availability of technical documentation
0 - General	Professional	Existence and availability of operation manuals
0 - General	Professional	Existence and availability of monitoring and evaluation plan
0 - General	Professional	Availability and update of monitoring and evaluation reports
0 - General	Basic	Access to PV panels, battery rooms and technical room is restricted and only authorized personnel is allowed

Example of maintenance schedule

- **MONTHLY TASKS:**

TYPE	LEVEL O&M	DESCRIPTION
2 - Batteries	Basic	Visual check of battery conditions - presence of sediments and crystals, electrolyte level, presence of corrosion, tight and protected connections
2 - Batteries	Basic	Availability check for the hydrometer, gloves, glasses, distilled water, thermometer
2 - Batteries	Basic	Check battery voltage
3 – Charge controller and data logger	Basic	Check that the performance parameters agree with the system specifications. Log the basic parameters in the logbook.
3 – Charge controller and data logger	Consultant Supervisor	Check that the operational parameters agree with the system specifications. Log the operational parameters in the logbook.
6 – Technical room	Basic	Check for good ventilation, restricted area and availability of safety equipment (fire extinguisher, danger signs)

Example of maintenance schedule

- **QUARTERLY TASKS:**

TYPE	LEVEL O&M	DESCRIPTION
1 – PV generator	Basic	Cleaning of possible dirt in the PV modules.
1 - PV generator	Basic	Visual check of color defects, hotspots and cracks in the PV modules.
1 - PV generator	Basic	Check the coating around the fixing points of the mounting structure.
1 - PV generator	Basic	Visual check of all fixing screws, tightening, corrosion, etc.
1 - PV generator	Basic	Check radiation and temperature sensors (tightening, contact, wiring).
1 - PV generator	Basic	Visual check of the cables.
2 - Batteries	Basic	Check the density and voltage of each battery cell, fill with distilled water
3 – Charge controller and data logger	Supervisor	Download recorded data, check raw data for possible errors.

Example of maintenance schedule

- **SEMESTER TASKS:**

TYPE	LEVEL O&M	DESCRIPTION
1 – PV generator	Basic	Prevention of possible plant growth that could provoke shades.
1 - PV generator	Professional	Check PV modules and wiring
2 - Batteries	Professional	Check cables and terminals (including earth), tightening, dust, etc
3 - Charge Controller and data logger	Supervisor	Data analysis and preparation of evaluation reports. Conclusions and recommendations on basic operational parameters.
4 - Inverter	Professional	Check the inverter status: operation, screen, alarms, modes, etc.
5 - DC distribution and protections	Professional	Check the condition of the cables and terminals, including earth: clamping, dust, etc.
5 - DC distribution and protections	Professional	Check combiner box – switches, cables, terminals, etc.
7 - AC connection to Grid	Professional	Check combiner box – switches, cables, terminals, etc.

Example of maintenance schedule

- **YEARLY TASKS:**

TYPE	LEVEL O&M	DESCRIPTION
0 - General	Professional	General check of all the elements and operational conditions.
1 – PV Generator	Basic	Visual check of the shades on the PV modules during the day.

Thanks for your attention!