Promotion of village grids

Quality and safety guidelines for solar village grids

Contents

1. Introduction

Promoting private sector-based investments in village mini-grids, EnDev Rwanda aims to leave as much freedom as possible to the project developer in regards to technical design and business model. However, some minimum requirements for the quality and safety of the village grid installation must be fulfilled to ensure:

- a reliable power supply within the village grid,
- the quality of electricity supplied to protect electrical appliances connected, and
- the safety of the customers and staff.

The following document provides guidelines for the development of solar PV based village grids. Only general orientation is provided on issues that EnDev deems critical during the design phase, finally contributing to a sustainable and safe operation of the village grid.

We recommend using more detailed technical guidance available (see literature overview in section 6, all publicly available documents can be provided on request).

Beside the distribution network, for which the design standards and guidelines for EARP Rural electrification must be applied, the guidance provided in this document shall be considered as recommendations. More orientation is provided by the EnDev Commissioning Checklist, which represents a binding part of the contract, and describes the detailed checks and measurements conducted by EnDev Rwanda during site commissioning to determine if the village grid meets the required quality and safety level.

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2. Site identification, sizing of solar PV system and distribution network

The project developer should determine power consumption demands:

- Based either on the actual load curve (if the village is already electrified e.g. by a diesel generator) or on an accurate socio-economic survey. Companies should estimate the daily energy needs (kWh/day) in case they expect a strong demand growth, plan their system in a modular way and consider sufficient space in the power house for a later extension.
- Ideally, for villages with expected energy demand higher than 100 kWh/day, the average load curve is to be determined.
- Average daily energy demand (kWh/day), peak active power (kW) and peak reactive power (kVA) must be determined as precisely as possible.
- Sizing of the installation:
- Based on energy demand, peak power and minimum daily sun energy on the appropriate tilt angle (kWh/m2/day), EnDev recommends designing the PV system by using specific software such as Homer[1] or other commercial simulation software.
- Quick review of the minimum requirement for main system component sizing:
  - PV modules: the daily energy produced out from the PV field, based on the lowest sunny period, should be higher than 1.5 x daily demand.
  - Solar charge controller: adapted with PV field voltage and current, as well as battery voltage and current.
  - Battery: for systems without a backup diesel generator, the minimum recommended storage battery capacity @ C20[2] should be in the range of 3 x daily energy demand (as storage costs are high, cost should be compared to a configuration with smaller storage and back-up diesel generator). In case of a hybrid system, the battery capacity will depend on the ratio between operating PV scheme vs generator. Except for systems bigger than 100 kWp, we recommend not to design the battery rated voltage higher than 48 V DC for safety reason.
  - Inverters: inverter sizing must consider both active and reactive expected peak demand. In practice, nominal inverter power (W) must be at least higher than 1.3 times the expected peak demand (W). The inverter capacity to provide reactive power (kVA) for short period must comply with expected current peak demand with a very low power factor. As grid connection is a realistic scenario in Rwanda within the lifetime of the inverter, the selection of an inverter that also can operate in grid-parallel mode should be considered.

3. PV area

3.1. PV modules and PV array

- PV module quality and size: compliant with international standard IEC 61215 / 61730-1-2 for PV crystalline module (highly preferable for off-grid applications). For small systems (up to 2 kWp), 36 or 72 cells PV modules can be used with direct charging using a Pulse Width Modulation (PWM) solar charger. However, for larger system, it is more preferable to use 60 cells modules and a Maximum Power Point Tracking (MPPT) solar charger scheme.
- PV module array foundation: foundation structure firmly anchored into the ground, using concrete

[1] HOMER is a micro-grid simulation software (http://homerenergy.com).

[2] Battery capacity at C20 means the capacity of the battery in case of discharging it within 20 hours.

support. Detailed calculation of the support size and implementation must be done in accordance with local climatic constraints and mounting structure manufacturer.

- PV array mounting structure: array firmly fixed on the structure, ground clearance respected as well as the recommended distance between PV arrays, and all PV array support grounded. The The panels should be mounted at a tilt of at least 10 degrees ideally facing the north for easier maintenance and production maximization. The mounting structure should be made of aluminium, stainless steel with stainless steel screws and bolts or comparable quality.
- PV array wiring: modules wires well insulated, safe from water and moisture; junction boxes should be carefully and neatly wired, grounded and waterproofed. Wiring must be done to reducing cable loops in order to prevent any surge damages.

3.2. Combiner box and cabling to power house

- Type: If several PV strings are to be connected in parallel, PV combiner boxes are to be installed either directly on the mounting structure, or in the powerhouse. This box must have a rated DC voltage higher than 1.2 Voc[3] and a rated DC current higher than 1.25 Isc[4] of the connected PV array. If more than 3 strings are connected in parallel, DC gPV[5] fuses are required. If Surge Protection Devices (SPD) are considered, these have to be properly installed in the DC combiner box. If boxes are installed outdoor, sun protection and a strict waterproof design are required.
- Cabling: Any external cable should be designed to be resistant against UV radiation and extremely high temperature fluctuations, and should generally be unaffected by weather, water, humidity. Cables should pass through cable ducts or trenches. Wire terminals should be rated to fit the range of wire sizes used. For all the cabling from each PV array to the solar charge controller (towards combiner boxes or not) must be specific solar cable: single pole with double insulation, UV resistant and 1.5kV rated voltage.

4. Power House and components

4.1. Power house

- The power house typically should have 3 separate rooms: battery room, electronic component room (boxes, controllers, inverters, monitoring), and a storage room (extra-distilled water and maintenance tools).
- The power house structure shall be made of concrete and/or wood, the size will depend of the overall size of the system.
- The battery rooms shall be designed to support more than 2 tons/m2 grounded. The house should be well ventilated (especially battery room), safe from moisture, well lit and safe from intrusion and vandalism.

4.2. Solar charge controller

- A charge controller is incorporated in the system to avoid battery damage by excessive charging or discharging. The controller shall ensure that the batteries are charged as quickly as possible whilst ensuring that overcharging does not damage the batteries. Minimum requirements are presented below:
- Basic recommendations for sizing are exposed in chapter 2 of the present document.

[3] Open circuit voltage
[4] Short circuit current
[5] International standard for fuses used in photovoltaic systems (DC side)

- Shunt / series / PWM regulating technology for small systems (up to 2 kWp) can be accepted. However, MPPT controllers are strongly recommended for system above 1 kWp (10-15% more efficiency).
- Controller design and sizing must comply with: (i) PV array Voc max voltage and Isc current (with 1.25 safety margin), (ii) max DC current supported by battery bank (typically 10% x C100 capacity), (iii) voltage thresholds and charging scheme (bulk, float, equal, boost) adjustable according to the type of battery and battery manufacturer recommendation.
- Controller must be able to adapt its voltage threshold with battery temperature. It is also preferable to have a specific voltage probe to properly read battery voltage without using the power cables.
- The charge/discharge regulation can be done either by voltage reading (small system) or SOC (stage of charge) calculation for bigger installation.
- Brand: choosing equipment from a reputable company is recommended (compliance with specifications, warranty procedures).

4.3. Battery

- Basic recommendations for sizing are exposed in chapter 2 of the present document.
- Deep-cycle, lead-acid batteries with tubular plates are widely used in renewable energy and grid-backup system, and are ideally suited for these applications because of their long, reliable life and low cost of ownership.
- If the site is not provided with regular maintenance staff, gel batteries can be used. In that case, charging configuration of the controller must strictly fulfil manufacturer recommendation.
- In case permanent or regular trained staff is available in the powerhouse, we recommend using open lead-acid batteries as they are more robust and less expensive as long as the electrolyte level is well maintained.
- Cycle life: ideally, good solar battery from well-known manufacturers can provide up to 4000 cycles @ 60% Depth of Discharge (DOD) @ C20.
- End terminal of battery blocks should be protected with non-conductive material.
- Brand: Choosing a battery from a reputable company is recommended (compliance with specifications, warranty procedures).

4.4. Inverter

- Basic recommendations for sizing are exposed in chapter 2 of the present document.
- Systems designed to deliver alternating current (AC), such as grid-connected applications need an inverter to convert the direct current (DC) from the solar modules to AC. For DC distribution system, the inverter can be omitted.
- Inverter shall be designed with galvanic insulation between DC and AC parts.
- Inverter shall have efficiency higher than 85% on the operating range 20-100% of its rated power.
- Several inverters can be connected (and synchronized) in parallel to increase available power (both active and reactive) in case of single phase configuration.
- Several inverters can be connected (and synchronized) to create a triple phase scheme if necessary.
- It is strongly recommended to use inverters from the same manufacturer as the charge controller for a proper charge/discharge control, especially in case of hybridization with diesel generator or other power sources.

4.5. Monitoring system

- PV systems need to be monitored to detect breakdown and optimise their operation. There are several

PV monitoring strategies depending on the output of the installation and its nature. Monitoring can be performed on site or remotely.

- It is recommended to capture historic production data, and to manage revenue data from consumer payments.
- It is recommended to have a user-friendly interface to monitor the PV system. Choosing a unique manufacturer for charge controller and inverter allows for a fully operational, reliable and easy to use monitoring system.

5. Power distribution and consumer installation

5.1. AC/DC distribution

- The design voltage will be 400/240 Volt. To supply household users with energy for lighting, TVs and other domestic appliances a 1-phase system is generally sufficient. However, 3-phase connections should be considered for larger costumers.
- The maximum permitted voltage drop at the end of the LV service connection (customer supply point) shall not be more than ±5% for single phase and ±10% for three phase of nominal voltage with the calculated saturation load.
- For DC distribution system, system voltage can be of 12V, 24V or 48V. The preceding recommendations will determine the conductors' size and type. Even though DC cables are not dangerous to touch, they should not be reachable for everybody and their deflection height should be at least 2.5 meters above ground. In case of DC cables crossing the roads, their deflection should be at higher than 4 meters above ground.
- The network's design shall be overhead bundle conductor radial systems with Areal Bundled Cables (ABC). The covered neutral carrier system should be used.
- Requirements for the construction of LV distribution network applicable in Rwanda are detailed in the EARP guidelines. The guidelines provide minimum ground clearances and acceptable line spans.
- The grounding scheme for the power distribution (IT/TN/TT) must comply with the EARP guidelines. Inverters and AC main cabinets must be designed to comply with local requirements regarding the grounding scheme.

5.2. Consumer interfaces and installations

- Service connections are of the overhead type, connecting directly from the pole to the house and fixed onto the house's roof structure or the wall by means of a suitable tension clamp with eye bolt or pigtail bolt.
- Metering and/or load limitation shall be done through energy meters or current limiting devices such as MCB. Energy limitation devices or prepayment management system can also be implemented in case of many customers.
- Appropriate cables with correct size and insulation shall be used depending on the required current of the consumer.
- All power sockets must have protective earthing that is connected to the grounding scheme.
- Distribution boxes installed between the distribution grid and the house inner cabling must fulfil safety requirements, and comply with the grounding scheme.
- The project developers must think about their ownership and responsibility: (i) inner/household wiring, including bulbs, can be provided, owned and maintained by the company (this enables to better control energy use and demand), or (ii) the company only provides service connections and meters or power/energy limiter.

6. Selection of recommended manuals and guides on PV Mini-Grids

Technical guidance is provided by the following standards and guidelines (RS/IEC standards to be purchased):

1. EWSA (2013): Design standards and guidelines for EARP Rural electrification
2. RS 116 – 2011 Electrical wiring of premises – Part I: Low Voltage installations
3. RS EAS 811-1 to 5: 2014 Code of practice for safety of electrical installations
4. IEC UTE NF C15-712-2 (French) - Installations électriques à basse tension - Guide pratique.
5. IEC TS 62257 - Recommendations for small renewable energy and hybrid systems for rural electrification.

Other helpful publications include:

1. GIZ (2015): Solar PV-diesel hybrid business planning checklist. For applications in local power distribution systems in off-grid areas in the Philippines. https://energypedia.info/images/0/07/Solar_PV-diesel_Hybrid_Business_Planning_Checklist.pdf
2. GIZ (2014): Where shall we put it? Solar mini-grid site selection handbook. https://www.giz.de/en/downloads/giz2014-en-solar-mini-grid-handbook-kenya.pdf
3. UKAID (2013): Low Carbon Mini grids - Identifying the gaps and building the evidence base on low carbon mini-grids. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/278021/IED-green-min-grids-support-study1.pdf
4. USAID & ARE (2011): Hybrid Mini-Grids for Rural Electrification: Lessons Learned. http://www.ruralelec.org/fileadmin/DATA/Documents/06_Publications/Position_papers/ARE_Mini-grids_-_Full_version.pdf
5. NRECA (2009): Guides for Electric Cooperative Development and Rural Electrification. https://www.nreca.coop/wp-content/uploads/2013/07/GuidesforDevelopment.pdf
6. SERC (2013): Review of Strategies and Technologies for Demand-Side Management on Isolated Mini-Grids. http://www.cleanenergyministerial.org/Portals/2/pdfs/Review_of_Strategies_and_Technologies_for_DSM_on_MiniGrids.pdf
7. SERC (2013): A Guidebook on Grid Interconnection and Islanded Operation of Mini-Grid Power Systems up to 200 kW. http://www.cleanenergyministerial.org/Portals/2/pdfs/A_Guidebook_for_Minigrids-SERC_LBNL_March_2013.pdf
8. ARE (2015): Risk Management for Mini-Grids. http://ruralelec.org/fileadmin/DATA/Documents/06_Publications/RISK_Management_for_Mini-Grids_2015_Final_web.pdf
9. Solar Electric Systems for Africa (1995). A guide for planning and installing solar Electric Systems in Rural Africa by Mark Hankins. Illustrations by Francis Njeru & Mike; layout by Micheal Okendo; edited by Dr. Timothy Simalenga

The IEA Photovoltaic Power Systems Programme has published a large series of technical reports on PV Mini-Grids:

1. IEA PVPS (2013): Rural Electrification with PV Hybrid Systems, Overview and Recommendations for Further Deployment. https://www.iea.org/media/openbulletin/Rural_Electrification_with_PV_Hybrid_systems.pdf
2. IEA PVPS (2011): Design and Operational Recommendations on Grid Connection of PV Hybrid Mini-Grids. Technical Report, IEA-PVPS T11-06:2011. Paris: IEA PVPS Task 11. http://www.iea-pvps.org/index.php?id=95&eID=dam_frontend_push&docID=1027.
3. IEA PVPS (2011): World-Wide Overview of Design and Simulation Tools for Hybrid PV Systems. Technical

Report, PVPST 11-01:2011. Paris: IEA PVPS Task 11. http://iea-pvps.org/fileadmin/dam/public/report/technical/rep11_01.pdf.

4. IEA PVPS (2011): The Role of Energy Storage for Mini-Grid Stabilization. Technical Report, IEA-PVPS T11-02:2011. Paris: IEA PVPS Task 11. http://www.iea-pvps.org/index.php?id=9&eID=dam_frontend_push&docID=744.
5. IEA PVPS (2011) : Social, Economic and Organizational Framework for Sustainable Operation of PV Hybrid Systems within Mini-Grids. Technical Report, IEA-PVPS T11-05:2011. Paris: IEA PVPS Task 11. http://www.iea-pvps.org/index.php?id=95&eID=dam_frontend_push&docID=1027.
6. IEA PVPS (2012): PV Hybrid Mini-Grids: Applicable Control Methods for Various Situations. Technical Report, IEA-PVPS T11-07:2012. Paris: IEA PVPS Task 11. http://www.iea-pvps.org/index.php?id=95&eID=dam_frontend_push&docID=1127.
7. IEA PVPS (2011): Recommendations for Communication System Needs for PV Hybrid Mini-Grid Systems. Technical Report, IEA-PVPS T11-04:2011. Paris: IEA PVPS Task 11. http://www.iea-pvps.org/index.php?id=95&eID=dam_frontend_push&docID=1025.
8. IEA PVPS (2012): Overview of Supervisory Control Strategies Including a MATLAB® Simulink® Simulation Tool. Technical Report, IEA-PVPS T11-08:2012. Paris: IEA PVPS Task 11. http://www.iea-pvps.org/index.php?id=95&eID=dam_frontend_push&docID=1211.
9. IEA PVPS (2011): Sustainability Conditions for PV Hybrid Systems: Environmental Considerations. Technical Report, IEA-PVPS T11-03:2011. Paris: IEA PVPS Task 11. http://www.iea-pvps.org/index.php?id=3&eID=dam_frontend_push&docID=745.

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