

Current State of the Art in PV Hybrid Mini-Grids – Early Results from IEA PVPS Task 11

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1 Overview and Background

The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organization of Economic Co-operation and Development (OECD) which carries out a comprehensive programme of energy co-operation among its twenty four member countries [1]. The European Commission also participates in the work of the Agency.

The IEA Photovoltaic Power Systems (PVPS) Implementing Agreement is one of the collaborative research and development agreements established within the IEA [2]. IEA PVPS Task 11 [3], which has a mandate to operate from 2006 to 2011, is an international R&D collaboration to collate and disseminate international knowledge of hybrid systems and to further develop PV hybrid technology. In particular there is the need to develop technology and application knowledge for larger hybrid systems consisting of multiple different energy sources interconnected by a local electrical distribution network – the mini-grid concept.

This paper briefly reviews the goals and objectives of Task 11, discusses the work plan and approach that is being used to achieve the objectives, and summarizes some of the early results from the Task activities.

2 Scope and Objectives

The scope of Task 11 is PV based hybrid electricity generators with a focus on mini-grid systems. The main *goal* of Task 11 is to promote PV technology as a technically viable and economically competitive energy source in mini-grids. It aims to improve the knowledge-base of PV hybrid mini-grids and reduce barriers to market penetration of these systems. Specific objectives to meet this goal are to:

- i) define application domains for PV hybrid mini-grids and identify the factors - technical,

economic, social, and environmental – that lead to successful and sustainable applications,

- ii) provide recommendations on design approaches (system architecture, generation types, control strategies) to achieve high penetration of PV as a means to improve the quality, reliability and economics of electrification systems such as mini-grids;
- iii) assess the potential of technologies to be mixed with PV for hybridisation; and,
- iv) compile and disseminate best-practices on PV hybrid power systems.

3 Approach and Work Plan

Task 11 activities address both technical and non-technical issues that affect the market penetration and uptake of PV hybrid systems. Technical issues include

- design methodologies for PV hybrid mini-grid systems,
- control and interconnection of mini-grids, and
- increasing the energy contribution of PV versus fossil fuel generators within hybrid systems.

These form the bulk of the work in Task 11. Non-technical issues pertain to the social, economic and environmental conditions through which these systems become sustainable.

In general, Task 11 follows a strategy, similar to previous PVPS Tasks, in which the current states of technology and design practice in the participating countries are first assessed and summarized. Further work will then focus on those areas where technology improvements or better design practices are needed. This may require new research or data, or simply an expert consensus on best practices.

4 PV Hybrid Mini-Grid Application Domains

PV hybrid mini-grids have a range of potential applications. Three broad application domains can be defined as village microgrids, diesel mini-grids, and urban mini-grids.

Village microgrids provide ac electricity to “off-grid” settlements, offering a step up from batteries, solar home systems, and portable engine-generators. The primary

motivation for installation is to achieve human development goals associated with the reliable delivery of electric power. The principal technical challenge is to design systems that are affordable and also sustainable over the long term in settings where capital and operating budgets are often small and infrastructure for operation and maintenance may be minimal. The technology employed must be appropriate for the social, economic, and environmental conditions of the settlement.

Diesel mini-grids are established independent power grids using (primarily) diesel reciprocating engines as the generation source. They serve remote communities, resource extraction industries, and islands in many parts of the world. The PV hybrid opportunity is to supplement the diesel generators, thereby reducing fuel consumption. The primary motivations for installing PV are to reduce operating (fuel) costs, improve reliability and availability of power, and achieve greenhouse gas reductions and other environmental benefits. At low penetration of PV in the mini-grid there are now relatively few technical challenges with integration – the issues are similar to conventional grid-tie PV. Instead, the needs are to make the economic and environmental case for PV, and to overcome institutional barriers. At higher penetration of PV, there is a need for cost-effective technology to maintain grid-stability.

Urban mini-grids are envisaged to be local distribution networks in developed areas that have an established electricity grid. The mini-grid can operate autonomously with local generation sources or interconnect to operate in parallel with the central grid. The primary motivations for implementing urban mini-grids are to allow the integration of high levels of distributed and renewable generation sources into the grid and to increase reliability and availability of electric power through the provision for autonomous operation. At this point urban mini-grids are at the R&D stage with some demonstration projects in progress. There are technical challenges to maintaining mini-grid stability and power quality during autonomous operation and to achieving a disturbance-free transfer between autonomous and grid parallel

operation. In addition, there are regulatory hurdles to overcome and there is still a need to develop a compelling financial case for urban mini-grids.

5 Design practices for PV hybrid mini-grids

Task 11 participants have surveyed available material on design of PV hybrid mini-grids, with a focus on design guidelines suitable for practitioners rather than research-oriented literature. They have also gathered information on the architecture and technical characteristics of installed PV hybrid mini-grids in numerous locations around the globe. Design practices are most developed for village microgrids, which also are the most commonly installed systems. For example, the International Electrotechnical Commission (IEC) is publishing a series of Technical Specifications (TS62557 series [4]) that provide recommendations for the design of village microgrids. Design guidelines for adding PV to existing diesel mini-grids – particularly systems without battery storage - are less developed (or not published). Design practices for urban mini-grids are still at the R&D level.

Although Task 11 has not finished assessing current design practices, it has noted that selection of system architecture is driven by the following considerations in order of increasing specificity:

1. What is the application domain?
2. Does the system support stand-alone operation only or also interconnection to a central grid?
3. What is the target penetration level of PV (fraction of non-load following power/energy in the system)?
4. Are the generation sources centralized or distributed throughout the mini-grid?
5. What are the system capacity and service levels?
 - a. Power level and electrical distribution characteristics (voltage, number of phases, etc.)
 - b. Availability requirement (24 hours, day-time only, etc.)
 - c. Capability for demand-side management

Since there are so many factors which affect the choice of system architecture, the architectures used in the installed systems surveyed by Task 11 are diverse. Task

11 is still developing performance indicators for PV hybrid mini-grids, and has not yet gathered performance data on its surveyed systems, so it cannot make any observations about relative performance of different architectures at present.

However, the following trends are observed:

- More use of ac bus architectures in which the PV and storage are directly connected to the mini-grid ac distribution network
- More systems with multiple energy sources (not just PV, battery, and a genset)
- Higher quality of electrical service offered (ac power, 24 hours per day)
- Increased focus on demand-side management
- Increasing control and data communication capability
- Considerable R&D activity in mini-grids that can interconnect with a central grid.

Another significant trend is the migration to software tools for PV hybrid system design. These tools replace “paper and pencil” calculations and often embed design guidelines and rules that were previously incorporated in manuals and other documents. Task 11 has completed a survey and analysis of software design and simulation tools used by Task 11 participants, which considers availability, applicability, and quality [5].

6 Control of PV hybrid mini-grids

Task 11 has examined current PV hybrid mini-grid system architectures and has classified them into four categories for purposes of studying mini-grid control. The classification is based on which ac power sources in the mini-grid perform the “grid forming” function to control the mini-grid frequency and voltage.

The single fixed master mini-grid architecture (see Figure 1) has only the PV inverters connected to the mini-grid and therefore these do the grid forming. The single switched master mini-grid architecture (see Figure 2) has multiple ac sources connected to the mini-grid (typically the PV inverters and a fossil fuel genset), but only one source supplies ac to the mini-grid at any time and that source does the grid forming. These architectures are typical in village microgrids.

The multi-master rotating machine dominated mini-grid (see Figure 3), which is a typical configuration for a diesel mini-grid, has multiple ac sources (fossil fuel gensets and PV inverters) connected to the mini-grid and simultaneously supplying power [6]. The gensets do the grid forming and the PV inverters follow the mini-grid voltage and frequency.

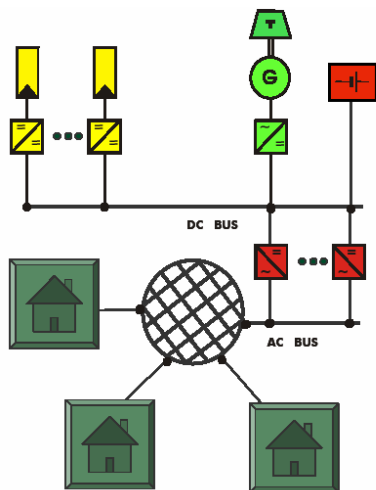


Fig. 1 Single fixed master mini-grid

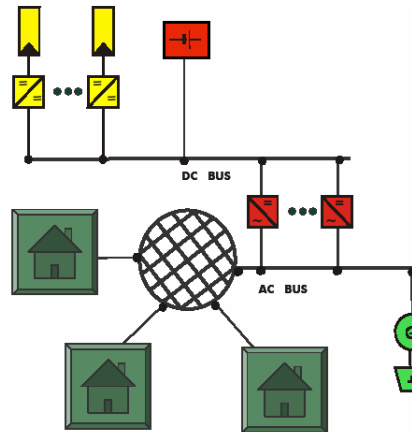


Fig. 2 Single switched master mini-grid

The multi-master inverter dominated mini-grid (see Figure 4) also has multiple ac sources (fossil fuel gensets and PV inverters) connected to the mini-grid and simultaneously supplying power, but in this case certain inverters participate in the grid forming along with the gensets [7]. This approach is well suited for mini-grids with many generators distributed throughout the network.

For each of these mini-grid architectures, Task 11 is studying the following issues

- Grid forming control techniques and techniques to ensure stability of voltage and frequency
- Power sharing among ac sources
- Control of PV generation and storage to maximize PV energy contribution
- Demand side management techniques to manage loads and limit fuel consumption
- Connection of the mini-grid to the central grid

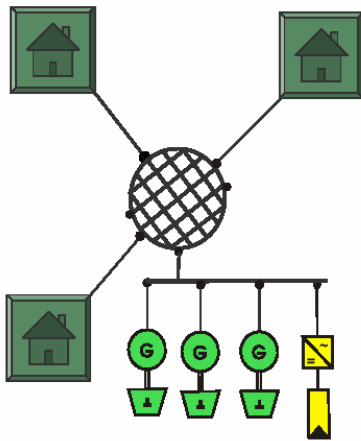


Fig. 3 Multi-master rotating machine dominated mini-grid

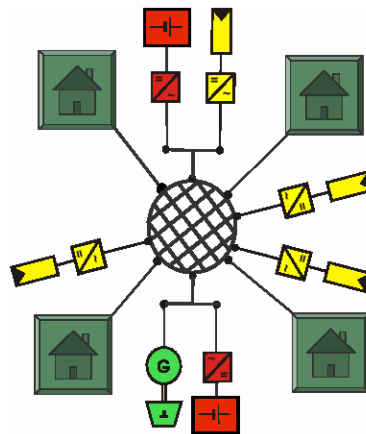


Fig. 4 Multi-master inverter dominated mini-grid

A key requirement in many mini-grid control strategies is communication among the generation sources and other system components. This may be fast communication for power sharing and system stability or slower communication for supervisory control. Task 11 surveyed participants, who include several equipment manufacturers, about the nature and capability of the communication networks they employ in mini grid applications. At this time relatively simple serial data links (e.g. RS232/RS485) predominate but there is increasing use of faster data buses, such as CAN. The data protocols used today are largely proprietary and there is little or no ability for equipment from different manufacturers to interoperate. There is activity within the PV industry and at the IEC to develop standard open protocols for distributed generation equipment which will enable interoperability [8,9].

Another key requirement in many mini-grid control strategies is an energy storage system to balance power supply with power demand in the mini-grid to maintain stability. Task 11 is evaluating energy storage technologies that may be suitable for this application and has decided to assess the status of the following technologies

- Lead-acid batteries (baseline current technology)
- Lithium-ion batteries
- Redox flow batteries
- Supercapacitors
- Flywheels

7 Sustainability Conditions

Task 11 is using a case-study approach to study the social, economic and economic conditions required for sustainable operation of PV hybrid mini-grids [10]. A total of 36 system descriptions have been submitted by Task 11 countries as candidate case studies. The systems have a worldwide spread, with varying architectures, power ratings, and data availability. Task 11 is currently determining a short list (10 to 12) for in-depth case studies and, in parallel, determining the main indicators of social, economic, and environmental sustainability in order to assess the systems and extract the sustainability conditions.

8. References

- [1] IEA web-site: <http://www.iea.org/>
- [2] IEA PVPS web-site: <http://www.iea-pvps.org/>
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- [10] J.-C. Marcel, “IEA PVPS Task 11 (Hybrid System within Mini-Grid) Sub Task 40: Sustainability Conditions”, 4th European PV-Hybrid and Mini-Grid Conference, May 2008.