PV HYBRIDS IN MINI-GRIDS - NEW IEA PVPS TASK 11

Konrad Mauch[1], Georg Bopp[2], Michel Vandenbergh[3], Jean-Christian Marcel[4]
1. Task 11 Operating Agent, 2. Fraunhofer ISE, 3. ISET, 4. Transenergie

ABSTRACT

The International Energy Agency Photovoltaic Power System Executive Committee has launched a new Task 11: "PV Hybrid Systems within Mini-grids" for the period 2006-2011. This paper presents the goals and objectives of Task 11 and discusses the work plan and approach that is being used to achieve the objectives.

1. OVERVIEW AND BACKGROUND

The International Energy Agency (IEA) [1] carries out a comprehensive program of energy co-operation among its twenty four member countries. The European Commission also participates in the work of the Agency.

The IEA Photovoltaic Power Systems (PVPS) Implementing Agreement, one of the collaborative research and development agreements established within the IEA, conducts a variety of joint projects (called Tasks) in the applications of photovoltaic power systems.

The IEA PVPS Executive Committee recognized the need for a new Task to develop technology and application knowledge for larger PV hybrid systems interconnected by a local electrical distribution network – the mini-grid concept. Definition workshops were held in 2004 and 2005 and Task 11 officially began in 2006. The fourth Task 11 Experts Meeting was held in Fukuoka, Japan, in conjunction with PVSEC 17, on 29 November to 2 December, 2007.

2. TASK 11 WORK PLAN

2.1 Scope and Approach

The scope of Task 11 is PV based hybrid generators that combine PV with other electricity generators and also energy storage systems. A particular focus is on mini-grid systems in which energy generators, storage systems and loads are interconnected by a "stand-alone" AC distribution network with relatively small rated power and limited geographical area. The mini-grid concept has potential applications that range from village electrification in less developed areas to "power parks" that offer ultra-reliable, high quality electrical power to high tech industrial customers. These systems can be complex, combining multiple energy sources, multiple electricity consumers, and operation in both island (stand-alone) and utility grid connected modes.

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.

Task 11's work plan is divided into four subtasks and a number of detailed work activities on key aspects of PV hybrid and mini-grid technology and implementation.

2.2 Subtask 10 - Design Issues

Subtask 10 addresses PV hybrid system design practices. Tradeoffs have to be made between first cost, energy efficiency, and reliability. The correct choice of components and system architecture is critical. The task has the following three activities

- Review, analysis and documentation of current hybrid mini-grid system architectures
- Evaluation and comparison of system design methodologies and tools and development of guidelines for design tools
- Development of best practices for design, operation, and maintenance of PV hybrid projects

2.3 Subtask 20 - Control Issues

Subtask 20 addresses the need for new coordinating control mechanisms in hybrid mini-grids to maintain grid stability and to optimize the contribution of all generation sources. It has the following five activities

- Investigate existing methods for stabilizing voltage and frequency in mini-grids and develop new, improved methods if required
- Investigate data communication architectures and protocols for mini-grids
- Develop supervisory control parameters and strategies for mini-grids
- Evaluate the role of energy storage technologies to stabilize mini-grid operation
- Investigate technical issues associated with autonomous and interconnected operation of mini-grids and a main utility grid.

2.4 Subtask 30 - PV Penetration in Mini-Grids

Subtask 30 addresses the goal of increasing the use of the PV resource in PV hybrid systems and displacing fossil fuel resources. It has the following two activities

- Develop performance assessment criteria for PV hybrid systems that allows for objective comparison of different systems

- Develop recommendations to maximize the solar fraction in hybrid systems through demand side management, dispatch strategies and optimization of the battery energy storage system.

2.5 Subtask 40 - Sustainability Conditions

Subtask 40 addresses the social, political, economic, and environmental factors necessary for successful implementation of PV hybrid power systems within mini-grids. It has the following three activities

- Develop case studies that demonstrate the social and political framework for successful operation of PV hybrid systems within mini-grids
- Evaluate the financial aspects of PV hybrid power systems, considering both first costs and operating costs, and determine the conditions for economic sustainability
- Evaluate the environmental impacts and benefits of PV hybrid systems with focus on greenhouse gas emission mitigation and potential for recycling of system components

3. TASK 11 ORGANIZATION

3.1 Task 11 Management

Activities within Task 11 are carried out on a task-sharing basis among participating countries which appoint subject area experts to implement the work plan. An Operating Agent is responsible for overall coordination among subtasks and for coordination and communication with other IEA PVPS Tasks and the IEA PVPS Executive Committee. Each subtask has a leader who is responsible for coordination, scheduling and communication between activities. Activity leaders are responsible for planning, scheduling and coordinating the activities and for the production of the deliverable items.

3.2 Task 11 Participants

Currently there are expert participants from 12 IEA PVPS countries from Europe, the Americas, and the Asia-Pacific region. The participants represent PV hybrid system integrators, equipment manufacturers, research institutes, and universities. The participation of a wide range of countries and diverse organizations is one of the strengths of the IEA PVPS program and produces results that truly represent a consensus of expert knowledge and opinion.

4. EARLY RESULTS FROM TASK 11

4.1 Design Tools

Many software tools exist to assist in the design of PV hybrid systems [2] but they have different purposes and capabilities. Some are best suited for feasibility analysis, others for system sizing and design, and others for research into new system concepts. It can be difficult to assess which tool to use for a particular purpose.

Task 11 Subtask 10 on Design Issues has completed a survey of software design and simulation tools used by Task 11 participants. The survey questionnaire and subsequent analysis dealt with

- Tool availability (generally available or proprietary) and cost,
- Tool features and application area (e.g. feasibility analysis, system sizing and design, simulation)
- Characteristics and quality of user interface and documentation

Results were obtained for over 20 software tools. In addition to tools focused on PV hybrid systems, the survey also gathered information on tools for the design of distribution networks for mini-grids. The final outcome of the survey will be a report that provides an overview of available software tools and guidelines for the selection and use of the tools for particular applications.

4.2 Control of Mini-grids

Task 11 Subtask 20 on Control Issues has examined current PV hybrid mini-grid system architectures and has classified them into four categories for further study. 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 battery inverter connected to the mini-grid and therefore it does the grid forming.

The single switched master mini-grid architecture (see Figure 2) has multiple ac sources connected to the mini-grid (typically the battery inverter and a fossil fuel genset), but only one source at any time does the grid forming. In single master architectures, several battery inverters could be paralleled in a master-slave mode.

The multi-master rotating machine dominated mini-grid (see Figure 3) has multiple ac sources (fossil fuel gensets and PV inverters) connected to the mini-grid and simultaneously supplying power. The gensets do the grid forming and the PV inverters follow the mini-grid voltage and frequency.

The multi-master inverter dominated mini-grid (see Figure 4) is characterized by the coupling on the AC-bus of most power sources via inverters. The power sources can be distributed in the mini-grid (e.g. PV generators can be integrated in the roofs of different houses). Several grid forming units (like battery storage or rotating machines) could operate in parallel in a multi-master mode.

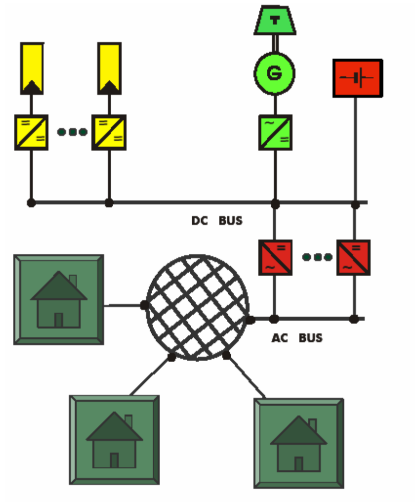

Fig. 1 Single fixed master mini-grid

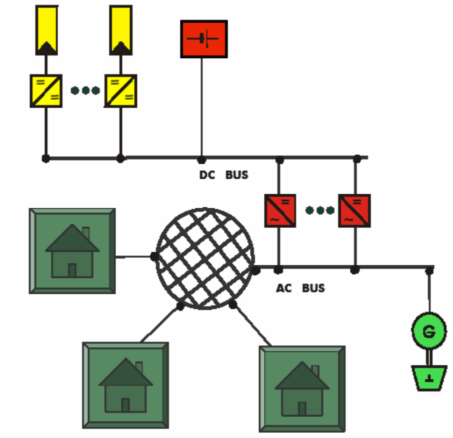

Fig. 2 Single switched master mini-grid

For each of these mini-grid architectures, Subtask 20 is studying the following issues

- Grid forming control techniques
- Power sharing among ac sources
- Control of PV generation
- Demand side management techniques to manage loads and limit fuel consumption
- Connection of the mini-grid to an external grid

The study for the multi-master inverter dominated technique is complete, based on systems and techniques developed by ISET [3,4,5,]. In the innovative concept developed by ISET, reactive power/voltage and active power/frequency droops are used for the power control of the inverters. The droops are similar to those in utility grids. The supervisory control just provides parameter settings for each component. Expensive control bus systems are not needed since the grid quantities, voltage and frequency, are used for co-ordination of the components. Such a structure results in the following features: (1) simple expansion of the system, (2) increased redundancy, as the system does not rely on a single grid forming unit, (3) a supervisory control or a grid code is required.

Work is now focusing on gathering information on the other architectures.

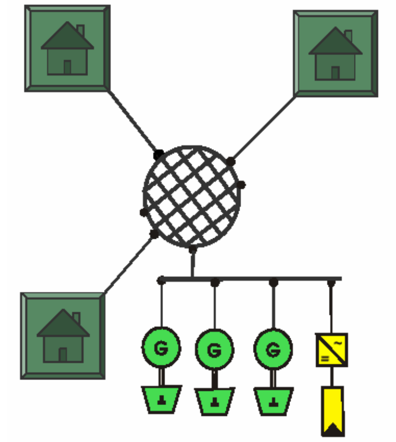

Fig. 3 Multi-master rotating machine dominated mini-grid.

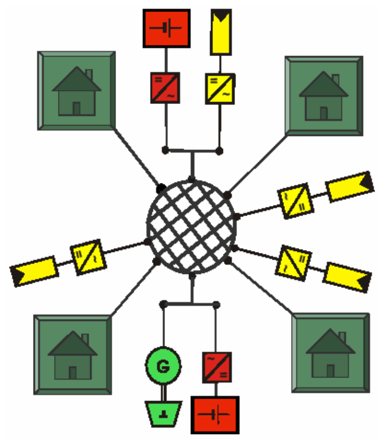

Fig. 4 Multi-master inverter dominated mini-grid

4.3 Sustainability Conditions

Task 11 Subtask 40 on Sustainability Conditions is using a case-study approach which will study the sustainability conditions for a number of PV hybrid mini-grid systems in locations around the world. The study is proceeding through the following steps:

1. Write and deliver a "light" case study template to all Task 11 participating countries to collect information on candidate PV hybrid mini-grid systems.
2. Produce a methodological tool to manage data collection and analysis with a focus on the social, financial, and environmental aspects of the systems,
3. Analyze the light case studies received from Task 11 participants and select a short list of « interesting » case studies for deeper analysis (considering the sustainability context),
4. Gather case study information using the tool developed in step 2,

5. Analyze the collected system data according to the 3 topics (social, financial, environmental) and summarize to highlight key issues and recommendations.
6. Prepare draft and final reports.

A total of 34 system descriptions using the light case study template have been submitted by Task 11 countries. The systems have a worldwide spread, with varying architectures, power ratings, and data availability.

The mix of energy sources (based on total capacity for all 34 systems) is:

- PV: 3 MWp
- Genset: 4 MVA
- Wind turbine: 180 kW
- Battery Storage: 86 kAh

Site locations are shown in Figure 5 and Figure 6 .

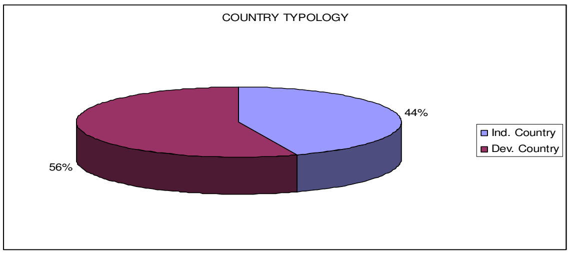

Fig. 5 Share of systems between industrialized countries and developing (emerging) countries

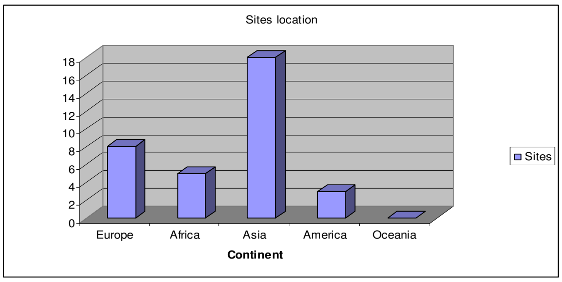

Fig. 6 Site location by continent

Using average values, the typical case study system has the following characteristics:

- PV: 87 kWp
- Genset: 110 kVA
- Wind turbine: 5 kW
- Batteries: 5 kAh
- Autonomy: 3 days
- Population served: 1500 inhabitants
- Installation date: 2002

Last but not least, 60% of these sites are monitored and have performance data available.

The next step is to select the short list of in-depth case studies (10 to 12) and, in parallel, to determine the main indicators of social, economic, and environmental sustainability in order to assess the systems and extract the sustainability conditions for the deliverable reports.

5. CONCLUSION

Mini-grid technology is being pursued in several OECD countries [6] with estimates that it will become viable in mainstream applications within five to ten years. However there are still open questions about technologies, principal justification (reliability of power delivery, integration of renewable energy sources at high penetration, diversification of energy supply, rural electrification), and business strategies for commercialization, with different countries pursuing different strategies. Task 11 plans to be a venue where the experiences of the national programs can be consolidated and best practices can be identified, which should reduce overlap in national programs and increase the probability that commercially viable mini-grids will arrive within the expected time frame. Task 11 will also be the champion for a significant PV fraction in the mini-grid energy mix.

Task 11 will disseminate its results through its Experts Meetings, technical papers, and reports. Official Task 11 reports will be available on the IEA PVPS web-site [7].

REFERENCES

[1] International Energy Agency web-site: http://www.iea.org/

[2] D. Turcotte, M. Ross, F. Sheriff, “Photovoltaic Hybrid Sizing and Simulation Tools: Status and Needs”, *Proceedings of PV Horizon: Workshop on Photovoltaic Hybrid Systems,* Montreal, September 2001.

[3] A. Engler, “ Device for equal-rated parallel operation of single or three-phase voltage sources”, (European patent: 02 018 526.26, US patent: 10/222,310, Japanese patent: 2002-240991)

[4] A.Engler, “Applicability of droops in low voltage grids”, *International Journal of Distributed Energy Resources*, Vol.**1** No.**1**, January-March 2005

[5] http://www2.sma.de/en/solar-technology/products/island-grids/sunny-island/index.html

[6] N. Hatziargyriou, H. Asano, R. Iravani, C. Marnay, “Microgrids : An Overview of Ongoing Research, Development, and Demonstration Projects” , *IEEE Power and Energy Magazine,* July/August, 2007.

[7] IEA PVPS web-site: http://www.iea-pvps.org/