IEA INTERNATIONAL ENERGY AGENCY

# Design and operational recommendations on grid connection of PV hybrid mini-grids

## Report of Activity 25, Subtask 20, Task 11

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

IEA-PVPS T11-06:2011

INTERNATIONAL ENERGY AGENCY
PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

# Design and operational recommendations on grid connection of PV hybrid mini-grids

IEA PVPS Task 11, Subtask 20, Activity 25
Report IEA-PVPS T11-06: 2011
October 2011

## Contents

## Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD) which carries out a comprehensive program of energy co-operation among its member countries. The European Commission also participates in the work of the IEA.

The IEA Photovoltaic Power Systems Program (PVPS) is one of the collaborative R&D Agreements established within the IEA. Since 1993, the PVPS participants have been conducting a variety of joint projects in the application of photovoltaic conversion of solar energy into electricity. The mission of the IEA PVPS program is: To enhance the international collaboration efforts which accelerate the development and deployment of photovoltaic solar energy as a significant and sustainable renewable energy option.

The IEA PVPS Program aims to realize the above mission by adopting four objectives related to reliable PV power system applications for the target groups of governments, electricity utilities, energy service providers and other public and private users.

1. To stimulate activities that will lead to a cost reduction of PV power systems applications.
2. To increase the awareness of PV power systems' potential and value and thereby provide advice to decision makers from government, utilities and international organizations.
3. To foster the removal of technical and non-technical barriers of PV power systems for the emerging applications in OECD countries.
4. To enhance co-operation with non-OECD countries and address both technical and non-technical issues of PV applications in those countries.

The overall program is headed by an Executive Committee composed of one representative from each participating country, while the management of individual research projects (Tasks) is the responsibility of Operating Agents. By mid 2010, thirteen Tasks were established within the PVPS program.

The overall goal of Task 11: "PV Hybrid Systems within Mini-grids" is to promote the role of PV technology as a technically relevant and competitive source in mini-grids. It aims at enhancing the knowledge-base of multi-source power generation systems including PV and associated electric distribution networks.

The objectives of the Task are to:

- define concepts for sustainable PV hybrid mini-grids taking into account local factors (specificity of the application, financing regimes, location, others);
- provide recommendations on individual designs (mix of technologies, architecture, size, performances, other) in order to achieve high penetration level of PV as a mean to improve quality, reliability and economics of electrification systems such as mini-grids;

- assess the potential of technologies to be mixed with PV for hybridisation; and,
- compile and disseminate best-practices on PV hybrid power systems.

The current members of the IEA PVPS Task 11 are:
Australia, Austria, Canada, China, France, Germany, Italy, Japan, Malaysia, Spain, and United States of America.

This report gives an overview of “interconnection and islanding issues”. The technical report has been prepared under the supervision of PVPS Task 11 by the following people:

As the author:
Ichiro Araki, GMG Corporation, JPN

As significant contributors:
Mr. Benjamin Kroposki, National Renewable Energy Laboratory (NREL), USA,
Mr. Christoph Mayr, Austrian Institute of Technology (AIT), AUT, and
the respondents to the questionnaire executed in the Activity.

The report expresses, as nearly as possible, the international consensus of opinion of the Task 11 experts on the subject dealt with. Further information on the activities and results of the Task can be found at: http://www.iea-pvps-task11.org and http://www.iea-pvps.org.

## Executive Summary


Task 11 is divided into four subtasks:

- Subtask 10 - Design Issues
- Subtask 20 - Control Issues
- Subtask 30 - PV Penetration in Mini-Grids
- Subtask 40 - Sustainability Conditions

Activity 25, is an activity of Subtask 20, and is concerned with interconnection and islanding issues. This report is on Activity 25.

Activity 25 concentrates on providing useful recommendations on the control method of connection and disconnection of a PV hybrid mini-grid to a main grid.

The following activities were performed in alignment with Activity 25:

a) Investigate control methods currently implemented at existing mini-grid sites (research questionnaire)
b) Research existing technical requirements for grid connection in Japan, Europe, and the United States
c) Consider the role of PV hybrid mini-grids in large-scale renewable energy deployments

Based on the results of these activities, this report proposes design and operational recommendations for grid connection and disconnection of a PV hybrid mini-grid to a main grid as follows.

In the case where a PV hybrid mini-grid connects to a main grid, designers, grid operators, and the other relevant stakeholders should consider the following issues in the initial stages of design to ensure power quality and power supply reliability:

1) **Compliance with existing rules on power quality and grid connection**.
The design should comply with the rules prescribed in existing regulations on power quality and grid connection.

2) **Implementation of additional countermeasures specific to the site**.
If specific factors related to the site include security risks, power quality issues, and other reliability concerns, then necessary technical countermeasures should be added to the initial design, based on consensus of the stakeholders.

3) **Awareness of current standards developments.**
There are many activities in various regions of the world that aim to establish, revise, and unify standards focused on power supply quality at high penetration levels of renewable energy. Research and development is being conducted in the field to assist standards development. Stakeholders should stay current with these activities.

## 1. Scope and objective

The role of Activity 25 was defined as follows:

- **Theme:** Interconnection and islanding issues
- **Method/Approach:** To investigate technical constraints and solutions due to connection and disconnection of a PV hybrid mini-grid to a main grid.
- **Description of Work:**
    - o Research existing regulations and guidelines to design and operate connection interfaces.
    - o Investigate the potential technical problems and possible solutions that may exist in the following situations:
        - Connection of a PV hybrid mini-grid to a main grid
        - Connection and disconnection of a PV hybrid mini-grid to a main grid
        - Connection of a cluster of PV hybrid mini-grids to a main grid
    - o Reliability, stability, quality, and safety issues.
    - o Sample solutions in the laboratory.
    - o The work focused on methods that guarantee smooth operation of the connected systems, utilizing all the potential advantages of this type of system design under all contingences and different modes of operation.
- **Target Audience of the Report**: Utilities, system integrators, manufacturers, infrastructure planners

In summary, the purpose of Activity 25 was to provide useful recommendations for control methods of connection and disconnection of a PV hybrid mini-grid to a main grid.

The following activities were performed in alignment with Activity 25:

a) Investigate actual control methods in existing mini-grid sites (research questionnaire)
b) Research existing technical requirements for grid connection in Japan, Europe, and the United States
c) Consider the role of PV hybrid mini-grids in large-scale renewable energy deployment

Based on the results of these activities, this report provides design and operational recommendations for grid connection and disconnection of a PV hybrid mini-grid to a main grid, although the recommendations are not so useful as we intended.

# 2. Investigation of control methods currently implemented at existing mini-grid sites

## 2.1 Sites investigated

### 2.1.1 Concept of site selection

Site selection was conducted according to the following four criteria:

1) **The site should provide useful information.**
   "Useful information" indicates that there is a certain reliability factor in the information provided, for example, information backed up by statistical figures, measured data, and practiced methodology. It does not matter whether the site is fully operational or in a design stage. It is important, however, that the responder to the questionnaire is willing to fill out the questionnaire and has a good understanding of Task 11's mission.

2) **Grid connection is not a necessary condition**.
   The information from autonomous sites is assumed to be useful for such similar sites where grid connection may be necessary in future.

3) **Renewable energy mini-grids without PV can be included**.
   The information of grid connection on sites where the renewable energy component is not PV is assumed to be useful for Activity 25.

4) **The site information should be easily accessible to the public.**
   In order to satisfy reader's inquiries or further investigation, site selection should be limited to those whose information is easily accessible to the public.

### 2.1.2 Sites selected for questionnaire research

With consideration of the above criteria, site selection resulted in mainly the sites presented at the 4$^{th}$ European Conference, PV-Hybrid and Mini-Grid, including Kythnos 2008 Symposium and NEDO (Japan) related sites.

A list of the selected sites is shown in Annex 1, where the site code related to regional classification is included for each site for convenience of adding and deleting works. The total number of sites selected reached more than 40 at the planning stage of the research.

## 2.2 Questionnaire content and result

### 2.2.1 Content of questionnaire

The desired outcome and corresponding questionnaire items were prepared as shown in Table 1. Please see Annex 2 for the actual questionnaire.

**Table 1. Desired outcome and corresponding question items prepared**

| Desired Outcome | Corresponding questionnaire items |
|---|---|
| To make the site information traceable. | • Literature or website to be referred to regarding the mini-grid. |
| To make the mini-grid system configuration clear at a glance. | • The system components itemized.<br>• A single line diagram, i.e. a schematic drawing showing voltages and facilities. |
| To get the information of the rules of power quality and laws, standards, guidelines, etc. on which they are based. | • The rules of power quality at the site and laws, standards, guidelines, etc. on which they are based.<br>• Sequences in case of power quality violation. |
| To get the information of measures for power quality stability in case of connection / disconnection. | • Measures for power quality stability in case of connection/disconnection, at present & in future. |
| To get the information of sequences on disconnection, reconnection, etc. after islanding detection. | • Detection method of islanding.<br>• After islanding detection, operation-stop? or switchover to islanding operation?<br>• Definition of the main grid return and sequences after it. |
| To get the information of the rules of reverse power flow. | In case reverse power flow is not allowed:<br>• Detection method of reverse power flow and the sequences after detection.<br>In case reverse power flow is allowed:<br>• Existence of money transaction contract, including selling electricity by a price, paying service fee, etc. |
| To get the opinion of sites stakeholders on interconnection (*). | • The primary obstacles against active interconnection and the methods to overcome them. |

(*) Interconnection means the mini-grid is not a slave to the main grid but the two are cooperative with each other in maintaining an acceptable voltage level in case of a grid voltage dip.

### 2.2.2 Results of questionnaire

The questionnaire research was conducted from December, 2008 to March, 2010. Answers were received from 16 out of 46 sites planned as shown in Table 2. The questionnaire response rate was 16/46, that is, 35%.

**Table 2. Regional account of sites for questionnaire research**

| Region | Site code | Number of sites planned | Number of sites answered |
|---|---|---|---|
| Asia | AS- (Serial Nos.) | 22 | 13 |
| Oceania | OC- (Serial Nos.) | 3 | 0 |
| North America | NA- (Serial Nos.) | 5 | 1 |
| South America | SA- (Serial Nos.) | 1 | 0 |
| Africa | AF- (Serial Nos.) | 4 | 1 |
| Europe | EU- (Serial Nos.) | 11 | 1 |
| | **Total** | **46** | **16** |

A management list of questionnaire answers is shown in Table 3, where the segmentation of autonomous / grid connected and the composition of facilities are also indicated. Each questionnaire received is posted in the Public Downloads section of the Task 11 website [1].

**Table 3. Management list of questionnaire answers**

| Site code | Location, "Site name" | A/G (*1) | Composition of facilities | File name of each questionnaire, stored in [1] |
|---|---|---|---|---|
| AS-1 | Miyako-island, JPN | A | DG(*2)+PV(750kW)+B(*3) | Act25-AS01-Miyako.pdf |
| AS-2 | Noyon Sum, Mongolia | A | DG+PV(200kW)+BT | Act25-AS02-Noyon Sum.pdf |
| AS-3 | XingXingXia (Shinjang Uyghur Autonomous Region), CHN | A | DG+PV(70kW)+BT | Act25-AS03- XingXingXia.pdf |
| AS-4 | Chaungthar, Myanmar | A | DG+PV(80kW)+WT (40kW)+BT+BL(*4) (Ice making machines) | Act25-AS04- Chaungthar Village.pdf |
| AS-5 | Ko Libong, Thailand | G | DG+PV(85kW)+BT | Act25-AS05-Libong.pdf |
| AS-6 | Hachinohe City, JPN, " Regional Power Grid with Renewable Energy Resources: A Demonstrative Project in Hachinohe" | G | BGE(*5)+PV(130kW)+WT (20kW)+BT | Act25-AS06-Hachinohe.pdf |
| AS-7 | Kyotango City, JPN, "Kyoto Eco-Energy Project (KEEP)" | G | GE(*6)+MCFC+PV (50kW)+WT(50kW)+BT | Act25-AS07-Kyoto.pdf |
| AS-9 | Ota City, JPN, "Pal Town Jyosainomori" | G | [PV(3-5kW)+BT] ×553 houses | Act25-AS09-Ota.pdf |
| AS-10 | Sendai City, JPN, "Sendai Project" | G | GE+MCFC+PV(50kW) | Act25-AS10-Sendai.pdf |
| AS-11 | Tokyo Gas Yokohama, JPN | G | GE+BGE+PV(10kW)+WT (12kW)+BT | Act25-AS11-Tokyo Gas.pdf |
| AS-12 | Wakkanai City, Japan, "Wakkanai Site" | G | PV(5MW)+BT | Act25-AS12-Wakkanai.pdf |
| AS-13 | Hokuto City, Japan, "Hokuto Site" | G | PV(2MW) | Act25-AS13-Hokuto.pdf |
| AS-22 | Pulau Kapas, Malaysia | A | DG+PV(100kW)+BT | Act25-AS22-Kapas.pdf |
| NA-4 | Nemiah Valley, CAN | A | DG+PV(27kW)+BL(*4) (Dump Load) | Act25-NA04-Nemiah Valley.pdf |
| AF-4 | Nelson Mandela Educational Centre, Ruanda | G | PV(30kW)+BT(1000Ah) | Act25-AF04-NMEC.pdf |
| EU-11 | Kassel, DEU | G | PV(103kW)+BT | Act25-EU11-ISET_Multipv.pdf |

(*1) A: autonomous, G: grid connected, (*2) DG: diesel engine generator, (*3) BT: battery, (*4) BL: ballast load, (*5) BGE: bio-gas engine generator, (*6) GE: gas engine generator

## 2.3 Summary of questionnaire research

### 2.3.1 Significance of questionnaire research

Despite the low response rate, the questionnaire research conducted was significant from the following viewpoints:

a) It revealed the questionnaire research methodology related to:
   - Concept of site selection, including resulting site selection (See chapter 2.1.1. and Annex 1)
   - Design of questionnaire content (See chapter 2.2.1. and Annex 2.)

b) It let the respondents of the questionnaire become aware of Task 11 activities and the research benefits.

### 2.3.2 Questionnaire analysis

An analysis was conducted on the answers received from each viewpoint listed below:

- Regulations adopted
- Islanding or power quality anomaly detection methods and their countermeasures
- Opinions on issues surrounding interconnection or intentional islanding

#### 2.3.2.1 Regulations adopted

All the respondents indicated that rules exist on site (autonomous or grid connected) dedicated specifically to stability of power quality. The systems were designed and operate with conformity based on the rules shown in Table 4.

**Table 4. Regulations adopted (Analysis of the answers)**

| Site code | Country | A/G (*1) | Regulations adopted |
|---|---|---|---|
| AS-1 | JPN | A | The Act (*2), Voluntary control standard of Okinawa Electric Power Company, Inc., The Guideline (*3) |
| AS-2 | MNG | A | Electric supply guideline, etc. of a local electric power company. |
| AS-3 | CHN | A | GB/T 12325-2003, GB/T 15945-1995<br>(GB: Guojia Biaozhun, Chinese National Standard) |
| AS-4 | MMR | A | Guidebook of New Energy Resources – Introductory Course (NEDO), The guideline (1998), etc. |
| AS-5 | THA | G | System Management Criteria of Province Electricity Authority |
| AS-6 | JPN | G | The Act (*2), The Code (*4), The Harmonics Guideline (*5), JEMA 1354 (*6) |
| AS-7 | JPN | G | The Act (*2), The Code (*4), The Harmonics Guideline (*5) |
| AS-9 | JPN | G | The Act (*2), The Code (*4), The Harmonics Guideline (*5) |
| AS-10 | JPN | G | The Act (*2) |
| AS-11 | JPN | G | The Act (*2), The Harmonics Guideline (*5) |
| AS-12 | JPN | G | The Guideline (*3), The Code (*4), The Harmonics Guideline (*5) |
| AS-13 | JPN | G | The Guideline (*3) |
| AS-22 | MYS | A | EN 50160, EN 61000-2-2 |
| NA-4 | CAN | A | IEC 61000 |
| AF-4 | Rwanda | G | VDE 0126 |
| EU-11 | DEU | G | EN 50160, EN 61000 |

(*1) A: autonomous, G: grid connected
(*2) The Electricity Business Act [2] and Article 44 of the Enforcement Regulation of it [3], Japan
(*3) Technical requirements guideline of grid interconnection to secure electricity quality (2004) [4], Japan
(*4) Grid Interconnection Code (JEAC 9701-2006) [5], Japan
(*5) Harmonics restraint guideline for HV or SHV consumers [6], Japan
(*6) Regulation of phase unbalance, Japan

#### 2.3.2.2 Islanding or power quality anomaly detection methods

Table 5 shows the data arranged from the viewpoint of detection methods and countermeasures of islanding in grid connected sites or power quality anomaly in autonomous sites.

Key findings include:
- Various methods are adopted depending on purposes and situations dedicated to each site.
- Five sites (AS-6, AS-11, AS-22, AF-4, EU-11) are equipped with switchover function to islanding operation after islanding detection, some are under trial mode, and others are under practical mode.

**Table 5. Analysis of islanding or power quality anomaly detection methods**

| Site code | Country | A/G (*1) | Islanding (G) / Power quality anomaly (A) detection methods | Countermeasures after detection |
|---|---|---|---|---|
| AS-1 | JPN | A | OVR / UVR / OFR / UFR | Control of the output of DG and charge / discharge of BT.<br>If the method is insufficient;<br>the electricity supply is changed to utility grid. |
| AS-2 | MNG | A | Active / Passive detection of each inverter | Grid inverters stop and self-contained inverters switchover to islanding operation. |
| AS-3 | CHN | A | OVR / UVR / OFR / UFR | Control of the output of DG &PVs and charge / discharge of BT |
| AS-4 | MMR | A | OVR / UVR / OFR / UFR | BL and electricity limiter control depending on the output of DG |
| AS-5 | THA | G | ACB of the diesel power plant opens, or all diesel generators shut down. | Operation stop |
| AS-6 | JPN | G | Active / Passive detection of each generator and disconnection of the parallel CB | Normally operation stop, experimentally islanding operation |
| AS-7 | JPN | G | Active / Passive detection | Operation stop |
| AS-9 | JPN | G | Active / Passive detection of each inverter and a newly developed islanding detecting unit for clustered connection of PVs. | Operation stop |
| AS-10 | JPN | G | UVR / OFR / UFR | Islanding operation |

| Site code | Country | A/G (*1) | Islanding (G) / Power quality anomaly (A) detection methods | Countermeasures after detection |
|---|---|---|---|---|
| AS-11 | JPN | G | Active / Passive detection | Normally operation stop, experimentally Islanding operation |
| AS-12 | JPN | G | OFR / UFR | Operation stop |
| AS-13 | JPN | G | Active / Passive detection | Operation stop |
| AS-22 | MYS | A | OVR / UVR / OFR / UFR | Islanding operation |
| NA-4 | CAN | A | Power flow from gensets to be less than 1kW. | Connection of a dump load (*2) |
| AF-4 | Rwanda | G | VDE 0126 | Islanding operation |
| EU-11 | DEU | G | Impedance measurement | Islanding operation |

(*1) A: autonomous, G: grid connected.
(*2) Connection of a dump load for 1 second triggering disconnection of inverters due to perturbation of the voltage / frequency characteristics of the grid.

#### 2.3.2.3 Opinions on issues surrounding interconnection or intentional islanding

Table 6 is a summary of opinions gathered from each questionnaire relating to interconnection or intentional islanding.

**Table 6. Summary of opinions surrounding interconnection and intentional issues**

| Site code | Country | A/G (*1) | Responses |
|---|---|---|---|
| AS-2 | MNG | A | Existing functions:<br>• In case of DGs' out of order, the bi-directional inverters in the power center can supply the initial start voltage to DGs.<br>• In case of PV + batteries out of order, UPS can supply the initial start voltage to DGs.<br>Future issues:<br>• It is not clear what kind of method is suitable for the optimal demand control.<br>• It is not clear how much capacity of hybrid mini-grids is suitable when they are connected to an existing grid. |
| AS-5 | THA | G | • In the case of installing PV systems with comparatively big capacity in regard to grid capacity, it is necessary to absorb output fluctuation with the battery to prevent bad effects on electrical quality, but lead-acid batteries remain expensive.<br>• Development of batteries with low price and easy maintenance will be required. |

| Site code | Country | A/G (*1) | Responses |
|---|---|---|---|
| AS-6 | JPN | G | It seems very difficult for the mini-grid side to supervise the voltage adjustment on the situation of grid voltage under present arrangements where electricity rates are related to the power factor at receiving points. |
| AS-7 | JPN | G | • The balance of demand and supply is controlled by the battery.<br>• We assume the most important problem will be the transient behavior in the following switchovers:<br>o grid connection state to islanding operation state<br>o islanding operation state to grid connection state<br>• To realize a switchover without load dropping-out and power resource dropping-out, the following technologies should be established:<br>o switchover with high speed or no instantaneous breaking<br>o confirmation of synchronization of voltage and frequency (phase) |
| AS-10 | JPN | G | In case the major grid connected power sources are stationary, it should be considered what extent of ride through should be taken when an instantaneous grid voltage dip occurs. |
| AS-11 | JPN | G | • The following matters are assumed as cooperative actions:<br>o demand response utilizing reserve capability of non-utility generators<br>o cooperation to grid voltage control by way of reactive power control at demand side<br>However, it takes a long time to realize the above matters because:<br>o recognition and agreement of electric power companies is necessary<br>o handling method of consideration of the cooperation must be decided<br>• The solution may be a round-table conference where electric power companies also participate, verification tests, some incentives from the country and so on. |
| AS-22 | MYS | A | • Technically need to use grid inverter.<br>• There is no feed-in tariff. |
| EU-11 | DEU | G | • Battery prices and DC metering for a bi-directional AC/DC converter. |

(*1) A: autonomous, G: grid connected.

# 3. Investigation of existing technical requirements for grid connection

## 3.1 Japan

For the most part, the technical requirements for grid connection in Japan are common throughout the country, with three main regulations that are followed:

- Technical Requirements Guideline of Grid Interconnection to Secure Electricity Quality [4]
- Grid interconnection Code [5]
- Harmonics Restraint Guideline for HV or SHV Consumers [6]

### 3.1.1 Basic requirements for grid interconnection

The most basic of the three regulations, “Technical Requirements Guideline of Grid Interconnection to Secure Electricity Quality,” was enacted in 2004 [4] by the Agency for Natural Resources and Energy in the Japanese government to make clear the requirements for grid connection of distributed power resources.

According to the introductory document [7]:

- Technical requirements exist in the guide for generation facilities connecting to each distribution line, i.e., LV(<600V) / HV(600 – 7kV) / SNW (Spot Network) / SHV(>7kV).
- The actual detailed rules at each grid connection site are decided through mutual agreement between the operators of the connected side and the operators of the connecting side, based on the guidelines set forth.

Table 7 shows a list of the guideline’s requirements.

**Table 7. Outline of the technical requirements guideline of grid interconnection to secure electricity quantity in Japan (extracted from [7].）**

**(■: applied. －: not applied.)**

| Item | | Technical requirements | LV | HV | SNW | SHV |
|---|---|---|---|---|---|---|
| Power factor | In case reverse power flow is permitted. | Principle: ≥85%, and Not to be advanced from the main grid. Exception (*1) | ■ | ■ | － | － |
| | | To be such value as to keep the main grid voltage appropriate. | － | － | － | ■ |
| | In case reverse power flow is forbidden. | Principle: ≥85%, and Not to be advanced from the main grid. | ■ | ■ | ■ | ■ |
| | | Exception (*2) | ■ | | | |

| Item | | Technical requirements | LV | HV | SNW | SHV |
|---|---|---|---|---|---|---|
| Automatic load reduction | | In case overload occurrence of the power line or the line transformers is assumed due to the power sources dropping out, →To reduce the load automatically. | — | ■ | ■ | ■ |
| | | Special requirement to SHV, ≥100kV (*4) | — | — | — | ■ |
| Normal voltage fluctuation | Measures against voltage rise due to reverse power flow | In case voltage deviation from the appropriate voltage range of LV receivers is assumed due to reverse power flow, →To adjust the voltage automatically using an advanced VAR controller or an output controller. (If the measure is inapplicable, to reinforce the distribution line.) Exception in small-capacity inverters (*3) | ■ | — | — | — |
| | | In case voltage deviation from the appropriate voltage range of LV receivers is assumed due to reverse power flow, →To adjust the voltage automatically. (If the measure is inapplicable, to reinforce the distribution line, or to adopt grid connection using an exclusive line.) | — | ■ | — | — |
| | Measures against voltage dip due to power sources dropping out, etc. | In case voltage deviation from the appropriate voltage range of LV receivers is assumed due to power sources dropping out, etc., →To reduce the load automatically. (If the measure is inapplicable, to reinforce the distribution line, or to adopt grid connection using an exclusive line.) | — | ■ | — | — |
| | | In case voltage deviation from approx. 1 to 2% of normal voltage is assumed due to power sources dropping out, etc., →To reduce the load | — | — | ■ | — |

| **Item** | | | **Technical requirements** | **LV** | **HV** | **SNW** | **SHV** |
|---|---|---|---|---|---|---|---|
| | | | automatically. | | | | |
| | | | In case voltage deviation from approx. 1 to 2% of normal voltage is assumed due to power sources dropping out, etc.,<br>→To adjust the voltage automatically. | — | — | — | ■ |
| Instantaneous voltage fluctuation | Synchronous generator | | To use the one attached with damping windings or the same anti-hunting performance equal to or more than them. And to furnish with an automatic synchronism indicator. | ■ | ■ | ■ | ■ |
| | Induction generator | | In case voltage deviation from more than 10% of normal voltage is assumed due to voltage sag at connecting,<br>→To furnish with a current limiting reactor, etc. (If the measure is inapplicable, to adopt a synchronous one.) | ■ | ■ | ■ | — |
| | | | In case voltage deviation from more than approx. 2% of normal voltage is assumed due to voltage sag at connecting, →To furnish with a current limiting reactor, etc. (If the measure is inapplicable, to adopt a synchronous one.) | — | — | — | ■ |
| | Inverter | Self-excited | To have automatic synchronizing function. | ■ | ■ | ■ | ■ |
| | | Separate-excited | In case voltage deviation from more than 10% of normal voltage is assumed due to voltage sag at connecting,<br>→To furnish with a current limiting reactor, etc. (If the measure is inapplicable, to adopt a self-excited one, or to reinforce the distribution line.) | ■ | — | — | — |
| | | | In case voltage deviation from more than 10% of normal | — | ■ | ■ | — |

| Item | | | Technical requirements | LV | HV | SNW | SHV |
|---|---|---|---|---|---|---|---|
| | | | voltage is assumed due to voltage sag at connecting, →To furnish with a current limiting reactor, etc. (If the measure is inapplicable, to adopt a self-excited one.) | | | | |
| | | | In case voltage deviation from more than approx. 2% of normal voltage is assumed due to voltage sag at connecting, →To furnish with a current limiting reactor, etc. (If the measure is inapplicable, to adopt a self-excited one.) | — | — | — | ■ |
| | Wind turbine generator | | In case a bad influence on others is assumed due to voltage fluctuation (flicker, etc) caused by output power fluctuation or frequent connection / disconnection, →To do the measures for reducing voltage fluctuation (flicker, etc.). (If the measure is inapplicable, to reinforce the distribution line, or to adopt grid connection using an exclusive line.) | ■ | ■ | — | — |
| | | | In case a bad influence on others is assumed due to voltage fluctuation (flicker, etc) caused by output power fluctuation or frequent connection / disconnection, →To do the measures for reducing voltage fluctuation (flicker, etc.). (If the measure is inapplicable, to reinforce the transmission line, or to adopt grid connection using an exclusive line.) | — | — | — | ■ |
| Prevention of unneeded disconnection | Measures depending on time of voltage dip | | In case the voltage dip time is less than the setting time of UVR, →To keep connection or to restart operation automatically without disconnection. | ■ | — | — | — |

| Item | | Technical requirements | LV | HV | SNW | SHV |
|---|---|---|---|---|---|---|
| | | In case the voltage dip time is more than the setting time of UVR, →To disconnect. | | | | |
| | Voltage dip due to accidents, etc of the grid connected | To open the network protection circuit breaker of the troubled line, to keep connection with the sound line, and not to disconnect the power sources. | — | — | ■ | — |
| | Voltage dip due to accidents, etc of other grids than the one connected | To keep connection. | — | — | ■ | — |
| | | Not to disconnect in principle. In case of disconnection, to disconnect by RPR, LPR, etc., with such a setting time as to be less than the automatic circuit closing and to be able to avoid unneeded disconnection of the power sources due to transient power fluctuation. | — | ■ | — | ■ |
| Islanding | In case reverse power flow is permitted. | Islanding is forbidden. | ■ | ■ | ■ | — |
| | | Islanding is applicable in principle with furnishing with OFR and UFR, or with a telecommunication circuit breaker. | — | — | — | ■ |
| | In case reverse power flow is forbidden. | Islanding is forbidden. | ■ | ■ | ■ | — |
| | | Islanding is forbidden. To furnish with OFR and UFR to prevent islanding. In case those relays are assumed insufficient, to furnish with RPR. | — | — | — | ■ |
| Generator operation controller | | Special requirement to SHV, ≥100kV (*5) | — | — | — | ■ |
| Communication system (Guideline on a communication facility between the grid side and the power resources side) | | To furnish with a telephone facility for security communication (A telephone line for only security communication use or an exclusive telephone line served by a telecommunications company). In case of ≤35kV, able to furnish with a landline | ■ | ■ | ■ | ■ |

| Item | Technical requirements | LV | HV | SNW | SHV |
|---|---|---|---|---|---|
| | or a cellular phone line commonly installed. | | | | |
| | Special requirement in case of SHV, ≥60kV with reverse power flow being permitted. (*6) | — | — | — | ■ |

**<Notes>**

(*1) Exception of power factor restriction in case reverse power flow is permitted

- In case unavoidable for preventing voltage rising,
  → The power factor at the receiving point can be ≥80%.
- In case the power factor at the receiving point is assumed so appropriate as in the case of using a small-capacity inverter, ≤2kVA(1P-2L), or ≤6kVA(1P-3L), or ≤15kVA(3P-3L), or in the case of ordinary residential load,
  → If the power factor of the power sources are controlled by reactive power, the power factor of the power sources can be ≥85%. Otherwise, ≥95%.

(*2) Exception of power factor restriction in case reverse power flow is forbidden

- In case the power resources are connected to the main grid through inverters,
  → The power factor of the power sources can be ≥95%.

(*3) In the case of using a small-capacity inverter, ≤2kVA(1P-2L), or ≤6kVA(1P-3L), or ≤15kVA(3P-3L),
→ Able to omit advanced reactive power control function or output power control function.

(*4) In the case of connection with SHV, ≥100kV, in principle,
→To reduce power generation according to the signal from OLR furnished by the main grid according to necessity.

(*5) In the case of connection with SHV, ≥100kV, in principle,
→To furnish with a generator operation controller.
(A generator operation controller has such functions as synchronizing, load dispatch, constant power factor, constant voltage, constant frequency, and so on.)

(*6) In the case of SHV, ≥60kV with reverse power flow being permitted,
→To furnish with a Supervision (SV) and a Tele-meter (TM).

<u>Information to be transmitted by a SV</u>

1) Necessary to understand grid condition and to secure safety of work.
   - On/Off of circuit breakers of generators' connection
   - On/Off of circuit breakers and disconnecting switches of grid connection
   - On/Off of line earth switches of grid connection
   - On/Off of circuit breakers and disconnecting switches of bus lines and transformers
2) Necessary to understand condition of protective functions prescribed in the guide line and to make sure of power supply orders

- Status of changeover switches of protective relays of lines and bus lines

3) Necessary to understand the situation of a trouble and to recover it quickly
    - Status of protective relays of lines and bus lines

Information to be transmitted by a TM

- Voltage of bus lines at service entrances
- Generators' total active power and reactive power
- Active power and reactive power at service entrances
- Active electric energy supplied and received at service entrances

### 3.1.2 Switchover to self-contained operation in LV connection

Another important regulation is Section 2.2.5, "Disconnection Points in LV Connection", of the Grid Interconnection Code (JEAC9701-2006) [5] established by Japan Electric Association (JEA). The summary [8] of Section 2.2.5, prescribing what the disconnection points should be in case of LV connection, indicates which cases permit the generation system connected to LV networks to switchover to self-contained operation and what control functions are required for the switchover.

The regulations on disconnection points, if that grid connection is realized via an inverter, calls for grid connection protective facilities separately installed to allow self-contained operation as shown in Table 8, with Figure 1.a, Figure 1.b.1, Figure 1.b.2, and Figure 1.b.3.

**Table 8. Countermeasures in case of Inverters-Separated grid connection protective facilities, self-contained operation intended (extracted from [8].)**

| Countermeasures (Either countermeasures, a) or b) should be taken.) | Reference figures |
|---|---|
| a) To install 2 mechanical disconnection points or to install 1 mechanical disconnection point and 1 manual disconnection point. | Figure 1.a |
| b) To install one mechanical disconnection point and to furnish with the all following mechanisms. | |
| 1) Preventive mechanism from misconnection during grid outage<br>To inhibit connection of the generation facility during grid outage (grid voltage=0). | Figure 1.b.1 |
| 2) Preventive mechanism from switchover to self-contained operation in case of failure of the mechanical disconnection point<br>In case of grid outage and so on, to inhibit switchover to self-contained operation in the state that the generation facility stops with the inverter gate-blocked and with the disconnection point closed. | Figure 1.b.2 |
| 3) Preventive mechanism from asynchronous connection in case of grid return<br>In case grid returns during self-contained operation, to inhibit connection of the generation facility unless the inverter once stops. | Figure 1.b.3 |

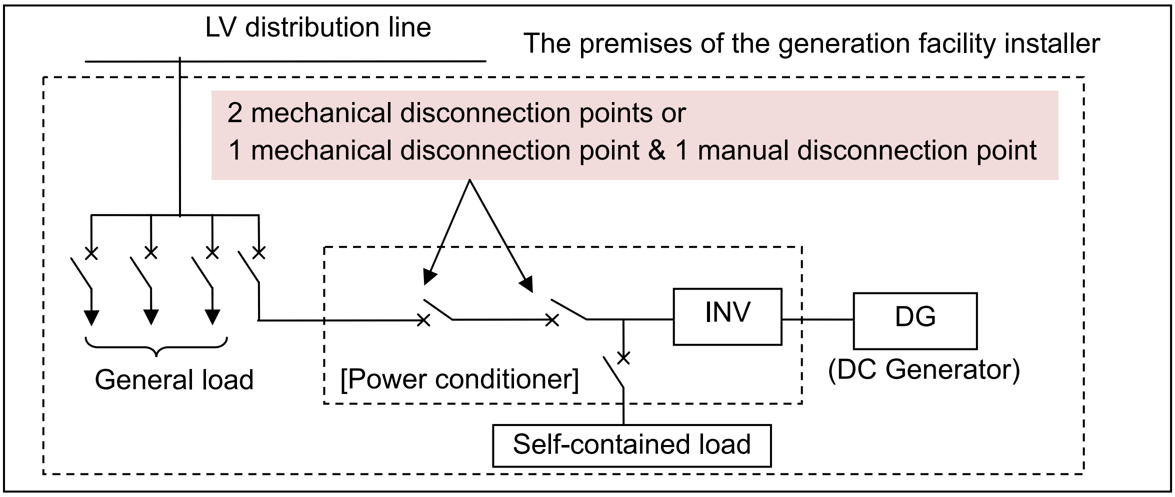



**Figure 1.a - An example of 2 mechanical disconnection points or one mechanical disconnection point and one manual disconnection point**

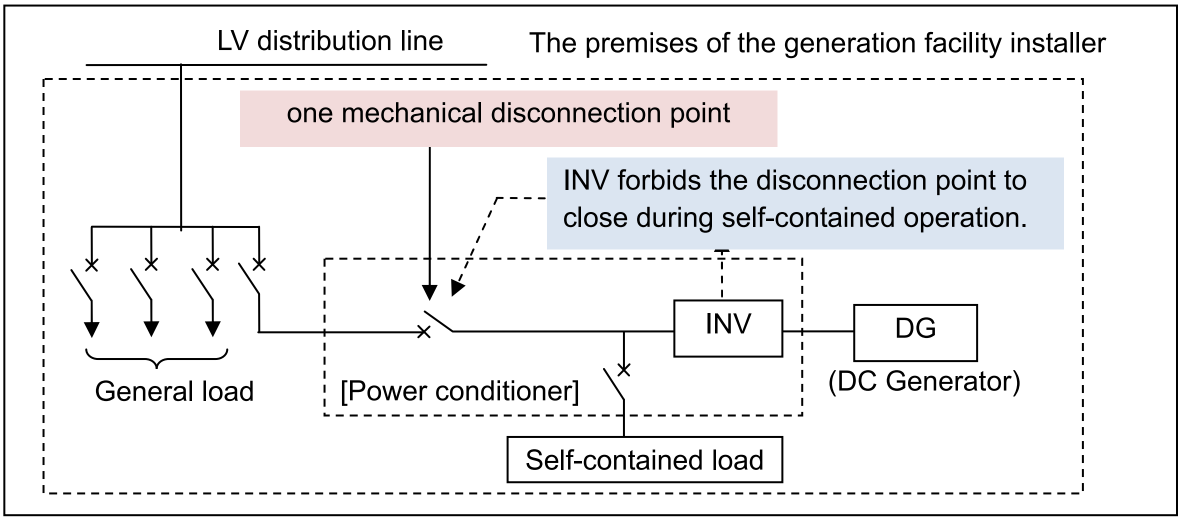



**Figure 1.b.1 - An example of preventive mechanism from misconnection**

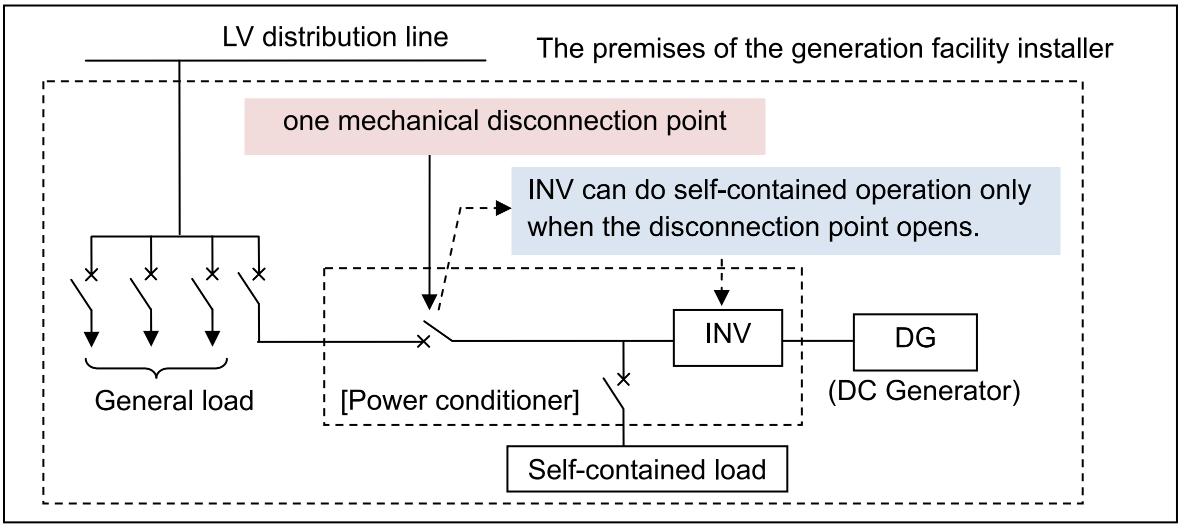



**Figure 1.b.2 - An example of preventive mechanism from switchover to self-contained operation in case of failure of the mechanical disconnection point**

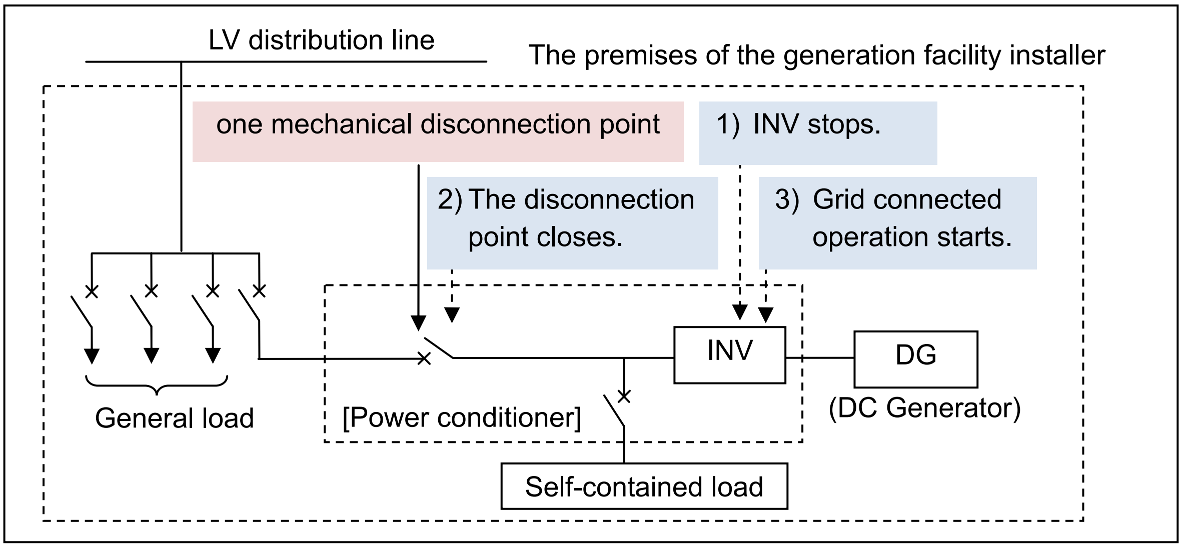



**Figure 1.b.3 - An example of preventive mechanism from asynchronous connection in case of grid return**

### 3.1.3 Harmonic restraint countermeasures for HV or SHV

The third regulation, "Harmonics Restraint Guideline for HV or SHV Consumers" [6] was enacted in 2004 by Nuclear and Industrial Safety Agency of METI, Ministry of Economy, Trade and Industry of Japan. According to the summary [9], the guideline requires HV / SHV connected generation facilities to take countermeasures to reduce harmonic outflow current below prescribed values, that is, below 5% in 6.6kV distribution lines and below 3% in special high voltage lines.

## 3.2 Europe

### 3.2.1 EDIS Proposed by DERlab

Existing regulations on distributed energy resource (DER) connections to grids in Europe are problematic. First, the regulations on DER connections vary according to the country, that is, a combined "European" standard does not exist. Second, these country-specific regulations on grid connection vary from regulation to regulation. Ultimately, these problems contribute to high DER installation costs in Europe.

Consequently, action is being taken to develop more consistent and harmonized European grid connection regulations. The European Distributed Energy Resources Laboratories (DERlab), made up of 11 European countries (DEU, GBR, NLD, ESP, DNK, AUT, GRC, ITA, FRA, BGR, POL) is developing requirements and quality criteria for the connection and operation of distributed energy resources. In 2008 DERlab published "Deliverable 2.1" [10] as a result of DERlab activities.

According to the summary [11] of “Deliverable 2.1”:

- Analysis of current interconnection requirements in 11 European countries participating in DERlab was performed for the purpose of proposing the European Standard for Interconnection of Distributed Energy Resources (EDIS).
- DERlab has contributed to DER relevant standardization activities on the European level, such as, the draft European standard prEN50438 and the setting up of CENELEC TC8X WG3.
- Based on those results, a draft structure of EDIS was proposed in the report.

Table 9 shows the draft structure of EDIS proposed by DERlab.

**Table 9. Draft structure of EDIS (extracted from [11].)**

| | | | | |
|---|---|---|---|---|
| **Part 0** | Recommended procedure for interconnection of DER (informative) | | | |
| **Part 1** | Interconnection requirements (normative) | | | |
| | **Section 1** | Micro scale DER | LV (<1kV) connected | < 5kW / <16A per Ph. |
| | **Section 2** | Intermediate scale DER | LV (<1kV) connected | > 5kW / >16A per Ph. |
| | **Section 3** | Large scale DER | MV (>1kV) connected | |
| **Part 2** | Conformance test procedure (normative) | | | |
| | **Section 1** | Micro scale DER | LV (<1kV) connected | < 5kW / <16A per Ph. |
| | **Section 2** | Intermediate scale DER | LV (<1kV) connected | > 5kW / >16A per Ph. |
| | **Section 3** | Large scale DER | MV (>1kV) connected | |
| **Part 3** | Application Guideline (informative) | | | |
| **Part 4** | Guideline for intentional islanding of DER and operation of Microgrids (informative) | | | |
| **Part 5** | Guideline for Control, Monitoring and Communication of DER (informative) | | | |
| **Part 6** | Guideline for Load, Supply and Energy management with DER (informative) | | | |

### 3.2.2 MV Network Connection Guideline Proposed by BDEW

In autumn 2007, four German associations merged into the German Association of Energy and Water Industries (BDEW). They four associations were:

- German Association of gas & water Industry (BGW)
- Association of Electricity Industry (VDEW)
- Association of Transmission Companies & Regional Energy Providers (VRE)
- Association of Network Operators (VDN).

Simultaneously, the role of setting technical rules moved from VDN or VRE to the Forum on Network Technology and Network Operation (FNN) within the Association of Electrical, Electronic and Information Technologies (VDE).

In 2009, as the final rule setting issue, BDEW published the technical guideline for MV connection, “Technical Guideline for Generating Plants Connected to the Medium-Voltage Network” [12]. According to the summary [13], this guideline emphasizes that generating plants supplying MV (1kV – 35kV) networks, such as those at the HV or extra-HV level, should make a contribution to network support, which comprises “dynamic network support” (not to disconnect from the network immediately in the event of failures) and “steady-state voltage control” (to make a contribution to voltage stability in the network during normal network operation). This element of the guide is shown in Table 10 with Figure 2.a, Figure2.b, and Figure 3.

Additionally, the low voltage interconnection requirement, VDE-AR-N 4105, was published in Germany in August 2011 and it is going into effect in January 2012 for PV generators. Its details can be found at:
http://www.vde.com/en/fnn/pages/n4105.aspx.

**Table 10. Feature of MV Connection Guideline of BDEW**

| **Item** | | **Plant type (*1)** | **Requirements** |
|---|---|---|---|
| Network support | Steady-state voltage control | | $\Delta Ua$ (*2) ≤ 2% |
| | Dynamic network support | Type 1 | (See Figure 2.a.) |
| | | Type 2 | (See Figure 2.b.) |
| Active power reduction | On request from the network | | By steps of max. 10% $P_{AV}$ |
| | In case of over-frequency | | – 40% $P_M$ / Hz for >50.2Hz (See Figure 3.) |
| Reactive power | | | cosΦ: from 0.95 underexcited to 0.95 over excited |

(*1) Type 1: All synchronous generators, Type 2: Including asynchronous generators.
(*2) $\Delta Ua$: Voltage change / the voltage without generating plants connected

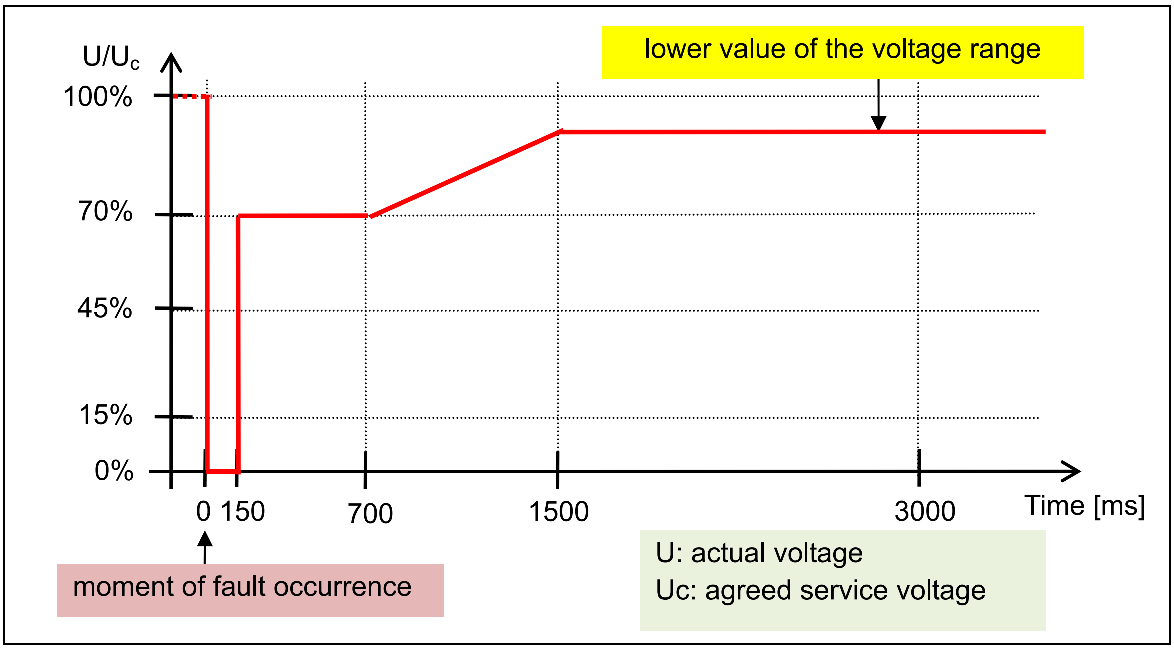



**Figure 2.a - Borderline of the voltage profile at the network connection point of a type-1 generating plant (extracted from [13].)**

In Figure 2.a;

- If the voltage drops at values above the red border line, generating plants must not be disconnected.

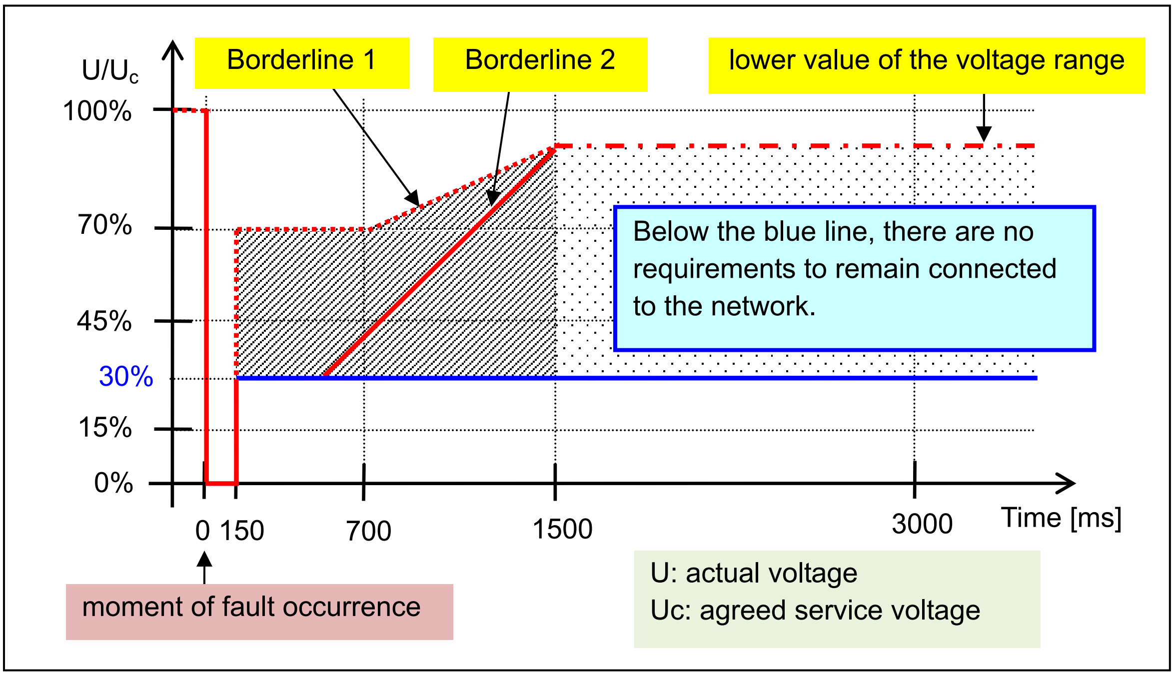
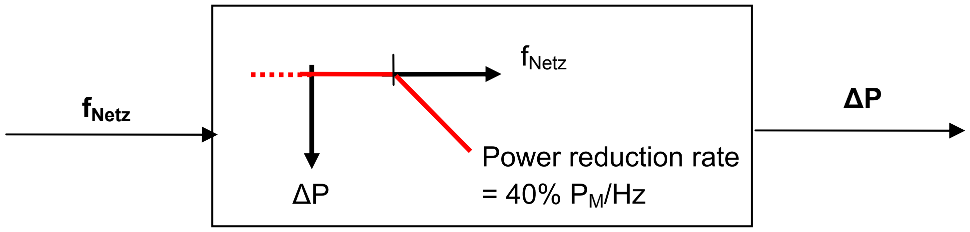



**Figure 2.b - Borderline of the voltage profile at the network connection point of a type-2 generating plant (extracted from [13].)**

In Figure 2.b, if voltage drop:

- Goes down to 0% Uc, disconnection is not permissible, in duration of ≤ 150ms.
- Is above the borderline 1, disconnection is not permissible

- Is between the borderline 2 and the borderline 1, a short-time disconnection may be permissible, while disconnection is not permissible in principle
- Is below the borderline 2, a short-time disconnection may be carried out at any time.




$$\Delta P = 20\,P_M \frac{50.2\text{ Hz} - f_{Netz}}{50\text{ Hz}} \quad \text{for } 50.2\text{ Hz} \le f_{Netz} \le 51.5\text{ Hz}$$

$P_M$ : Momentary available active power
$\Delta P$ : Reduction of active power
$f_{Netz}$ : Frequency of the network

For 47.5 Hz ≤ $f_{Netz}$ ≤ 50.2 Hz → (No restriction.)
For $f_{Netz}$ ≤ 47.5 Hz, or $f_{Netz}$ ≥ 51.5 Hz → Disconnection from the network.

**Figure 3. Active power reduction in case of over-frequency (extracted from [13].)**

## 3.3 The United States

### 3.3.1 IEEE 1547-2003

A summary [15] of the United States relevant descriptions is provided in a NEDO report, titled “Survey of actual situation of technical requirements, etc. on grid connection in foreign countries” [14], March 2004”, NEDO (the New Energy and Industrial Technology Development Organization), Japan. The report summarizes two issues often said to be the characteristics of electricity business systems in the United States:

- **Difference in control body for transmission lines and distribution lines.** In general the control body of transmission lines crossing state borders is the federation and the one of distribution lines not crossing state borders is each state.
- **Numerous electric power suppliers.** Over 3000, including public, municipal, federal, and cooperative companies.

To address these issues, the Unites States has adopted methods of problem sharing and voluntary consensus.

- **Problem Sharing.** A good example of this method is the report, “Making Connections: Case Studies of Interconnection Barriers and their Impact on Distributed Power Projects”, National Renewable Energy Laboratory (NREL) published in May, 2000. The report presents classification of problems and measures to mitigate barriers against grid connection based on 65 case studies on the spread of distributed generation sources.

- **Voluntary Consensus System.**
  A good example of this method can be explained in the history of IEEE 1547. The IEEE 1547 standard is a benchmark milestone for the IEEE standards consensus process and a model for developing further national standards. On a fast-track timeline, support for IEEE 1547 included more than 350 voluntary working group members and the electric power community. After nearly 5 years and 10 drafts, a successful working group ballot was achieved and the standard was published in 2003, as *IEEE 1547-2003 Standard for Interconnecting Distributed Resources with Electric Power Systems*. This document was reaffirmed with no changes in 2008.

The present situation in the United States can be summarized as follows:

1) Since the date of publication, IEEE 1547 has become the primary standard for distributed resource interconnection. Three-fourths of the states in the U.S. have adopted, referenced, or used IEEE 1547 in the development of their own interconnection standards, and the Energy Policy Act of 2005 designated it as the national standard for the interconnection of distributed resources. This national uniformity has made the interconnection process faster and easier and has encouraged the integration of many new distributed resource projects.
2) The IEEE 1547 standard is being followed by additional standards, recommended practices, and guidelines making up the IEEE 1547 Series of Standards under SCC21.
3) Special attention should be paid to development of *IEEE P1547.4 Draft Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems,* which provides alternative approaches and good practices for the design, operation, and integration of distributed resource island systems with electric power systems.
4) State interest in establishing their own grid connection requirements is growing. Technical requirements for grid connection in the State of California, New York, and Texas, assumed to be advanced states in the field, are using IEEE Std 1547-2003 as a reference in order to keep consistent with the nationally adopted IEEE 1547 Series of Standards.

IEEE 1547-2003 and the state level technical requirements for grid connection of California, New York, and Texas are listed for comparison in Table 11.

**Table 11. Existing technical requirements on grid connection in U.S. (extracted from [15].)**

| **Rule Name** | **IEEE 1547** | **Rule 21 [16]** | **(*1)** | **SUBSTANSIVE RULES Chapter 25.212 [18]** |
|---|---|---|---|---|
| State | Federation | California | New York | Texas |
| First Issue | 2003 | 2001 | 1999 | 1999 |
| Latest Revision | — | 2005 | 2009 | — |

| Rule Name | IEEE 1547 | Rule 21 [16] | (*1) | SUBSTANSIVE RULES Chapter 25.212 [18] |
|---|---|---|---|---|
| Generating Capacity | ≤10MVA | No restriction. | ≤2MW | ≤10MW |
| Power Lines | Primary or secondary distribution lines | Distribution lines | Distribution lines | Distribution lines of less than 60kV |
| Voltage (% of Nominal Voltage) | 88 ~ 110% | 88 ~ 110% | 88 ~ 110% | 90 ~ 105% |
| Frequency | 59.3~60.5Hz (≤30kW) [57~59.8]~60.5Hz (>30kW) | 59.3~60.5Hz (≤30kW) [57~59.8]~60.5Hz (>30kW) | 59.3~60.5Hz (≤30kW) [57~59.8]~60.5Hz (>30kW) | 59.3~60.5Hz |
| Power Factor | (No description.) | <0.9 (leading or lagging) | <0.9 (leading or lagging) | (No description.) |
| Harmonics | In accordance with 1st line of IEEE 519. (*2) | In accordance with 1st line of IEEE 519. (*2) | In accordance with IEEE 519. (*2) | In accordance with IEEE 519. (*2) |
| DC Injection | Max. 0.5% of rated output current | Max. 0.5% of rated output current | (No description.) | (No description.) |
| Flicker | Not to generate visible flicker. | In accordance with IEEE 519. | In accordance with IEEE 519. | In accordance with IEEE 519. & Not to exceed 3% of voltage. |
| Islanding | To disconnect within 2 seconds. | To disconnect within 2 seconds. | To be designed and operated so that islanding is not sustained. | (No description.) |
| Reconnection | At least 5 minutes waiting after EPS recovery. | At least 60 seconds waiting after EPS recovery. | At least 5 minutes waiting after EPS recovery. | No numerical regulation. |

(*1) New York State standardized Interconnection Requirements and Application Process for New Distributed Generators 2 MW or less Connected in Parallel with Utility Distribution Lines [17]

(*2) IEEE 519's actual prescription on harmonics:

| Individual harmonic order h (odd harmonics) (*) | h<11 | 11 ≤ h < 17 | 17 ≤ h < 23 | 23 ≤ h < 35 | 35 ≤ h | Total demand distortion (TDD) |
|---|---|---|---|---|---|---|
| Percent (%) | 4.0 | 2.0 | 1.5 | 0.6 | 0.3 | 5.0 |

(*) Even harmonics are limited to 25% of the odd harmonics limits above.

### 3.3.2 Update on IEEE P1547.4 – Intentional Islanding

IEEE Standards Coordinating Committee 21 (SCC21) is supporting the development of *IEEE 1547.4 Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power System,* as part of the further development of *IEEE 1547-2003 Standard for Interconnecting Distributed Resources with Electric Power Systems*.

In January 2010, a draft of IEEE P1547.4 [19] was issued by SCC21. In July 2011, the standard, IEEE 1547.4, was published. Highlights of the standard include:

1) The guide covers intentional islands in electric power systems that contain distributed resources, called "DR island systems". It covers the ability to separate from and reconnect to part of the utility while providing power to the islanded EPS.

2) The guide defines a variety of DR island systems: (See Figure 4.)
   - Local EPS island (facility island)
   - Secondary island
   - Lateral island
   - Circuit island
   - Substation bus island
   - Substation island
   - Adjacent circuit island

3) The guide prescribes functionality of the DR island system on the following four operation modes:
   - Area EPS-connected mode (normal parallel operation)
   - Transition-to-island mode
   - Island mode
   - Reconnection mode

4) The guide covers key consideration for planning and operating DR island systems, including impacts of voltage, frequency, power quality, inclusion of single point of common coupling (PCC) and multiple PCCs, protection schemes and modifications, monitoring, information exchange and control, understanding load requirements of the customer, knowing the characteristics of the distributed energy sources, identifying steady state and transient conditions, understanding interactions between machines, reserve margins, load shedding, demand response, cold load pickup, additional equipment requirements, and additional functionality associated with inverters.

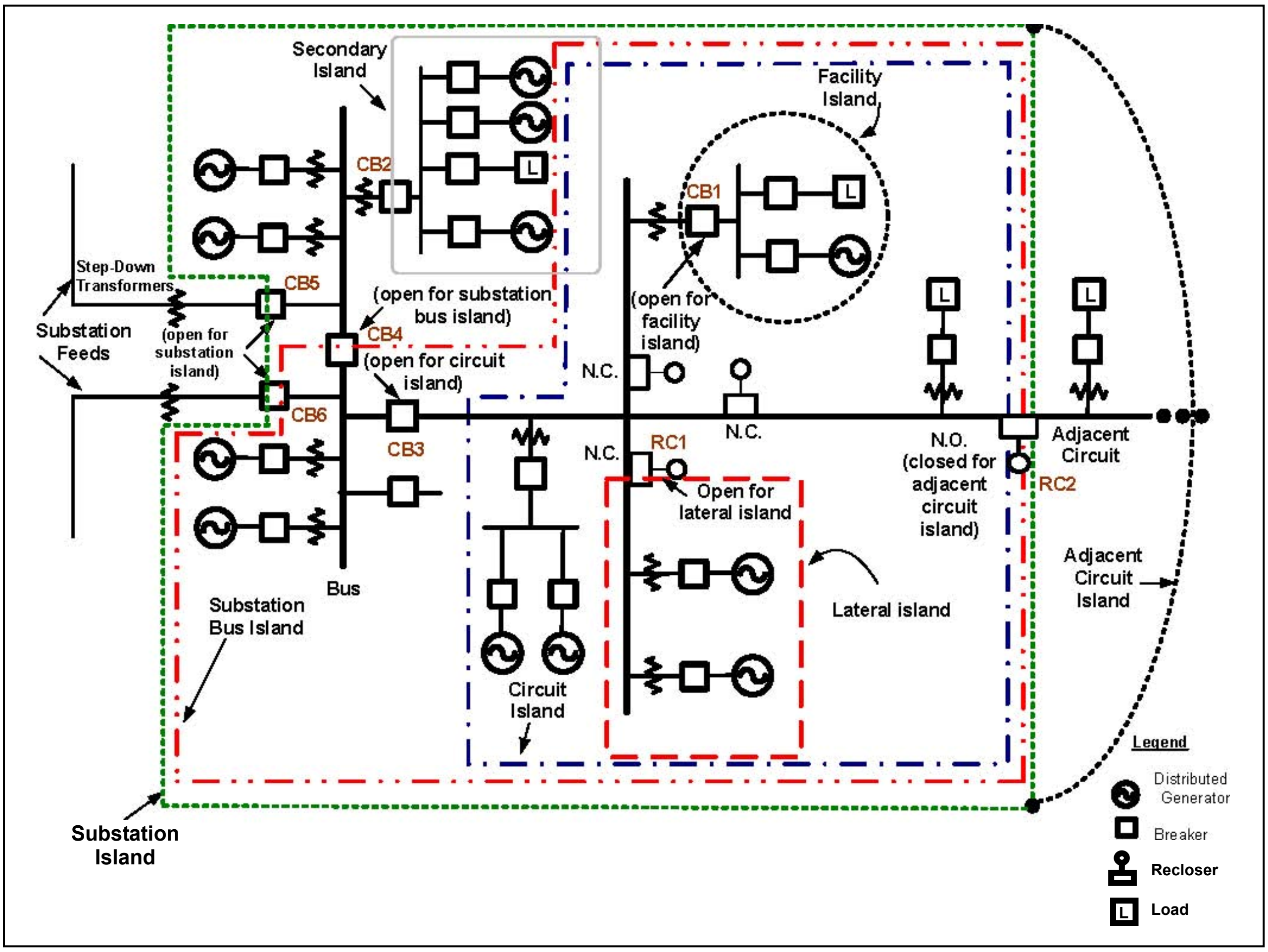



**Figure 4. Examples of DR island systems (extracted from [19].)**

# 4. Consideration of the role of PV hybrid mini-grids in RE mass spread age

## 4.1 Problems with mass spread of wind turbines in Europe

The report “On-site investigation report on European activities for power system stabilization against mass spread of new energy” [20], written by the Ministry of Economy, Trade and Industry of Japan (METI) indicates that the high penetration of RE (renewable energy) in Europe, especially wind turbines, is threatening power supply reliability. A summary [21] of the report lists problems and countermeasures as shown in Table 12.

**Table 12. Problems with mass spread of wind turbines and their countermeasures in Europe (extracted from [21].)**

| Problem | | Countermeasure | Outlook in future |
|---|---|---|---|
| Electric power system operation | Frequent occurrence of N–1 security threatening cases owing to heavy power flow (DEU, ESP) | ●Switchover of transmission networks, etc. from operator side, counter trade, etc. from market side, and suppression of WT’s output as the final measure (the exceptional countermeasures for supply security prescribed in Article 13 of EnWG) (DEU)<br>● Suppression of WT’s output (ESP)<br>● European 11 TSOs concluded an agreement on stable power supply, in December, 2008. | Essentially reinforcement of transmission lines is necessary, while there are inhabitants’ strong objections to it. The situation may possibly become more serious with further spread of WT. |
| | A risk of disconnection of international tie lines caused by simultaneous disconnection of WT (ESP) | ● Fault-Ride-Through function is requested to WT in Grid Code, reviseed in 2007. (ESP)<br>● Centralized restriction of REs output by CECRE, founded in 2006. (ESP) | There is a trend that the countries, like France, who do not request Fault-Ride-Through function to WT for the present, will request the obligation. |
| | Loop flow increase owing to WT generation (Around DEU) | ● Coreso, a cooperative organization among TSOs in relevant countries was established in February, 2009, for analysis of power supply reliability. (DEU, BEL, etc.)<br>●Installation of PSTs (Phase Shift Transformers) (BEL)<br>● Suppression of WT’s output as low as 60% when N–1 event of one transmission line occurs (BEL) | Enriching the content, etc. are necessary for the international organization. |
| Demand - supply control | Thermal output reduction shortage, surplus energy | ● Suppression of WT’s output (ESP) | The cases of suppression of WT’s output may possibly increase in future. |

| Problem | | Countermeasure | Outlook in future |
|---|---|---|---|
| | absorption (DEU, ESP, etc.) | ● Surplus energy absorption by electric energy storage facilities owing to a principle of receiving the whole electricity from REs. (DEU) | The whole surplus energy receiving may not be so easy in spite of new installation of electric energy storage facilities. |

## 4.2 Field researches for standardization of large-scale deployment of renewable energy

There are among the questionnaire sites several ones which have field research themes or results about Island Operation, Supply and Demand Control, Centralized / Decentralized Strategy, and so on, as shown in Table 13. Those researches aim at examining novel standardization of large-scale deployment of renewable energy.

**Table 13. Field research examples in PV hybrid mini-grids**

| Site code | Location | A/G (*1) | Composition of facilities | Theme or result of field research | Ref. |
|---|---|---|---|---|---|
| AS-6 | Hachinohe, JPN | G | BGE+PV(130kW)+WT (20kW)+BT | ● Demand-supply balancing error: 3% by 6 min.<br>● Island mode operation<br>● Effect of battery on inrush current of induction motors | [22], [23] |
| AS-7 | Kyotango, JPN | G | GE+MCFC+PV(50kW) +WT(50kW)+BT | ● Demand-supply balancing error: 3% by 5 min. | [22] |
| AS-8 | Aichi, JPN | G | MCFC+PAFC+SOFC+ PV(330kW)+BT (NaS) | ● Demand-supply balancing error: 3% by 10 min. | [22] |
| AS-9 | Ota, JPN | G | [PV(3-5kW)+BT] ×553 houses | ● BT charge / discharge effect on grid voltage<br>● Development of conflict-free islanding detection method | [22], [24], [25] |
| AS-10 | Sendai, JPN | G | GE+MCFC+PV (50kW) | ● Multiple power quality supply system with IPS (Integrated Power Supply)<br>● Island operation<br>● Voltage compensation at a voltage dip | [22], [26], [27], [28] |
| AS-11 | Tokyo Gas, JPN | G | GE+BGE+PV(10kW)+ WT(12kW)+BT | ● Power flow deviation at the connection point: ±1% by 5 min., with SOC control<br>● Island operation<br>● Contribution to grid voltage control | [29], [30] |

| Site code | Location | A/G (*1) | Composition of facilities | Theme or result of field research | Ref. |
|---|---|---|---|---|---|
| AS-12 | Wakkanai, JPN | G | PV(5MW)+BT(NaS) | ● Grid stabilization in large-scale PV systems with BT | [22], [31] |
| AS-13 | Hokuto, JPN | G | PV(2MW) | ● Grid stabilization in large-scale PV systems with function enhanced inverters | [22], [32] |
| NA-1 | AEP/CERTS, USA | G | Inverter(60kW×3) | ● Static switch (Smart switch)<br>● Intentional islanding | [33], [34] |
| NA-2 | GE, USA | G | – | ● MEM (Microgrid Energy Management) | [33] |
| NA-4 | Nemiah Valley, CAN | A | Diesel +PV(27.2kW)+ Dump load | ● Simulation study of grid dynamics | [35] |
| EU-1 | CRES, Gaiduromantra, GRC | A | Diesel+PV(11kW)+ WT(5kW) + BT | ● Island operation<br>● SOC-Grid frequency correlation | [36], [37] |
| EU-2 | MVV, Mannheim Wallstadt, DEU | G | PV(23kW)+ BT+ Dump load+CHP | ● Decentralized control | [36] |
| EU-3 | Bronsbergen, NLD | G | PV(315kW)+BT | ● Island operation | [36], [38] |
| EU-4 | OESTKRAFT, Bornholm Island, DNK | G | Steam plant (7.5MW) +Diesel(9MW) | ● Automatic isolation & reconnection | [36] |
| EU-5 | EDP, PRT | G | Microturbine | ● Island operation | [36] |
| EU-6 | MANU, Agria, GRC | G | Biogas based generator (15kW) | ● Island operation<br>● Centralized/Decentralized strategy | [36] |
| EU-7 | LABEIN, ESP | G | Diesel+μTurbine+PV(5.8kW)+ WT(6kW) + BT+ Flywheel+ Ultracapacitor +Controllable loads | ● Centralized/Decentralized strategy | [36] |
| EU-8 | CESI, ITA | G | PEM+ORC Biomass +μTurbine +PV(14kW)+Euro Dish(10kW) + BT (Redox, Pb, Zebra) +Flywheel | ● Dynamic behavior<br>● Intentional islanding | [36] |
| EU-11 | Kassel, DEU | G | PV(103kW)+BT | ● Multifunctional PV-inverter | [39] |

(*1) A: autonomous, G: grid connected

## 5. Design and operational recommendations on grid connection of a PV hybrid mini-grid to a main grid

From the questionnaire analysis, we found the following facts:

- There exist rules dedicated specifically to stability of power quality in the all sites, autonomous or grid connected.
- As for Islanding or power quality anomaly detection methods, various methods are adopted depending on purposes and situations of each site.
- Some sites are equipped with switchover function to islanding operation after islanding detection.

However, we could not lead more practical recommendations.

We also investigated the regulations on grid connection of distributed energy resources existing in Japan, Europe and the US. We found a lot of diversities in regions about the situation of standardization. However, we could not extract more helpful suggestions, because the standardization activities are progressing, but on their way.

We also investigated the problems with mass spread of renewable energy.

Consequently, we show the following descriptions as recommendations, although they are not so useful ones as we intended when this activity began.

In the case where a PV hybrid mini-grid connects to a main grid, designers, operators, and other relevant stakeholders should consider the following issues in the initial stages of design to ensure power quality and power supply reliability:

1) **Compliance with existing rules on power quality and grid connection**.
The design should comply with the rules prescribed in existing regulations on power quality and grid connection.

2) **Implementation of additional countermeasures specific to the site**.
If specific factors related to the site include security risks, power quality issues, and other reliability concerns, then necessary technical countermeasures should be added to the initial design, based on consensus of the stakeholders.

3) **Awareness of current standards developments.**
There are many activities in various regions of the world that aim to establish, revise, and unify standards focused on power supply quality at high penetration levels of renewable energy. Research and development is being conducted in the field to assist standards development. Stakeholders should stay current with these activities.

**Acknowledgements**

This report was completed with the cooperation of our questionnaire respondents, experts who participated in Task 11, members of the Japanese domestic Task 11 committee, and the NEDO people. We express our deepest thanks to them all.

## References


[1] Homepage of Task 11, IEA-PVPS
http://iea-pvps-task11.org/index.htm

[2] "The Electricity Business Act"
http://law.e-gov.go.jp/htmldata/S39/S39HO170.html (Japanese)

[3] "The Enforcement Regulation of the Electricity Business Act"
http://law.e-gov.go.jp/htmldata/H07/H07F03801000077.html (Japanese)

[4] "Technical requirements guideline of grid interconnection to secure electricity quality" (2004)
http://www.enecho.meti.go.jp/denkihp/genjo/rule/keito_guideline.pdf (Japanese)

[5] "Grid Interconnection Code"（JEAC 9701-2006）
http://www.denki.or.jp/pub/book_detail/355.html (Japanese)

[6] "Harmonics Restraint Guideline for HV or SHV Consumers" (2004)
http://www.nisa.meti.go.jp/8_electric/pdf/160131oshirase.pdf (Japanese)

[7] "Existing restrictions and guidelines of grid connection techniques in Japan"
♦ MG00810-Existing restrictions and guidelines of grid connection techniques in Japan.pdf, stored in the homepage of Task 11

[8] "Summary of Section 2.2.5 of Grid Interconnection Code (JEAC9701-2006) in Japan – Disconnection points in LV connection – "
♦ MG00910-Summary-LV-Disconnection points-Grid Interconnection Code-Japan.pdf, stored in the homepage of Task 11

[9] "Summary of Harmonics Restraint Guideline for HV or SHV Consumers in Japan"
♦ MG00911-Summary-HV&SHV-HarmonicsRestraint Guideline-Japan.pdf, stored in the homepage of Task 11

[10] Deliverable 2.1 of DERlab
http://www.der-lab.net/dokumente/D2.1_Rev7f_PU.pdf

[11] "Summary of Deliverable 2.1 of DERlab, 'Key needs, priorities and framework for the development of EDIS (a common European pre-standard on DER interconnection)' "
♦ MG00920-Summary-Deliverable 2.1 (DERlab).pdf, stored in the homepage of Task 11

[12] "Technical Guideline for Generating Plants Connected to the Medium-Voltage Network", June 2008, BDEW
http://www.bdew.de/bdew.nsf/id/DE_7B6ERD_NetzCodes_und_Richtlinien/$file/BDEW_RL_EA-am-MS-Netz_engl.pdf

[13] Summary of "Technical Guideline for Generating Plants Connected to the Medium-Voltage Network" (BDEW)
♦ MG01020-Summary-MV Connection Technical Guideline-BDEW-DEU.pdf, stored in the homepage of Task 11

[14] "Survey of actual situation of technical requirements, etc. on grid connection in foreign countries", March 2004, NEDO
http://www.tech.nedo.go.jp/PDF/100002908.pdf

[15] "Existing technical requirements of grid connection in USA"
♦ MG00930-Existing technical requirements of grid connection in USA.pdf, stored in the homepage of Task 11

[16] Rule 21-2005-CA
http://www.pge.com/tariffs/pdf/ER21.pdf

[17] "New York State standardized Interconnection Requirements and Application Process for New Distributed Generators 2 MW or less Connected in Parallel with Utility Distribution Lines"-2009-NY
http://www.dps.state.ny.us/Final_SIR_02-12-09_Clean.pdf

[18] SUBSTANSIVE RULES Chapter 25.212-1999-TX
http://www.puc.state.tx.us/rules/subrules/electric/25.212/25.212.pdf

[19] "Draft Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems", January 2010, SCC21
♦ P1547.4_D9.1.pdf, stored in the homepage of Task 11

[20] "On-site investigation report on European activities for power system stabilization against mass spread of new energy" (Japanese), April 2009, METI
http://www.meti.go.jp/committee/materials2/downloadfiles/g90522a09j.pdf

[21] "Summary of 'On-site investigation report on European activities for power system stabilization against mass spread of new energy' (METI) "
♦ MG00921-Summary-On-site investigation-Europe-Power system stabilization-Mass spread of new energy-METI.pdf stored in the homepage of Task 11

[22] "Grid-Connection Projects by NEDO: Results from Fiscal Year 2007", H. Nakama (NEDO), Kythnos 2008
http://der.lbl.gov/new_site/2008microgrids_files/Nakama.pdf

[23] "Simulation and Control of Microgrids", T. Goda (University of Kyushu), 2007 IEEE PES GM at Tampa
http://www.ieee.org/organizations/pes/meetings/gm2007/html/SLIDES/PESGM2007P-001234.PDF

[24] "NEDO Research related to Large-scale PV-related Grid-connection Projects", H. Nakama (NEDO), 2009 REGIS Workshop
http://www.sandia.gov/regis/presentations/H_Nakama-NEDO.pdf

[25] "Demonstrative Project on Grid-Interconnection of Clustered Photovoltaic Power Generation Systems", NEDO
http://www.nedo.go.jp/english/publications/brochures/pdf/ota-project_nedo.pdf

[26] "Update on the Sendai Demonstration of a Multiple Power Quality Supply System", K. Hirose (NTT Facilities), Kythnos 2008
http://der.lbl.gov/new_site/2008microgrids_files/Hirose.pdf

[27] "Field Demonstration on Multiple Power Quality Supply System in Sendai, Japan", K. Hirose (NTT Facilities), Barcelona EPQU2007
http://www.leonardo-energy.org/drupal/files/EPQU/2007conference/p90.pdf

[28] "A Voltage Dip Characterization of a Multiple Power Quality Supply System", K. Hirose (NTT Facilities), Poster A2, 4th European Conference, PV-Hybrid and Mini-Grid

[29] "Tie-line power flow control of PV-microgrid", H.Asano et al. (The University of Tokyo Institute of Electric Power Industry), Poster A7, 4th European Conference, PV-Hybrid and Mini-Grid

[30] "Demonstration of Microgrid through the Activities toward Holonic Energy Systems", T. Tsukada et al. (Tokyo Gas), IAQVEC 2007
http://www.inive.org/members_area/medias/pdf/Inive%5CIAQVEC2007%5CTsukada.pdf

[31] "Demonstration Project of 5MW PV Generator System at Wakkanai", R.Hara (Hokkaido University) and T.Funabashi (Meidensha Corp.), Kythnos 2008
http://der.lbl.gov/new_site/2008microgrids_files/Hara_Funabashi.pdf

[32] Introduction of "Hokuto" site, NTT Facilities
http://www.ntt-f.co.jp/ps/eco/kita.html (Japanese)

[33] "Status of Overseas Microgrid Programs: Microgrid Research Activities in the U.S.", C. Marnay (LBNL), 2008
http://repositories.cdlib.org/cgi/viewcontent.cgi?article=6193&context=lbnl

[34] "CERTS Microgrid", R.H.Lasseter (University of Wisconsin, Madison), Kythnos 2008
http://der.lbl.gov/new_site/2008microgrids_files/Lasseter.pdf

[35] "Modeling and dynamic analysis of a medium penetration PV-Diesel Mini-Grid system", F.Katiraei (Natural Resources Canada), 4th European Conference, PV-Hybrid and Mini-Grid

[36] "Overview of Microgrid R&D in Europe", N.Hatziargyriou (National Tech. U. of Athens), Kythnos 2008
http://der.lbl.gov/new_site/2008microgrids_files/Hatziargyriou.pdf

[37] "Performance evaluation of the Gaidoroumantra mini-grid with distributed PV generators", M.Vandenbergh (ISET), 4th European Conference, PV-Hybrid and Mini-Grid

[38] "Bronsbergen: First Microgrid in The Netherlands", S.Cobben (Continuon), Kythnos 2008
http://der.lbl.gov/new_site/2008microgrids_files/Cobben.pdf

[39] "Power Quality Improvement of Electrical Sub-Networks with Multifunctional PV-Inverters for Industrial Customers", D. Geibel, 23rd European PV Solar Energy Conference and Exhibition Valencia, Spain, 2008

## (Annex 1) List of sites to be researched

**Table A1-1 List of the sites to be researched [■: Site information]**

| Site code | Location, "Site name" Project participants | Composition of system | Research theme, Fund name, etc. |
|---|---|---|---|
| AS-1 | Miyako-island, Japan<br>Okinawa EPC, Miyakojima City | ● PV 750kW / BT 3000kWh / Diesel 300kW<br>● Autonomous (?V, ?ph) | "Verification of PV Power Generation System" (NEDO) |
| | ■ "Introduction of new energy hybrid systems" (Japanese), 'Denki' 12/2002, p16 , T. Nakao (JEMA, Japan Electrical Manufacturers' Association) http://www.jema-net.or.jp/Japanese/denki/2002/de-0212/p13-17.pdf (Japanese) | | |
| AS-2 | Noyon Sum, Mongolia<br>Sharp, Mongolian Government | ● PV 200kW / BT 576kWh / Diesel 300kW<br>● Autonomous (?V, ?ph) | "International Cooperative Demonstration Project Utilizing PV Power Generation Systems" (NEDO) |
| | ■ http://www.nedo.go.jp/informations/events/181211/kokusai-6.pdf | | |
| AS-3 | XingXingXia (Shinjang Uyghur Autonomous Region), China<br>Shikoku EPC, Shikoku Research Institute, Shikoku engineering, Chinese Government | ● PV 70kW / BT 400kWh / Diesel 70kW<br>● Autonomous (380V, ?ph) | ditto |
| | ■ http://www.nedo.go.jp/informations/events/181211/kokusai-11.pdf | | |
| AS-4 | Chaung Tar, Myanmar<br>NEWJEC, Hitachi Engineering Service, Myanmarese Government | ● PV 80kW / WT 40kW / BT 210kWh / 製氷機 8kW×3 / Diesel 60kW<br>● On-grid (210V, 3ph－400V, 3ph) | ditto |
| | ■ http://www.nedo.go.jp/informations/events/181211/kokusai-2.pdf | | |
| AS-5 | Ko Libong, Thailand<br>Showa Shell Sekiyu, Okinawa EPC, Thai Government | ● PV 85kW / BT 540kWh / Diesel 652kW<br>● On-grid (400V, 3ph–33kV, 3ph) | ditto |
| | ■ http://www.nedo.go.jp/informations/events/181211/kokusai-3.pdf | | |
| AS-6 | Hachinohe City, Japan, " Regional Power Grid with Renewable Energy Resources: A Demonstrative Project in Hachinohe"<br>Mitsubishi Research | ● PV(80kW) / WT (20kW) / BT (1440kWh) / Bio-gas engine (170kW×3)<br>● On-grid (?V, ?ph－?V, ?ph) | "Demonstrative Project of Regional Power Grids with Various New Energies" (NEDO) |

| Site code | Location, "Site name"<br>Project participants | Composition of system | Research theme, Fund name, etc. |
|---|---|---|---|
| | Institute, Mitsubishi Electric Corp., Hachinohe City | | |
| | ■ Included in "Grid-Connection Projects by NEDO: Results from Fiscal Year 2007", H.Nakama (NEDO), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Nakama.pdf | | |
| AS-7 | Kyotango City, Japan, "Kyoto Eco-Energy Project (KEEP)"<br>Fuji Electric Systems, Nissin Electric, Nomura Research Institute, Kyoto Pref., etc. | ● PV(50kW) / WT (50kW) / BT (100kW) / Bio-gas engine (80kW×5) / MCFC(250kW)<br>● On-grid (?V, ?ph－?V, ?ph) | ditto |
| | ■ Included in "Grid-Connection Projects by NEDO: Results from Fiscal Year 2007", H.Nakama (NEDO), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Nakama.pdf | | |
| AS-8 | Tokoname City, Japan, "the EXPO 2005 Aichi" → "Aichi Airport-site Demonstrative Research Plant for New Energy Power Generation"<br>NTT Facilities, KYOCERA, Mitsubishi Heavy Industries, Chubu EPC, Aichi Pref., etc. | ● PV (330kW) / BT(NaS) (500kW) / MCFC (570kW) / SOFC (25kW) / PAFC (800kW)<br>● On-grid (?V, ?ph－?V, ?ph) | ditto |
| | ■ Included in "Grid-Connection Projects by NEDO: Results from Fiscal Year 2007", H.Nakama (NEDO), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Nakama.pdf | | |
| AS-9 | Ota City, Japan, "Pal Town Jyosainomori"<br>Kandenko, Meidensha, Electric Power Engineering Systems, Matsushita Ecology Systems, Shin-Kobe Electric Machinery, Tokyo University of Agriculture and Technology, Nihon University, Ota City, etc. | ● PV(4kW)+BT(4000Ah) /House × 553Houses<br>● On-grid (?V, ?ph－?V, ?ph) | "Demonstrative Project on Grid-Interconnection of Clustered Photovoltaic Power Generation Systems" (NEDO) |
| | ■ Included in "Grid-Connection Projects by NEDO: Results from Fiscal Year 2007", H.Nakama (NEDO), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Nakama.pdf | | |
| AS-10 | Sendai-city, Japan, "Sendai Project"<br>NTT Facilities, NTT Building Technology Institute, Tohoku | ● PV(50kW) / Gas engine(350kW×2) / MCFC(250kW)<br>● On-grid (6.6kV, 3ph－?V, ?ph) | "Demonstrative Project on Power Supply Systems by Service Level" (NEDO) |

| Site code | Location, "Site name" Project participants | Composition of system | Research theme, Fund name, etc. |
|---|---|---|---|
| | Fukushi University, Sendai City http://www.sendaiproject.com/english/index.html | | |
| | ■ Included in "Grid-Connection Projects by NEDO: Results from Fiscal Year 2007", H.Nakama (NEDO), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Nakama.pdf ■ "Update on the Sendai Demonstration of a Multiple Power Quality Supply System", K.Hirose (NTT Facilities), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Hirose.pdf ■ "A Voltage Dip Characterization of a Multiple Power Quality Supply System", K.Hirose (NTT Facilities), 4th European Conference, PV-Hybrid and Mini-Grid, Poster A2 | | |
| AS-11 | Yokohama City, Japan, "Yokohama Laboratory of Tokyo Gas" Tokyo Gas, the University of Tokyo | ● PV (10kW) / WT (6kW×2) / BT (115kWh) / Gas engine (9.9kW, 25kW) ● On-grid (?V, ?ph－?V, ?ph) | "Verification Test of Micrograds (Holonic Energy System)" (Industry – University Cooperation) |
| | ■ "Tie-line power flow control of PV-microgrid", H.Asano (The University of Tokyo Institute of Electric Power Industry) , 4th European Conference, PV-Hybrid and Mini-Grid, Poster A7 | | |
| AS-12 | Wakkanai City, Japan, "Wakkanai Site" Hokkaido EPC, Meidensha, Matsushita Environmental & Air-conditioning Engineering, Hokkaido University, Wakkanai City, etc. | ● PV(2.0MW→5.0MW) / BT(NaS) (0.5MW×7.2h→1.5MW×7.2h) / EDLC (→1.5MW×1min) ● On-grid (?V, ?ph－33kV, 3ph) | "Verification of Grid Stabilization with Large-scale PV Power Generation Systems" (NEDO) |
| | ■ Included in "Grid-Connection Projects by NEDO: Results from Fiscal Year 2007", H.Nakama (NEDO), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Nakama.pdf ■ "Demonstration Project of 5MW PV Generator System at Wakkanai", R.Hara (Hokkaido University) and T.Funabashi (Meidensha Corp.), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Hara_Funabashi.pdf ■ "Introduction of Demonstrative Project of 5MW PV Generation System Conducted at Wakkanai and Proposal of Output Fluctuation Suppression Methods Utilizing Energy Storage System", M.Akatsuka (Hokkaido University) , 4th European Conference, PV-Hybrid and Mini-Grid , Poster A11 | | |
| AS-13 | Hokuto City, Japan, "Hokuto Site" NTT facilities, Hitachi, Tokyo University of Agriculture and Technology, Tokyo Institute of Technology, AIST, Hokuto City | ● PV(0.6MW→2MW) ● On-grid (?V, ?ph－?V, ?ph) | ditto |

| Site code | Location, "Site name" Project participants | Composition of system | Research theme, Fund name, etc. |
|---|---|---|---|
| | ■ Included in "Grid-Connection Projects by NEDO: Results from Fiscal Year 2007", H.Nakama (NEDO), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Nakama.pdf | | |
| AS-14 | Jurong Island, Singapore, "SINERGY (Singapore Initiative in New Energy Technologies) Centre" | | (Government) |
| | ■ "Overview of Microgrid R&D Plans for Singapore", A.Chong (A*STAR), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Chong.pdf | | |
| AS-15 | Korea, "Pilot Plant System" RCIM (Research Center for Intelligent Micro-grid) | | (Government) (Matching Fund) |
| | ■ "Overview of Microgrid R&D Plans for Korea", B.Han (Myongli University), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Han.pdf | | |
| AS-16 | China<br>Projekt-Consult GmbH | ● 167 plants, Totally, 167MW | Sino-German Financial Cooperation, MoF-KfW program |
| | ■ "Case Studies of PV-Diesel Hybrid Systems in Operation in Rural Asia: Experiences and Conclusions from China, Thailand and Vietnam", G.Shrestha and C.Menke (JGSEE), W.Klinghammer (Projekt-Consult), 4th European Conference, PV-Hybrid and Mini-Grid | | |
| AS-17 | Thailand<br>JGSEE, KMUTT | ● 9 plants, Totally, PV(40kW) / WT(23kW) / Diesel(220kW) | ECON (Thai Government's Energy Conservation) fund |
| | ■ "Case Studies of PV-Diesel Hybrid Systems in Operation in Rural Asia: Experiences and Conclusions from China, Thailand and Vietnam", G.Shrestha and C.Menke (JGSEE), W.Klinghammer (Projekt-Consult), 4th European Conference, PV-Hybrid and Mini-Grid | | |
| AS-18 | Vietnam | ● 60 plants, PV / Diesel | VSRE (Vietnam-Sweden Rural Energy Programme) |
| | ■ "Case Studies of PV-Diesel Hybrid Systems in Operation in Rural Asia: Experiences and Conclusions from China, Thailand and Vietnam", G.Shrestha and C.Menke (JGSEE), W.Klinghammer (Projekt-Consult), 4th European Conference, PV-Hybrid and Mini-Grid | | |
| AS-19 | Lao PDR | | |
| | ■ "Profitable and Affordable Energy Services for Remote Areas in Lao PDR: Private – Public Partnership as Mutual Leverage for Hybrid Village Grids in Remote Areas off the National Grid in Laos", A.Schroeter (Sunlabob Rural Energy LTD), S.Martin (Helvetas Swiss Association for International Corporation), 4th European Conference, PV-Hybrid and Mini-Grid | | |
| AS-20 | Ladakh, India<br>SunTechnics Energy | ● PV(40kW) / WT(10kW) / Diesel | |

| Site code | Location, "Site name" Project participants | Composition of system | Research theme, Fund name, etc. |
|---|---|---|---|
| | Systems Pte Ltd. | | |
| | ■ "PV-Wind Hybrid Power on the Roof of the World", A.R.Deblon (SunTechnics Energy Systems Pte Ltd.), I.Mitra (University of Kassel), 4th European Conference, PV-Hybrid and Mini-Grid, Poster A15 | | |
| AS-21 | Sunderban Islands, India, "WBREDA projects"<br>West Bengal Renewable Energy Development Agency | ● 5 projects, PV / WT / BT / Diesel | |
| | ■ "Field lessons from India, in process to Africa", L.Lecesve (Hybrid Energies), 4th European Conference, PV-Hybrid and Mini-Grid, Poster A16 | | |
| AS-22 | Pulau Kapas, Terengganu, Malaysia<br>TNBES (Tenaga Nasional Berhad Energy Services) | ● PV(100kW) / BT(480kW) / Diesel(350kW) | Perbadanan Memajukan IktisadNegeri Terengganu |
| | http://www.leonics-moc.com/ | | |
| OC-1 | Apolima, Samoa (Polynesia)<br>EPC (Electric Power Corporation) | ● PV(13.76kW) / BT(3000Ah, 48V)<br>● Autonomous(230V, ?ph) | UNDP (the United Nations Development Program)<br>MCO (Samoa Multi Country Office)<br>UNESCO (the United Nations Educational, Scientific and Cultural Organization) |
| | ■ "A Trial PV Mini-Grid Installation for Small Islands", J.Walter (EPC), 4th European Conference, PV-Hybrid and Mini-Grid, Poster A1 | | |
| OC-2 | Futuna, Vanuatu (Western Melanesia)<br>VANREPA (Vanuatu Renewable Energy and Power Association) | ● PV / WT<br>● Autonomous(?V, ?ph) | The Wuppertal Institute for Climate, Environment and Energy |
| | ■ "Community Powerhouse: A Rural Electrification Model for Vanuatu", JW.Mohns (VANREPA), 4th European Conference, PV-Hybrid and Mini-Grid, Poster A5 | | |
| OC-3 | Yap state, the Federated States of Micronesia(FSM)<br>IT Power, Transénergie, ADEME, YSPSC (Yap State Public Service Corporation) | ● PV<br>● Autonomous(230V, ?ph) | The REP-5 programme "Support to the Energy Sector in 5 ACP Pacific Islands" |
| | ■ "PV Mini-Grids for Yap State: Sustainable design for remote Pacific islands", P.Konings (IT Power Pacific), 4th European Conference, PV-Hybrid and Mini-Grid, Poster A12 | | |

<table>
<tr><th>Site code</th><th>Location, "Site name"<br>Project participants</th><th>Composition of system</th><th>Research theme, Fund name, etc.</th></tr>
<tr><td rowspan="2">NA-1</td><td>Wisconsin, USA,<br>"AEP/CERTS Microgrid"<br>CERTS</td><td>● Inverter(60kW×3)<br>● On-grid(480V, 3ph－13.8kV, 3ph)</td><td>(DOE)</td></tr>
<tr><td colspan="3">■ Included in "Overview of Microgrid R&D in U.S.", M.Smith (DOE), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Smith.pdf<br>■ "CERTS Microgrid", R.H.Lasseter (University of Wisconsin, Madison), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Lasseter.pdf</td></tr>
<tr><td rowspan="2">NA-2</td><td>USA<br>"GE Microgrid Demonstration"</td><td></td><td>(DOE)</td></tr>
<tr><td colspan="3">■ Included in "Overview of Microgrid R&D in U.S.", M.Smith (DOE), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Smith.pdf</td></tr>
<tr><td rowspan="2">NA-3</td><td>USA<br>"US Army CERL/Sandia Labs Energy Surety Project"</td><td></td><td>(DOE)</td></tr>
<tr><td colspan="3">■ Included in "Overview of Microgrid R&D in U.S.", M.Smith (DOE), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Smith.pdf<br>■ "Development of An Energy Surety Microgrid for Military Applications", A. Akhil (Sandia National laboratories), Army Installation Energy Security & Independence Conference 2006<br>http://www.cecer.army.mil/techreports/ERDC-CERL_TR-07-9/Session%20II/Akhil.pdf</td></tr>
<tr><td rowspan="2">NA-4</td><td>Nemiah, Canada<br>"Nemiah Valley Mini-Grid"</td><td>● PV(27.2kW) / Dump load(18.6kW) / Diesel(90kW×2, 35kW)<br>● On-grid(600V, 2ph－14.4kV, 1ph)</td><td></td></tr>
<tr><td colspan="3">■ Included in "Overview of Microgrid R&D in Canada", K.Mauch (K.M.Technical Services), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Mauch.pdf<br>■ Included in "Remote Electrification research: Applied Photovoltaic and Hybrid Systems Nemiah Valley, British Columbia, Canada", A.Swingler (Xantrex), 5th Task 11 Experts Meeting<br>■ "Modeling and dynamic analysis of a medium penetration PV-Diesel Mini-Grid system", F.Katiraei (Natural Resources Canada), 4th European Conference, PV-Hybrid and Mini-Grid</td></tr>
<tr><td rowspan="2">NA-5</td><td>Newfoundland, Canada<br>"Ramea Island wind-diesel mini-grid"</td><td>● WT(390kW) / Dump load(200kW) / Diesel(925kW×3)<br>● Autonomous(?V, ?ph)</td><td></td></tr>
<tr><td colspan="3">■ Included in "Overview of Microgrid R&D in Canada", K.Mauch (K.M.Technical Services), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Mauch.pdf</td></tr>
<tr><td>SA-1</td><td>Pará, Brazil</td><td>● PV(10kW) / BT / Diesel(10kW)</td><td></td></tr>
</table>

| Site code | Location, "Site name" Project participants | Composition of system | Research theme, Fund name, etc. |
|---|---|---|---|
| | "2 Pilot project in Pará, Brazil" | ● On grid?(?V, ?ph－?V, ?ph) | |
| | | ● PV(20kW)/WT(20kW)/BT/ Diesel(35kW)<br>● On grid?(?V, ?ph－?V, ?ph) | |
| | ■ "PV-Hybrid Systems in Brazil Sustainability", W.Klaus (GTZ), 5th Task 11 Experts Meeting | | |
| AF-1 | Akkan, Morocco | ● PV(5.76kW) / BT(48V, 1500Ah) / Diesel(8.2kVA)<br>● Autonomous(230V, 1ph) | |
| | ■ Included in "PV-Hybrid Microgrids for Rural Electrification: Field Experience", X.Vallvé (Trama TecnoAmbiente), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Vallve.pdf<br>■ "PV Hybrid Micro-Grid Experience in Morocco", X.Vallvé (TTA), 4th European Conference, PV-Hybrid and Mini-Grid | | |
| AF-2 | Diakha Madina, Senegal | ● PV(3.15kW) / BT(672Ah) / Diesel(4.2kW)<br>● Autonomous(230V, 1ph) | |
| | ■ Included in "PV-Hybrid Microgrids for Rural Electrification: Field Experience", X.Vallvé (Trama TecnoAmbiente), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Vallve.pdf | | |
| AF-3 | Egypt | ● PV(0.9kW) / BT(12V, 600Ah) / Diesel(1kW) | |
| | ■ "Optimal Design of Hybrid Energy Systems with Battery Storage", M.A.Badr (Mechanical Engineering Department, NRC), 4th European Conference, PV-Hybrid and Mini-Grid, Poster A18 | | |
| AF-4 | Ntarama, Rwanda "Nelson Mandela Educational Centre"<br>Juwi Solar GmbH, RET-consult, SMA | ● PV(30kW) / BT(48V, 1000Ah) | Greenhelmets e. V. |
| | http://www.ret-consult.de/index.php?option=com_content&task=view&id=26 | | |
| EU-1 | Gaiduromantra, Kythnos, Greek "CRES Microgrid in Gaiduromantra"<br>SMA, ISET, CRES (Hellenic National Research Center for Renewable Energy Sources) | ● PV(11kW) / BT(53kWh) / WT(5kW) / Diesel(5kW)<br>● Autonomous(230V, 1ph) | |
| | ■ Included in "Overview of Microgrid R&D in Europe", N.Hatziargyriou (National Tech. U. of Athens), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Hatziargyriou.pdf | | |

| Site code | Location, "Site name" Project participants | Composition of system | Research theme, Fund name, etc. |
|---|---|---|---|
| | ■ "Performance evaluation of the Gaidoroumantra mini-grid with distributed PV generators", M.Vandenbergh (ISET), 4th European Conference, PV-Hybrid and Mini-Grid | | |
| EU-2 | Mannheim Wallstadt, Germany, "MVV Microgrid" | ● PV(23kW) / BT(60kW) / Dump load(Water pumping 8-10kW, Refrigeration 2kW) / CHP<br>● On-grid(400V, ?ph－20kV, ?ph) | |
| | ■ Included in "Overview of Microgrid R&D in Europe", N.Hatziargyriou (National Tech. U. of Athens), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Hatziargyriou.pdf | | |
| EU-3 | Bronsbergen, The Netherlands<br>Continuon | ● PV(315kW) / BT<br>● On-grid(400V, ?ph－10kV, ?ph) | |
| | ■ Included in "Overview of Microgrid R&D in Europe", N.Hatziargyriou (National Tech. U. of Athens), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Hatziargyriou.pdf<br>■ "Bronsbergen: First Microgrid in The Netherlands",S.Cobben (Continuon), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Cobben.pdf | | |
| EU-4 | Bornholm Island, Denmark<br>"OESTKRAFT Microgrid" | ● Steam plant(7.5MW)/Diesel(9MW)<br>● On-grid(60kV, 3ph－132kV, 3ph) | |
| | ■ Included in "Overview of Microgrid R&D in Europe", N.Hatziargyriou (National Tech. U. of Athens), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Hatziargyriou.pdf | | |
| EU-5 | Portugal<br>"EDP Microgrid" (Swimming pool) | | |
| | ■ Included in "Overview of Microgrid R&D in Europe", N.Hatziargyriou (National Tech. U. of Athens), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Hatziargyriou.pdf | | |
| EU-6 | Agria, Greece<br>"MANU Microgrid" (Pig farm) | | |
| | ■ Included in "Overview of Microgrid R&D in Europe", N.Hatziargyriou (National Tech. U. of Athens), Kythnos 2008<br>http://der.lbl.gov/new_site/2008microgrids_files/Hatziargyriou.pdf | | |
| EU-7 | Spain<br>"LABEIN Microgrid" | ● PV(5.8kW) / WT(6kW) / BT(48V-1925Ah, 24V-1120Ah) / Flywheel(250kVA) / Ultracapacitor(48V-2.8MJ) / | |

| Site code | Location, "Site name" Project participants | Composition of system | Research theme, Fund name, etc. |
|---|---|---|---|
| | | Diesel(110kW) / μTurbine(50kW) / Controllable loads(resistive 150+55kW, reactive 2×36kVA)<br>● On-grid(?V, ?ph－?kV, ?ph) | |
| | ■ Included in "Overview of Microgrid R&D in Europe", N.Hatziargyriou (National Tech. U. of Athens), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Hatziargyriou.pdf | | |
| EU-8 | Italy<br>"CESI Microgrid" | ● PV(14kW) / Euro Dish(10kW) / BT(Redox 45kW, Pb 100kW, Zebra 64kW) / Flywheel(100kW) / PEM(3kW) / ORC Biomass(10kW) / μTurbine(100kW)<br>● On-grid(400V, ?ph－23kV, ?ph) | |
| | ■ Included in "Overview of Microgrid R&D in Europe", N.Hatziargyriou (National Tech. U. of Athens), Kythnos 2008 http://der.lbl.gov/new_site/2008microgrids_files/Hatziargyriou.pdf | | |
| EU-9 | Austria, "Starkenburg Lodge"<br>ISET | ● PV(5kW) / BT(48V, 1200Ah) /CHP(5kW)<br>● Autonomous(230V / 400V, ?ph) | |
| | ■ "10 Years PV Hybrid Systems as an Energy Supply for a Remote Alpine Lodge", M.Landau (ISET), 4th European Conference, PV-Hybrid and Mini-Grid, Poster A4 | | |
| EU-10 | Lubia, Spain, "CICLOPS I"<br>Ecotècnia | ● PV(5kW) / WT(7.5kW) / BT(120V, 595Ah) / Diesel(20kVA) | |
| | ■ "A Wind-PV-Diesel Hybrid System Performance Evaluation", L.M.Arribas (CIEMAT), 4th European Conference, PV-Hybrid and Mini-Grid, Poster A6 | | |
| EU-11 | Kassel, Germany<br>Institut für Solare Energieversorgungstechnik (ISET) e.V. Kassel, SMA Solar Technology AG Niestetal, Städtische Werke AG Kassel, HÜBNER GmbH Kassel, Daimler AG Kassel, Mercedes-Benz Werk Kassel | ● PV(103kW) / BT | Co-financed by Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) - Research project (Förderkennzeichen 0329943) |
| | http://www.multi-pv.de/ | | |

## (Annex 2) Content of questionnaire

**Questionnaire I - Regarding fundamental information of your Mini-grid**

| Item | Question/Request | Answer example in case of site identification No.: AS-10 |
|---|---|---|
| **I-1** Location | Please answer municipalities, country. | Sendai City, Japan |
| **I-2** Site name | Please answer some special site name if it is used in the releases. | "Sendai Project" |
| **I-3** Project participants | Please answer the project participants related to design, construction, operation and research of the Mini-grid. | NTT Facilities, NTT Building Technology Institute, Tohoku Fukushi University, Sendai City |
| **I-4** Research theme, Fund name, etc. | Please answer research theme, fund name, etc., that is the source of money of the Mini-grid. | "Demonstrative Project on Power Supply Systems by Service Level" (NEDO) |
| **I-5** Releases | Please answer the releases of the Mini-grid with their website if possible. | ■ Included in "Grid-Connection Projects by NEDO: Results from Fiscal Year 2007", Kythnos 2008, H.Nakama (NEDO) http://der.lbl.gov/new_site/2008microgrids_files/Nakama.pdf ■ "Update on the Sendai Demonstration of a Multiple Power Quality Supply System", Kythnos 2008, K.Hirose (NTT Facilities) http://der.lbl.gov/new_site/2008microgrids_files/Hirose.pdf ■ "A Voltage Dip Characterization of a Multiple Power Quality Supply System", 4th European Conference, PV-Hybrid and Mini-Grid, Poster A2, K.Hirose (NTT Facilities) |
| **I-6** Composition of system | **I-6-a** Please answer the outline of the system composition. | ● PV(50kW)<br>● Gas engine(350kW×2)<br>● MCFC(250kW) |
| | **I-6-b** Please give the single line diagram of the system. (Please attach it as another file.) | (A Schematic system configuration drawing with voltage description is better than a strict single line diagram in order to understand your answers.) |
| **I-7** Grid connected or Autonomous | Please answer the Mini-grid is grid connected or autonomous. | Grid connected. |

In case the answer of I-7 is Autonomous, please answer the questionnaire II.
In case the answer of I-7 is Grid connected, please answer the questionnaire III.

**Questionnaire II - In case of Autonomous**

| Item | Question/Request |
|---|---|
| **II-1** The rule of power quality of the Mini-grid | **II-1-a** Please answer DC/AC, voltage, phases, and the applied rule of the tolerance of the voltage. |
| | **II-1-b** Please answer the frequency and the applied rule of its tolerance. |
| | **II-1-c** Please answer the other applied rules of power quality, such as distortion level, harmonics, etc. . |
| | **II-1-d** What laws, standards, guidelines, etc. the above rules are based on? |
| **II-2** Sequences in case of power quality violation | **II-2-a** What event detection is defined as power quality violation? |
| | **II-2-b** When power quality violation is detected, what sequences the Mini-grid executes? |
| **II-3** Measures for power quality stability in case of connection/disconnection of the generation sources composing the Mini-grid | **II-3-a** What measures are adopted now? |
| | **II-3-b** What measures do you hope or plan should be adopted in future? |
| **II-4** Measures for power quality stability from the different views | **II-4-a** What measures are adopted now? |
| | **II-4-b** What measures do you hope or plan should be adopted in future? |

**Questionnaire III In case of Grid connected**

| Item | Question/Request |
|---|---|
| **III-1** The rule of power quality of the Main grid | **III-1-a** Please answer DC/AC, voltage, phases of the Main grid, and the applied rule of the tolerance of the voltage. |
| | **III-1-b** Please answer the frequency of the Main grid and the applied rule of its tolerance. |
| | **III-1-c** Please answer the other applied rules of power quality, such as distortion level, harmonics, etc. . |
| | **III-1-d** What laws, standards, guidelines, etc. the above rules are based on? |
| **III-2** Sequences in case of power quality violation | **III-2-a** What event detection is defined as power quality violation? |
| | **III-2-b** When power quality violation is detected, what sequences the Mini-grid executes? |

| Item | Question/Request |
|---|---|
| **III-3**<br>Detection of islanding<br>→ Disconnection<br>→ Detection of grid return<br>→ Connection | **III-3-a** What method is adopted for detection of islanding? |
| | **III-3-b** When islanding is detected, what sequences the Mini-grid executes? (Operation stops? / Moving to islanding operation?) |
| | **III-3-c** What event detection is defined as the Main grid return? |
| | **III-3-d** When the Main grid return is detected, what sequences the Mini-grid executes? |
| **III-4** Reverse power flow | **III-4-a** Is reverse power flow allowed? |
| | **III-4-b** (In case reverse power flow is not allowed)<br>What method is adopted for detection of reverse power flow?<br>When reverse power flow is detected, what sequences the Mini-grid executes? |
| | **III-4-c** (In case reverse power flow is allowed)<br>Is there any money transaction contract between the Main grid side and the Mini-grid side? (Selling electricity by a price, Paying a kind of service fee, etc..) |
| **III-5** Interconnection (*1) | **III-5-a** What do you think is the primary obstacle to active interconnection (e.g. technical problem, regulatory issue, cost constraint)? How do you think it should be overcome? |
| **III-6** Measures for power quality stability in case of connection/disconnection of the Mini-grid to the Main grid | **III-6-a** What measures are adopted now? |
| | **III-6-b** What measures do you hope or plan should be adopted in future? |
| **III-7** Measures for power quality stability from the different views | **III-7-a** What measures are adopted now? |
| | **III-7-b** What measures do you hope or plan should be adopted in future? |

(*1) Interconnection means the Mini-grid is not a slave to the Main grid but the two are cooperative to each other for keeping the voltage in case of the grid voltage dip.

IEA INTERNATIONAL ENERGY AGENCY

ISBN 978-3-906042-04-6

9 783906 042046 >