BRINGING TOGETHER INTERNATIONAL RESEARCH ON HIGH PENETRATION PV IN ELECTRICITY GRIDS – THE NEW TASK 14 OF THE IEA-PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

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ABSTRACT: This paper presents the approach and objectives of the new IEA-PVPS[1] [1] Task 14 on "High Penetration PV in Electricity Grids" which aims at reducing the technical barriers to achieving high PV penetration levels and thus promoting the use of grid connected PV as an important source in electric power systems. Task 14 will focus on working with utilities, industry, and other stakeholders to develop the technologies and methods enabling the widespread deployment of distributed PV technologies into the electricity grids. Using the highly accepted dissemination tools of IEA PVPS easy access to the main findings of the work is expected to mitigate concerns of high penetration PV to the benefit of a large number of countries.

Keywords: Grid connected PV, high penetration, international collaboration

1 INTRODUCTION

The market for grid-connected PV has been growing rapidly over recent years. Currently, the world-wide cumulative grid-connected PV capacity is estimated to have reached levels of more than 20 GW [2] with long term growth rates expected to continue spurred by falling costs and new market incentives announced in various countries around the world. The development is also highlighted by the fact that PV represented 17% of the electricity generation capacity added in the European Union during 2009.

As PV continues to expand its share of the global electricity generation mix, it becomes increasingly important to understand the key technical challenges facing high penetrations of PV within power systems. Key issues include the variable and somewhat unpredictable nature of PV generation, the power electronics interconnection to the grid and its location within an electricity network typically designed only for supplying loads. Power system protection, quality of supply, reliability and security may all be impacted.

Due to the different characteristics of PV compared to other renewable generation in all of these regards only limited lessons can be learned from more established intermittent renewable technologies such as wind generation.

Overcoming the technical challenges will be critical to placing PV on an even playing field with other energy sources in an integrated power system operation and augmentation planning process and will allow PV to be fully integrated into power system, from serving local loads to serving as grid resources for the interconnected transmission and generation system.

2 APPROACH

Although PV remains very small contributor to electricity generation in most of the countries, the nature of its deployment means that already today, significant penetrations have become reality at local and even regional scale.

Recognizing that a limited number of high-penetration PV installations currently exist, their effects on the reliability of grid operations are the subject of research programmes in a number of countries around the globe. Even though there are not many representative cased studies, it is important to discuss these in a collaborative manner. With further growth of distributed as well as centralized PV capacities, the need for international R&D collaboration to address this evolving field and to collect and disseminate international knowledge of PV systems at high penetration levels is becoming critical for the further large-scale deployment of PV.

Against this background, a new work item, has been developed within the framework of the IEA-PVPS programme during 2009. This new Task 14 will focus on the role of PV in electricity grid configurations with a high penetration of Renewable Energy Sources (RES), where PV constitutes the main RES. Although up to now, no common definition of "high-penetration PV scenarios"

[1] International Energy Agency - Photovoltaic Power Systems Programme; www.iea-pvps.org

exists, there is common consensus that high penetration situation exists if additional efforts will be necessary to integrate the dispersed generators in an optimum manner.

While penetration levels of PV discussed in the literature are based on general experience from DG (not only from RES), Task 14 will analyze the particular issues related to the penetration of PV in electricity grids and establish penetration scenarios in order to show the full potential of grid integrated Photovoltaics.

Easy access to the main findings of the reports are expected to mitigate concerns of high penetration PV to the benefit of a large number of countries.

By international collaboration, issues relating to the role of PV in the future electricity supply system will be investigated, particular facing future high-penetration scenarios, which are now becoming reality in a number of locations around the globe.

The main goal of Task 14 is to facilitate the use of grid connected PV as an important source in electric power systems on a high penetration level where additional effort is be necessary to integrate the dispersed generators in an optimum manner. The aim of these efforts is to reduce the technical barriers to achieving high penetration levels of distributed renewable systems on the electric power system. Due to the fact that a number of distribution system integration-related issues are emerging first for PV systems, Task 14 will focus on working with utilities, industry, and other stakeholders to develop the technologies and methods enabling the widespread deployment of distributed PV technologies into the electricity grids.

The work programme of Task 14 addresses mainly technical issues, including energy management, grid interaction and penetration aspects related to local distribution grids and central PV generation scenarios, including integration in buildings and focus on multifunctional inverters as a smart interface between PV and the electricity system.

Following two Task Definition Workshops which took place in Sydney in late 2008 and Montreal in August 2009, a comprehensive work programme has been developed by international collaboration of experts from ten countries. In October 2009 this new Task 14 was officially endorsed by the Executive Committee of the IEA-PVPS programme. The kick-off meeting which took place in Vienna, Austria in April 2010 marked the official start of the activities.

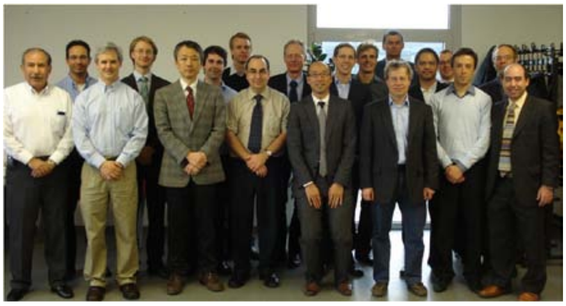

Fig. 1 The Task 14 experts at the Kick-Off Meeting at AIT, Vienna

3 TECHNICAL CHALLENGES WITH HIGH PENETRATION OF PV ADDRESSED BY TASK 14

Increasing penetration PV in electricity grids brings a broad variety of technical challenges, which have to be dealt with. Within the Task 14 group, the main technical challenges have been identified and categorized in order to be able to effectively analyze and investigate methods and solutions.

3.1 Challenges & issues at the local distribution level

In the local LV and MV distribution grids, increasing penetration of PV mostly creates challenges with respect to maintaining voltage levels and voltage quality. In addition, increasing levels of distributed generation have a strong impact on the functioning of the existing protection and distribution infrastructure. The widely existing lack of information on the state of the distribution network and insufficient communication and real-time data processing makes it difficult to evaluate and assess the influence of PV generation down to the “last mile”.

Furthermore, the lack of PV visibility and (commercially available) control capability of PV systems creates a situation of uncertainty, in particular during critical situations in the grid.

3.2 Challenges from an overall system wide perspective

It is expected that the operation of Electric Power System will become increasingly complex with the presence of higher and higher penetration of PV. At certain penetration levels, PV will be replacing conventional generation which leads to additional challenges. Capabilities of existing power plants such as ramping and control functions will need to be improved and extended to cope with the new requirements.

Moving the generation to the distribution level will lead to changing of system behavior during critical situations (e.g. loss of a large generator), e.g. simultaneous tripping of a large number/capacity of small scale PV systems or loss of inertia today provided by central (rotating) generators. Current central EMS at the system level are in many cases not prepared to monitor and operate dispersed Renewable Energy (RE) generation.

3.3 EPS planning challenges with high level of PV generation

Current EPS planning tools do not have the necessary capabilities to model power systems with high RE penetration. There is a broad lack of validated models for RE generation, particularly for inverter based generation (as PV). Also, the current tools used for system planning are commonly not prepared to deal with high numbers of small scale generators – typically PV. Furthermore, there is a strong need for high-resolution, solar resource data, which is necessary for conducting system augmentation planning and operation planning studies.

4 ORGANIZATION OF THE IEA-PVPS TASK 14

4.1 Overview

Task 14 will address mainly technical issues with high penetration of PV in electricity networks. Technical issues include energy management aspects, grid interaction and penetration aspects related to local distribution grids and central PV generation scenarios.

A strong focus will be on inverters with multifunctional characteristics which act as the interface between the generator and the electricity network. In order to evaluate the aforementioned technical issues, modeling and simulation techniques will be applied.

Work in pursuit of the foregoing objectives will be performed by photovoltaic system specialists, engineers and researchers working in the fields of planning, installation and research in the Participants' countries.

The work programme is organized into four main subtasks and one cross-cutting subtask, which will be the link between the main subtasks.

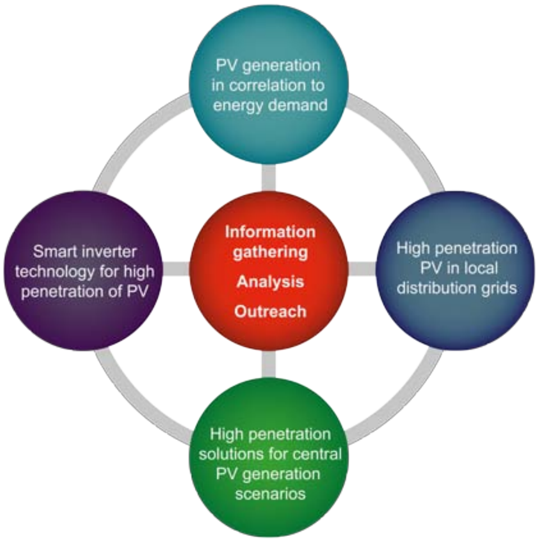

Fig. 2 Organization of the new IEA-PVPS Task 14

4.2 Cross-cutting Subtask:
Information Gathering, Analysis and Outreach
Subtask lead: CanmetENERGY, Canada

The scope of this subtask is to collect and share state of the art information amongst the various tasks as well and collating information for the general public. The objective is to review and document worldwide implementations of high penetration PV scenarios into electric power systems and based on subtasks work, generalize and refine them to generate a set of convincing cases of safe and reliable implementation. It has the following activities:

- *Setup a repository for information and models exchange*
  This work will put together an exchange platform that will allow all members to input information and modeling files. This platform will be accessible to Task 14 members as well as key researchers they have designated in their respective countries.

- *Collect state of the art information about existing high penetration PV installation including:*
  To establish the base case of high penetration scenarios and have the necessary information for subtasks to start working, this activity will lead a data collection phase, which will include a review of the current literature as well as information on existing systems in the various countries. In order to carry this work in a pertinent manner, subtasks 1-4 will provide the CC subtask with a list of the parameters necessary for their work. An assessment of the current state of the art will be performed and a report on the state of the art and a collection of cases will be prepared.

- *Gather a collection of existing modeling cases for existing installations*
  In order to facilitate and ensure repeatability of their modeling work, task members will have to share their experience and follow consistent approaches for their development work. While it is well admitted that each group may use different platforms for various reasons, the mathematics and physical reasons governing the model should be transposable from one platform to the other. The work of this activity is to collect existing knowledge in an ordered manner and deduct commonalities and differences.

- *Using the knowledge developed in the various subtasks*
  Task 14 work will involve the refinement of numerous models to reach a better integration of PV to the grid. This activity endeavors to merge the findings and advanced control techniques developed in the various subtasks and come up with a set of pertinent cases/scenarios that can be useful to the industry and utilities worldwide in solving PV integration issues.

4.3 Subtask 1:
PV generation in correlation to energy demand
Subtask lead: Planair, Switzerland

The subtask deals with local solutions to improve PV penetration in grids without large infrastructure investment. The objective of the task is to show and determine how with better prediction tools, an optimized local energy management and a better understanding of temporal fluctuation PV penetration level can be improved in grid. Case study will be oriented to demonstrate the feasibility of local high PV penetration in grid (different penetration scenarios and different urban scale in case studies).
The task has the following activities:

- *Review monitoring tools and adapt prediction tools to anticipate the shift in local grid*
  This activity will review monitoring and adapt prediction tools to anticipate the shift in local grid to answer to the prediction need of utilities (interaction on solar resource prediction with task 36 of IEA SHC [3])

- *Review and analyze local storage and energy management system to improve the penetration of PV in local grid (Network driven demand side management from a house to a city level).*
  A review of Demand Side Management (DSM) – PV approaches in different countries, including profiling

(annual,…) will be made. The necessity of storage (options) will be investigated in order to achieve an optimum scale for micro smart grids.

- *Characterize temporal fluctuations in relation to local weather conditions according to the topology of the PV plants (small urban plants with different orientations, MW PV plants) to improve short terms predictions.*

4.4 Subtask 2:
High PV penetration in local distribution grids
Subtask lead: Fraunhofer IWES, Germany

Subtask 2 addresses the Identification and Interpretation of the Role of PV in Distribution Grids and includes an Impact Analyses of high PV penetration in Distribution Grids and concludes with recommendations on grid codes, incentives and regulation. It has the following four main activities:

- *Review of State-of-the-Art of actual and future Distribution Grids with High PV Penetration:* Information provided by distribution system operators will be used to review the current state of distribution grids with high PV penetration in a number of case studies. The grid operator's expectation of the required future grid expansion can be used to identify the future challenges. Upon these evaluations gaps between state-of-the-art and future high PV penetration grids will be identified. This will be compared with information from different countries to identify best practice examples that may be a reference for challenges and solutions.

- *Optimized Reactive Power Balancing in distribution grids: Review of optimization approaches and comparison of impacts on country-specific grids* Possible optimization approaches for reactive power control, such as central coordinated control and local unit parameterization, will be reviewed. Leading experts (e.g. in Austria, Germany, US, Australia and Japan) already have developed approaches that will be analyzed with regard to their applicability in other participating countries. On the basis of grid simulations the different impacts on country-specific grids with high PV penetration will be analysed. Aspects to be regarded are voltage stability, losses, component heating and economical impacts. These parameters provide measures to assess the technical effectiveness and economic efficiency of the analyzed approaches of reactive power balancing for country-specific distribution grids in an international benchmark.

- *Optimized Active Power Control Strategies in distribution grids: Review of optimization approaches and comparison of impacts on country-specific grids*
  Possible optimization approaches for active power control, such as energy management and curtailment strategies, will be reviewed. Leading experts (e.g. in Austria, Germany, US, Australia and Japan) already have developed approaches that will be analyzed with regard to their applicability in other participating countries. Grid simulations and cost-benefit analyses are used for the investigations and comparisons.

- *Change from Distribution to Supply Grids and Dynamic Studies*
  Case studies of distribution grids in different countries with high PV penetration that have changed to supply grids (at least at certain periods of time reverse power plows) are analysed. Dynamic simulation studies assess the challenges and impacts for grid operators. Possible solutions for improving the security of supply and efficiency will be investigated**.** Steady-state, dynamic simulations and transient simulations will be used and complemented with cost-benefit-analyses.

4.5 Subtask 3:
High penetration solutions for central PV generation scenarios
Subtask lead: University of Tokyo, Japan

Subtask 3 addresses the PV integration into power systems from the total power system view point. In order to realize high PV penetration to a power system, it is crucial to evaluate the impact and envision the future power system. The focus will be laid on grid interaction and penetration related aspects. Gaps in current PV system technology and electric power system operation practises will be identified. Furthermore, detailed analyses, how large numbers of PV installations can be successfully integrated total power system including the technology of smart grids will be made.

- *System-wide PV generation analysis and forecast:*
  This activity will survey and review the existing methodologies to analyze and forecast the system-wide PV Generation including smoothing effects. Methodologies considering the applicability to different structures of power markets for different forecast-range and accuracy will be evaluated, in order to conduct simulation case studies for selected regions.

- *Power system operation planning with PV integration*
  Existing methodologies for long-term power system operation planning including PV integration and Demand Side Management/Demand Response technologies for DSM/DR will be reviewed, in order to develop criteria and scenarios for case studies including applicability of new technologies such as power storage, generation load dispatch, and DSM/DR.
  Based on the outcome, simulation case studies of long-term power system operation planning for selected regions will be conducted.

- *Power system augmentation planning with PV integration*
  This activity will evaluate and select one or more methodologies and technologies for long-term power system augmentation planning including PV integration. Criteria and scenarios including new generation technologies, fossil fuel availability and price, power system demand, and energy policy will be developed and simulation case studies will be made for selected regions in order to distill the generic scenarios of PV integration.

4.6 Subtask 4:
Smart inverter technology for high penetration of PV
Subtask lead: AIT Austrian Institute of Technology

PV inverters play a key role as interface between PV generation and the electricity grid and integrate grid protection, system monitoring and control functions and also act as interface to storage. Subtask 4 addresses the inverter technology, technical requirements and standards, and system integration aspects for successful smart integration of a high penetration of PV by effectively applying the opportunities offered by modern power electronics. The activities include:

- *Outline of opportunities for smart PV inverters in high-penetration scenarios*
  Current functional, protection, control, safety and other requirements for inverters will be reviewed and the impact of different applications (residential vs. utility scale), connection levels (Low Voltage, Medium Voltage, etc.) and network topologies (feeder length,…) will be investigated in order to define performance, operating ranges and utility compatibility with high penetration PV.

- *Analysis of technical capabilities and Inverter Topologies including simulation modeling of devices*
  A collection and review of the suitability of different hardware and control topologies for the application in High PV Penetration scenarios will be made. The impact of additional functionalities on the design, dimensioning and performance of PV inverters will be investigated, aiming at the improvement of available inverter simulation models.

- *Review and Analysis of remote control and communication for Smart Inverters*
  This activity will include a review of remote control practices (interfaces, communication technologies, protocols…) and currently available communication standards suitable for Smart Inverters. The aim is to assess the suitability of current standards/practices for high PV penetration scenarios.

3 CONCLUSIONS

The new IEA PVPS Task 14 will offer a forum for experts from all IEA countries to share knowledge on the grid integration of PV in high penetration scenarios. Currently, experts from research as well as industry from Australia, Austria, Canada, Denmark, Germany, Italy, Israel, Japan, Norway, the U.S.A, Sweden and Switzerland are participating in Task 14.

Task 14 will as a task have focus on technical issues related to the grid and will have utilities, grid operators, transmission system regulators, energy authorities and industry as stakeholders.

This activity will provide added value by contributing to a common understanding and a broader consensus on how to adequately evaluate the value of PV in high penetration by showing the full potential of grid integrated photovoltaics. Using the highly accepted dissemination tools of IEA PVPS easy access to the main findings of the work is expected to mitigate concerns of high penetration PV to the benefit of a large number of countries.

6 REFERENCES

[1] Website of the IEA Photovoltaic Power Systems Programme http://www.iea-pvps.org/
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