TAMPERE UNIVERSITY OF TECHNOLOGY

The Finnish Solar Revolution Project

ETIP-SNET Workshop, Espoo, Finland

October 3-4, 2018

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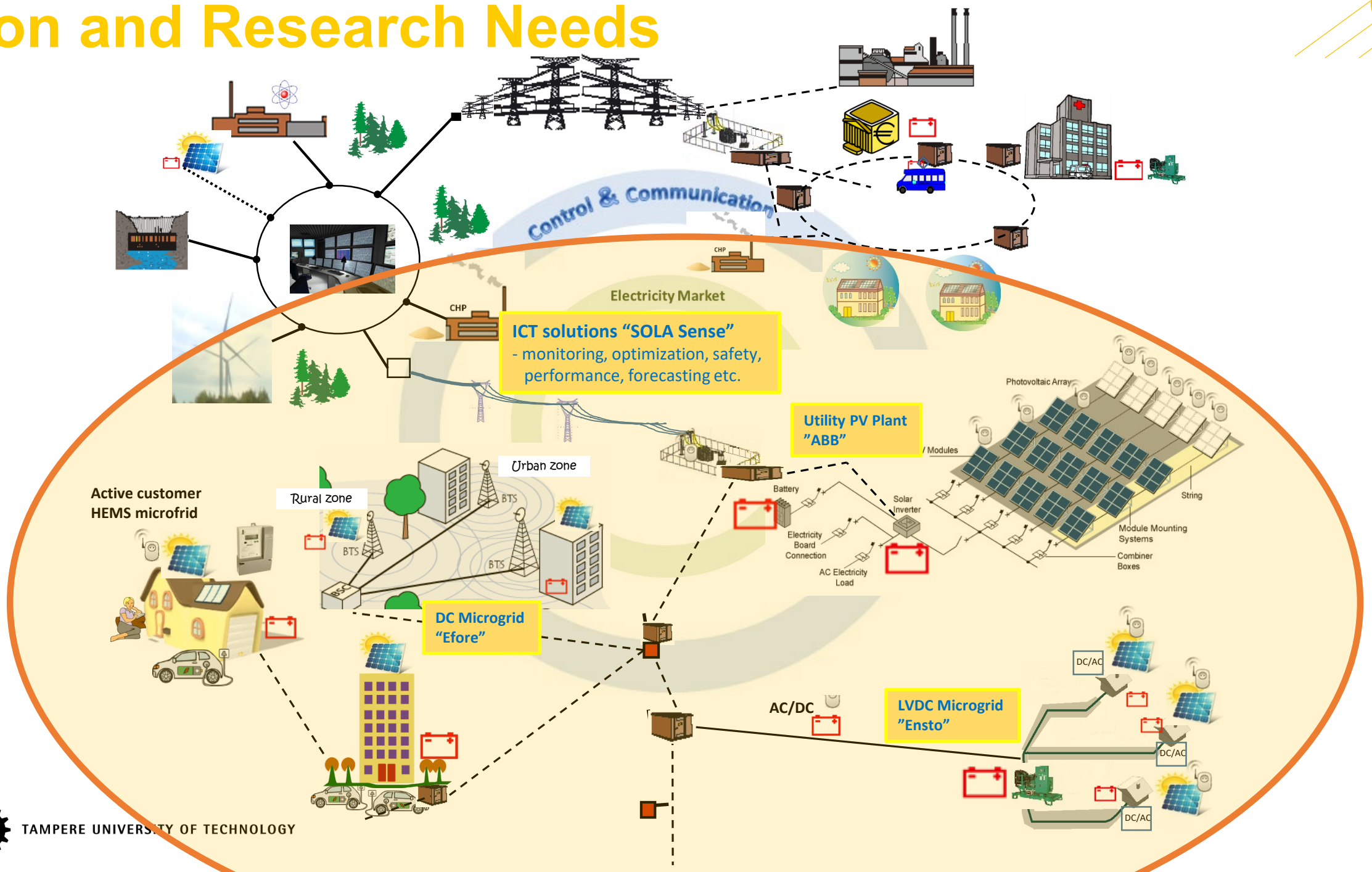
Tampere University of Technology

Vision and Research Needs



Co-Innovation Consortium

Finnish Solar Revolution

Company Specific Research projects

ABB	Efore	Ensto	Sola Sense
(30 FTE)	(5 FTE)	(1 FTE)	(10 FTE)
Subcontracting from Universities: 5	2	1	1

Public Research Project

(9 researchers)

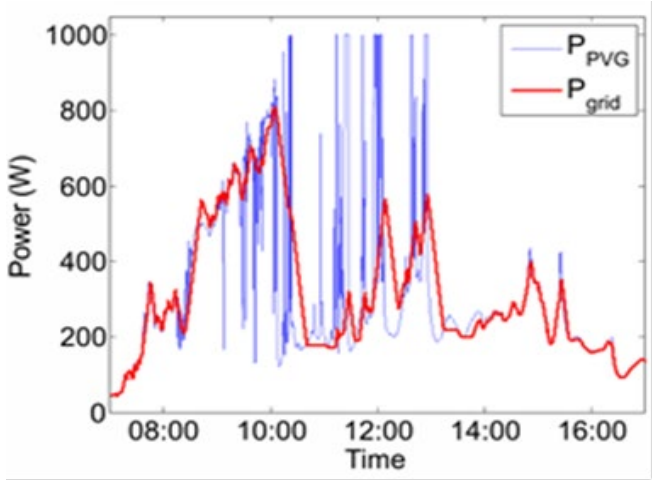
Universities: Aalto, LUT, TUT

Companies: ABB, Ainoenergia, Caruna, Convion, Eaton, Efore, Elenia, Ensto, Fortum, Lempäälän Energia, MX Electrix, Nocart, Sola Sense, Tampereen Sähkölaitos, Tampereen Sähköverkko

FTE = Full Time Employee

Project overall objectives

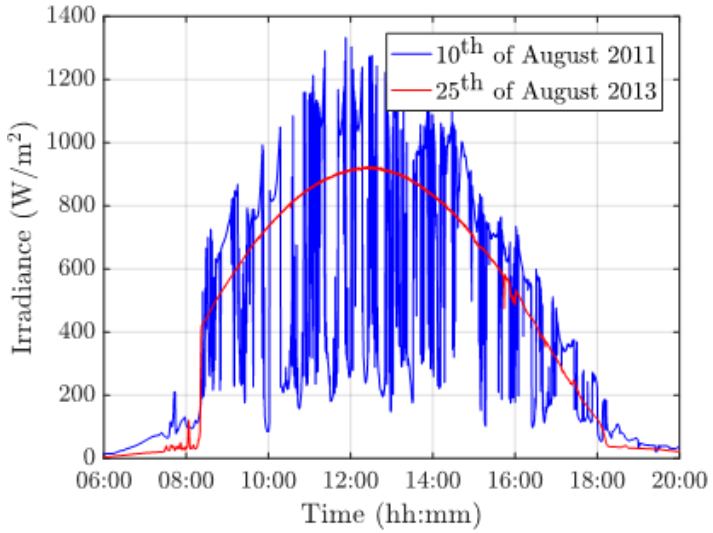
- The aim of the research consortium is to ensure that the companies have the leading edge scientific knowledge on their disposal on the main future technology and business concept trends related to global solar PV power production.
- Due the increasing share of solar PV power production the following research focus areas were identified for the project:
  - Requirements for energy storages to compensate PV power fluctuation and maintain power balance
  - Balance, control, operation and power quality of PV powered micro grids
  - Grid stability with high level of renewables
  - Reliable and efficient operation of PV power generators and reliability of PV converters
  - Future of the renewable business including market, system and technology development scenarios



1 kWp PV generator power and smoothed grid feed-in power by the use of battery storage.

Project main outcomes

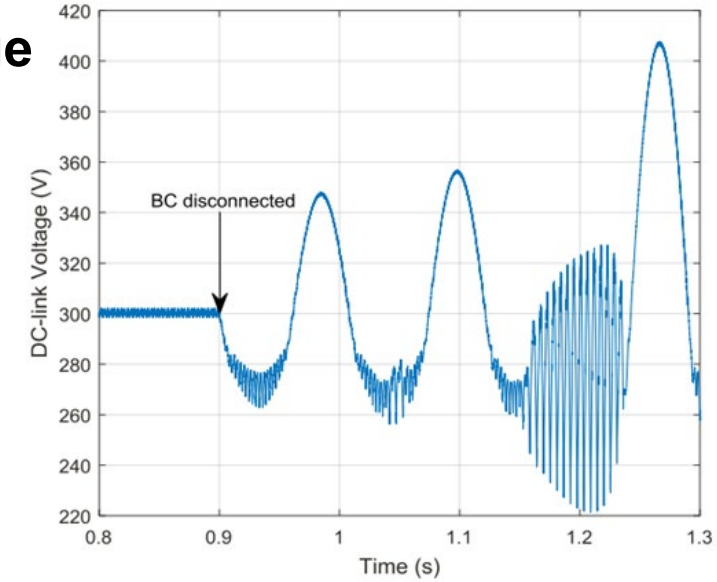
- Irradiation fluctuations alone does not cause **flicker limit violations** of PV power production.
- An **instantaneous active/reactive control** is proposed to reduces the load induced flicker.
- A **coordinated voltage control method** is proposed being capable to increase distribution grid hosting capacity up to 45% and to decrease PV curtailment by 30% in cases of distributed PV generation.
- **Shading transitions caused by overpassing moving cloud** are now fully analyzed and understood as well their effects on PV generators.
  - Speed, duration, shading strength, mismatch losses, maximum power points etc.
- Also the frequency, duration, area and strength **of irradiance enhancements caused by clouds** has been analyzed systematically based on experimental measurements.
  - They have an impact on the operation of PV plants of all sizes.
- Momentary irradiance enhancement increases the PV generator output current and power, but can also increase the PV inverter operational voltage in case of power curtailment.



Irradiance on a partly cloudy day on 10th of August 2011 and on a clear sky day on 25th of August 2013.

Project main outcomes

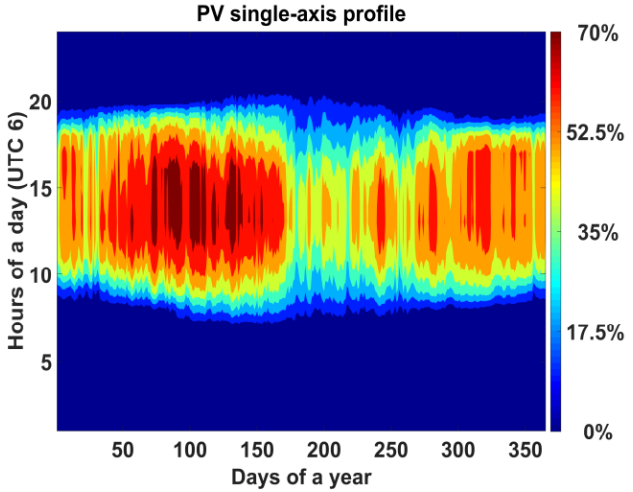
- Small-signal model of a **grid-forming three-phase PV inverter** has been developed to optimize control performance when the PV inverter feeds various loads, i.e., the grid impedance changes due to varying load
- Dynamic models of **PV inverter with electrical energy storage** have been developed:
  - Small-signal model of a grid-forming three-phase inverter with electrical battery storage
  - A method to analyze the relative stability of DC voltage
  - A method to include the dynamic effects of source and load impedances in to the model
- Hardware In the Loop (HIL) platform has been used in model verification

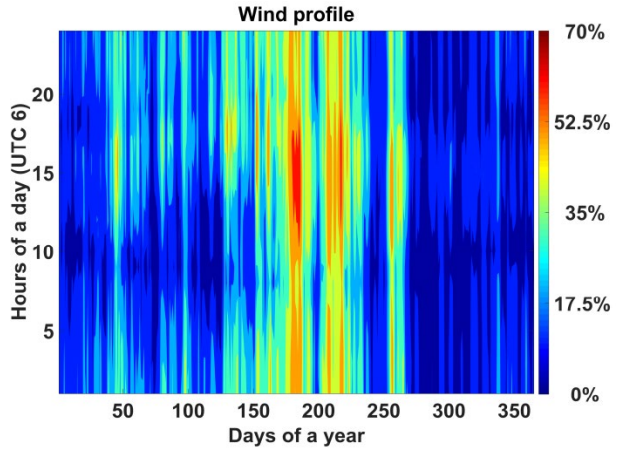


Battery storage stabilizes the DC link voltage, which becomes unstable when the storage is disconnected.

Project main outcomes

- **A fully renewable energy system is feasible** for India and the proposed system can effectively handle the monsoon period of reduced power generation from solar PV by increase in power generation from wind and hydro.
- **Artificial neural network** based data analysis methods have been developed to effectively compare and classify **acoustic signals** measured from systems, devices and components.
  - Better than 80% recall rate (accuracy) in capacitor defect detection.
- **Future PV power production business scenarios** have been made and related **research and development needs** have been identified.





Almost constant solar resource all year around in India and in the monsoon months wind overcomes solar resource unavailability.

Project main outcomes

- The total number **of published scientific journal and conference papers** will be close to 100 at the end of the project.
- The scientific publications are naturally key elements in **more than 10 ongoing PhD thesis projects**. The thesis will be defended soon after the end of the project.
- Co-operation with **international partner universities** has been very active and fruitful:
  - TU Dresden in Germany
  - University of Padova in Italy
  - North Carolina State University in USA
  - Aalborg University in Denmark
  - TU Kraz in Austria
  - Politecnico Torino in Italy
  - Texas AM University in USA
  - University of Salerno in Italy
  - Benha University in Egypt
  - University of Grenoble in France

The main lessons learned

- Fully renewable power production is feasible for almost everywhere in the World
- New ideas and approaches are worth of studying, like the use of acoustic signal measurements for device and component fault analysis
- The highly needed online monitoring and control of the operation of PV generators is a poorly understood research area with major challenges
- Current design of grid-feeding PV inverters is not optimal for grid-forming PV operation
- Adding an energy storage to PV inverters is not a simple plug & play procedure
- Energy storage can help in maintaining stability of DC link voltage in PV inverters
- The increase of PV power production will cause several new unexpected phenomena and problems to the electric power grid, but it can also open opportunities for new functionalities and solutions.

→ **We just need to be open for research having fresh new ideas.**

The need for further R&D

- To develop online monitoring and control methods of PV generators and systems, since very promising totally new research approaches have been initiated during the present project.
- The operation of micro grids powered solely by PV plants jointly with electrical energy storages is in need of major research efforts to be operational.
  - How to maintain power quality in micro grids, how to support frequency and voltage with PV inverters and electrical energy storages, guidelines for inverter control design procedure are needed, what are the limiting factors in grid support functions and design rules of PV inverters.
- Integration of the expanding PV power production in power systems, distribution networks and energy markets.
  - Can the hosting capacity of the grid be increased by novel inverter control methods using local reactive power control and real-time grid impedance measurement or by some other means?
  - How to maintain power balance, quality etc. with increasing solar PV production?

TUT Solar PV Power Research Plant