Smart Multi-Terminal DC μ-grids for autonomous Zero-Net Energy Buildings

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ITT Mandi | 14-15th December 2014 | Mandi, India

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Background: DC-μ-grids

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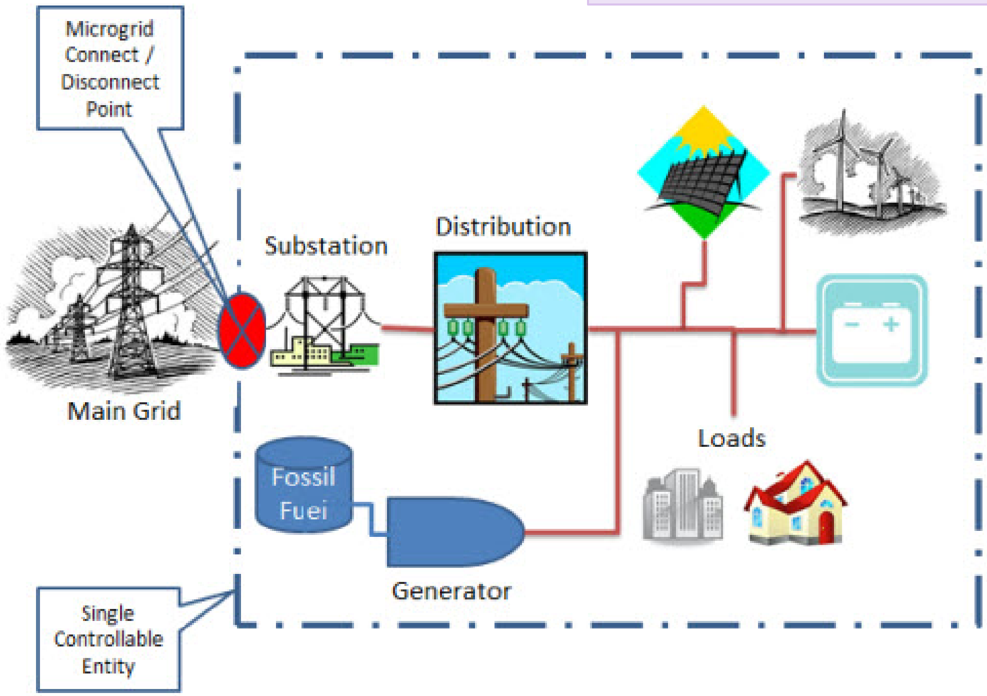
Micro grids (μg): Concept

- A **microgrid** is a local energy system which incorporates three key components; **Generation**, **Storage** and **Demand** all within a *bounded* and *controlled* network.
- It may or may not be connected to the **grid**.

Micro-grid Taxonomy

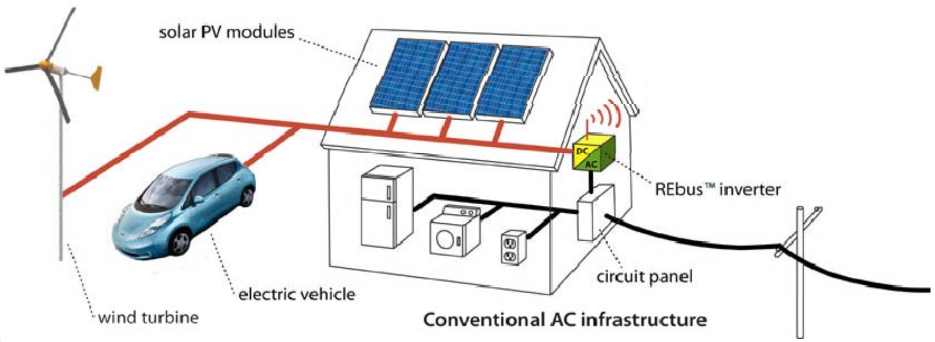
- Energy Supply
- Energy Storage
- Energy Load



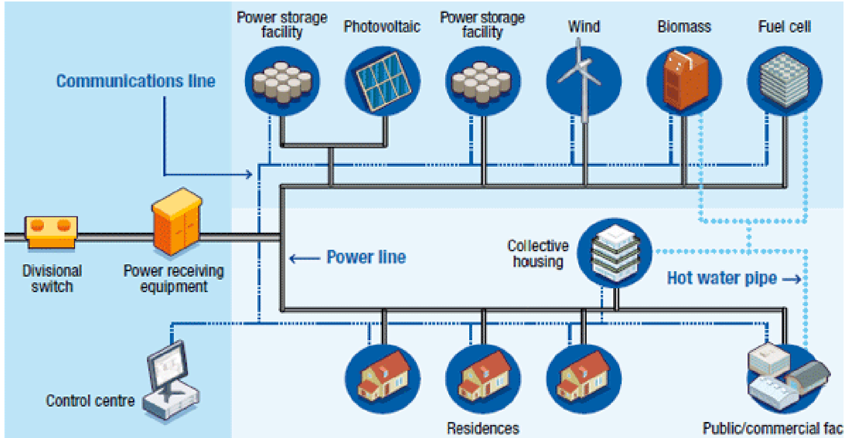
"A group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid [and can] connect and disconnect from the grid to enable it to operate in both grid connected or island mode." DOE USA

DC micro grids (DCμg)

- **DC micro grids** (DCμg) are designed to enable significant **energy saving** and the **simple integration** of advanced *low carbon technologies*.



Single building approach

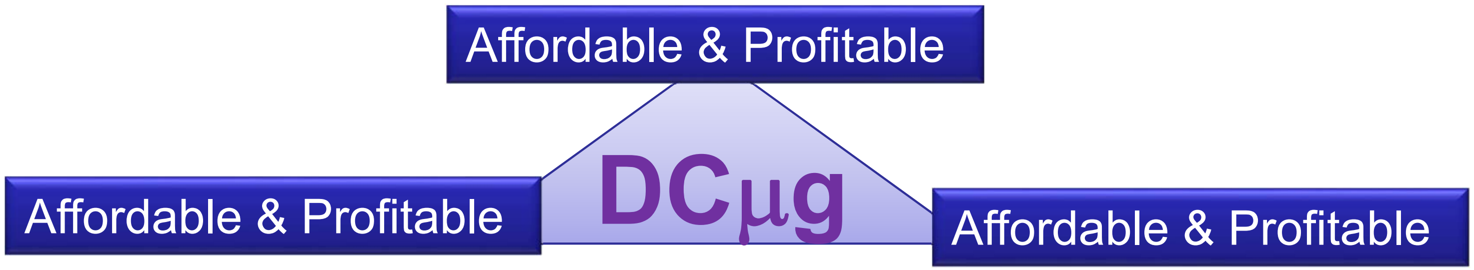


Multiple buildings approach

- Modern appliances run in **DC power** (batteries or connected to AC grid).
- Also, renewable generation technologies such as solar **photovoltaic** (PV) and wind become more and more prevalent at a household level, DCμg could be a cheaper and more efficient alternative

DCμg : Benefits

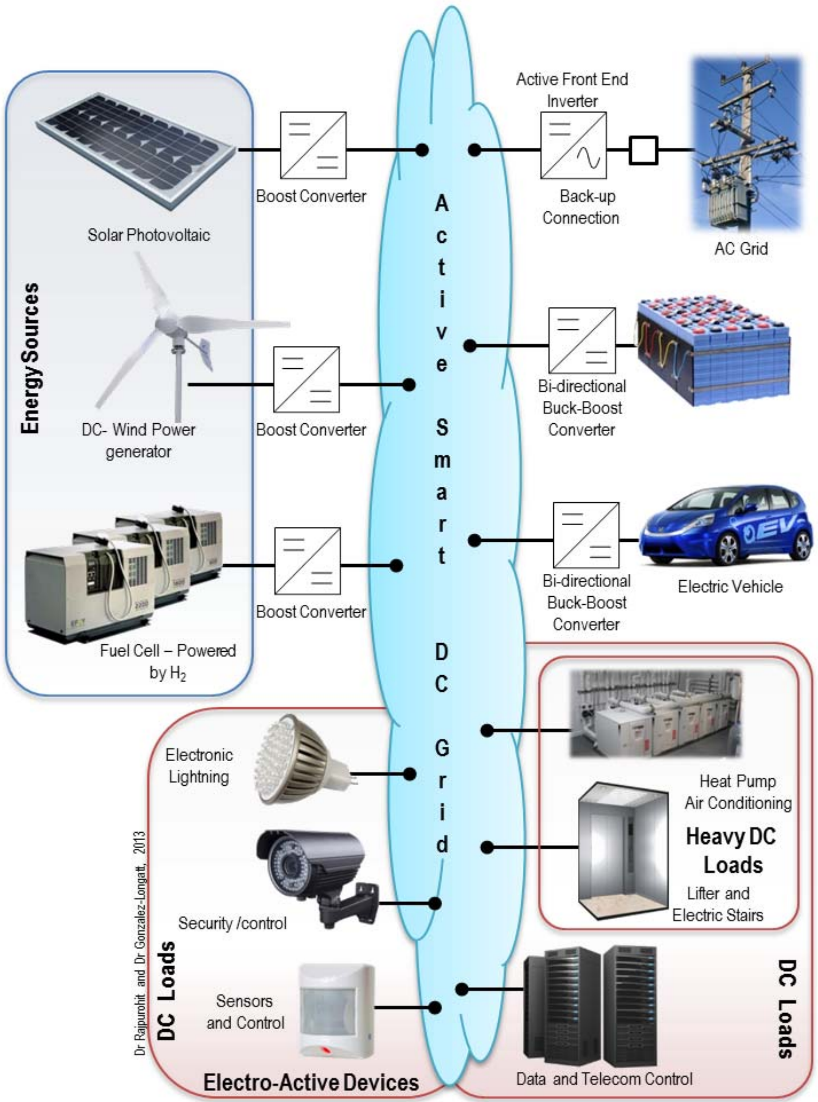
- **Reduces carbon footprint**
- **Generates revenue:** Reduced Energy costs
- **Helps consumers save money:** More efficient energy use (10% to 40%)
- **Increases Security and reliability**
  - Security against higher utility costs and more reliable service
  - Safer power at los DC voltages (e.g. $24V_{dc}$)
- **Makes the grid "futureproof"**
  - Highly scalable designs
  - Reduced future renovations costs
  - Percentage reduction in installation, moves and changes



Project Description

- DC μ-grid is an efficient way to interconnect **distributed energy resources** (DES) capable of providing sufficient and continuous energy to a significant portion (or total) of internal load demand.

- DC μ-grid can be deployed in a portion of a **building, building-wide** or **covering several buildings** that minimizes or eliminates entirely losses on conversion processes



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"The Concept"

"The CONCEPT"

- The Smart MTDCμg concept is a key component to create a building with <u>**zero net energy consumption and zero carbon emissions annually**</u>, known as **zero net energy building** (ZNEB).
- **ZNEB completely independent of the electricity grid** works solely with self-generated and distributed RES facilitating the goal of **100% sustainable** generation and **zero carbon emission**.
- Considering the modern use of electricity for other services (water, heat, communication, cooking, etc.), ZNEBs can be operated independently from infrastructural support services as an **autonomous buildings providing** an excellent solution for the electrification of rural areas in developing countries an alternative for urban areas everywhere.

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General Objective

Main Objective

- *To create a smart multi-terminal DC micro-grid capable to enable the development of autonomous zero net energy building.*
- This design is intended to facilitate India and UK **transition to a low-carbon sustainable electricity** the supply system for both urban and rural scenarios.
- The research plan is designed to realise this aim through an innovative and highly collaborative research programme involving **British and Indian partners**, which is mutually enriching and beneficial to both the countries.

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Specific Objectives

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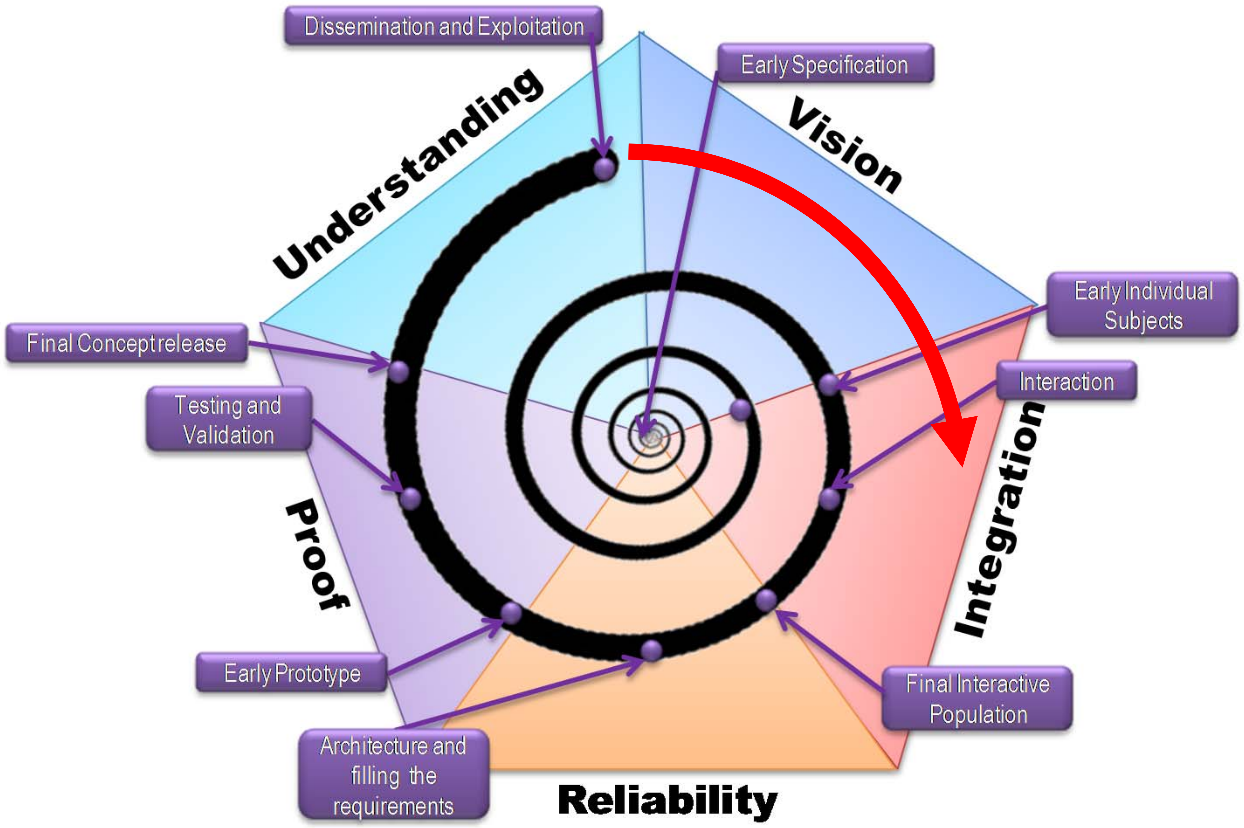
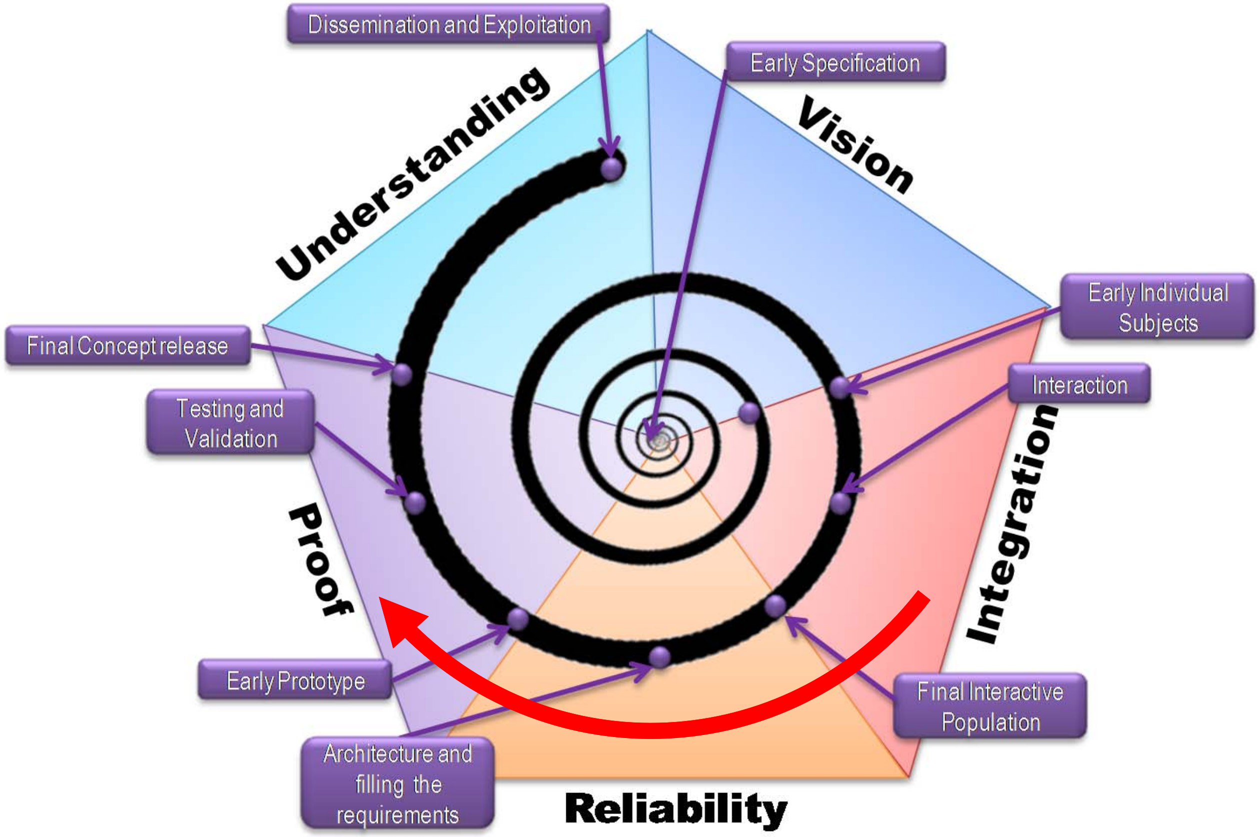
General Overview (1/3)

- **Vision:** To develop a shared and cross-disciplinary vision and project requirements;
- **Interaction:** To develop strategies, algorithms and models in order to define interactions of technologies, resources, communication systems and stakeholders.



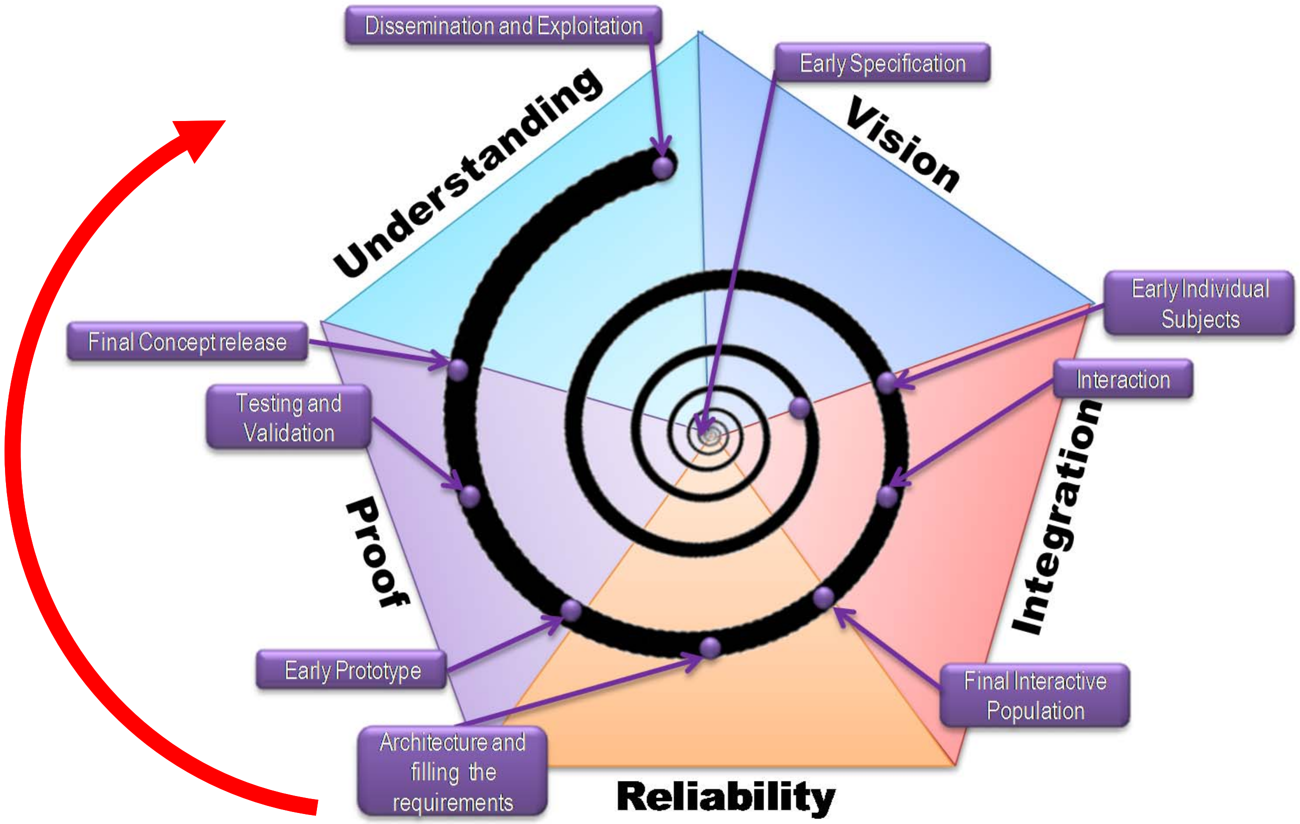
General Overview



- **Reliability:** To develop functional specifications, strategies, new functions and algorithms to ensure fulfil the project vision is fulfilled
- **Reliability:** To develop an architecture and information model suitable for the smart MTDCμg concept developed.

General Overview (2/3)

- **Proof:** To carry out simulations and tests using laboratory-based simulations, to test and validate the most promising solution and provide project outcomes.



- **Understanding:** disseminate and exploit the research outputs and results.

Specific Objectives (1/2)

1. **To develop a shared cross-disciplinary vision and project requirements** for a smart multi-terminal DC micro-grid (MTDCμg) systems to enable 100 % autonomous zero net energy building (aZNEB) for representative urban and rural areas in India and the UK;
2. **To develop strategies, algorithms, models in order to define interactions** of technologies, resources, communication systems and stakeholders in smart MTDC□g.
3. **To develop functional specifications, strategies, new functions and algorithms** to ensure an adequate, secure and cost-effective MTDCμg design, operation and management under the vision of a 100% aZNEB. A flexible design approach will be used, and an agent-based modelling framework to facilitate the transition to a low-carbon sustainable electricity supply system under considerations of urban and rural scenarios.

Specific Objectives (2/2)

4. **To develop an architecture and information model** suitable for the smart MTDC μg concept developed.
5. **To carry out simulations and tests using laboratory-based simulations**, to test and validate the most promising solution and provide project outcomes. Results of this testing and validation stage will provide capacity building, training and experimentation. Considerations about business models and institutional arrangements for practical implementation will be considered.
6. **To disseminate and exploit the research outputs and results**. This involves promoting the creation of a framework for the effective exploitation of the results considering different levels: local, sectoral, regional, national and European. The developed framework must have synergy with the communication activities and improve the research capacity through a two-way collaboration between partners and a training programme; and to engage in wider dissemination of the findings.

Advantages

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Advantages

- Reduced demand spikes.
- Better-Optimized power delivery providing reliability and redundancy.
- Conversion losses and line losses can be largely avoided.
- DC µ-grid has a superior compatibility of the DC power with electricity storage systems.
- DC µ-grid simplifies and raises the efficiency of how plug-in hybrid electric vehicles (PHEV) and electric vehicles (EV) connect to the grid.
- DC µ-grid simplifies provide the opportunity to integrate –at higher efficiency –renewable energy generators that are intrinsically DC sources

Challenges

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Challenges

- There are several challenges to face in the realization of the mentioned integrated Smart MTDCμg:

1. **Integrated design** and operations planning considering non-dispatchable RES with un-correlated primary source and constrained distributed energy storage systems.
2. **Real-time energy balance** considering 100% non-dispatchable RES (wind and solar power).
3. **Recovery energy** consumption of electricity **storage** systems after a major contingency.
4. **Risk of blackout** and large outages during adverse weather conditions.

Challenges

- Accordingly, this collaborative research project proposes to create a Smart MTDCμ-g capable of enabling a successful **100 % autonomous ZNEB**.
- This Smart MTDCμ-g design will consider the main aspects of the context in the case of **rural** and **urban** areas of the **UK** and **India**.

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Contributions

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Contribution (1/2)

- **The potential of emerging appropriate technologies** (e.g. off-grid solutions and decentralised and smart MTDCμg for rural areas, domestic DC demand management tools and DC smart metering infrastructure, smart sensing in rural areas, smart homes and buildings, integration of DC sources RES, innovative topologies for smart MTDCμg, development of new technologies for *Flexible DC transmission system* -FLDCTS among others).

Contribution (2/2)

- **Alternative business/ governance models**. Smart MTDCμg can be deployed in building-wide or covering several autonomous ZNEB to maximize the benefit, it open the door for potential research outcomes in the form of new codes, standards utility regulations, new federal and government tax law, opportunity of business model between Smart MTDCμg.
- **Innovative balance (supply-demand) management and system control/ operation strategies**. A Smart MTDCμg feed by 100% RES (solar and wind power) has a high risk of generation deficit during unexpected weather conditions; innovative design/operation techniques must be developed to cope with unforeseen events associated to RES and making energy storage system economically feasible.

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Work Plan

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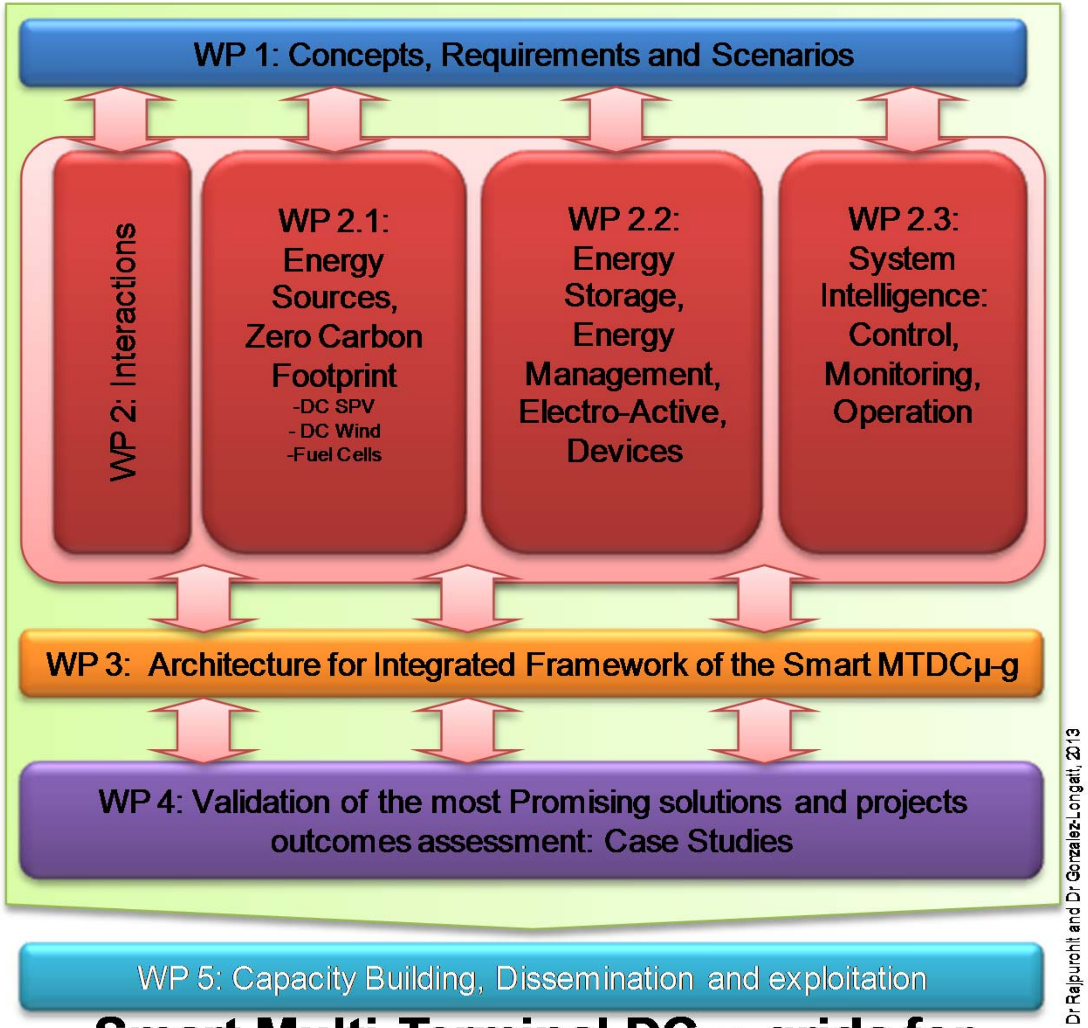
Work Plan



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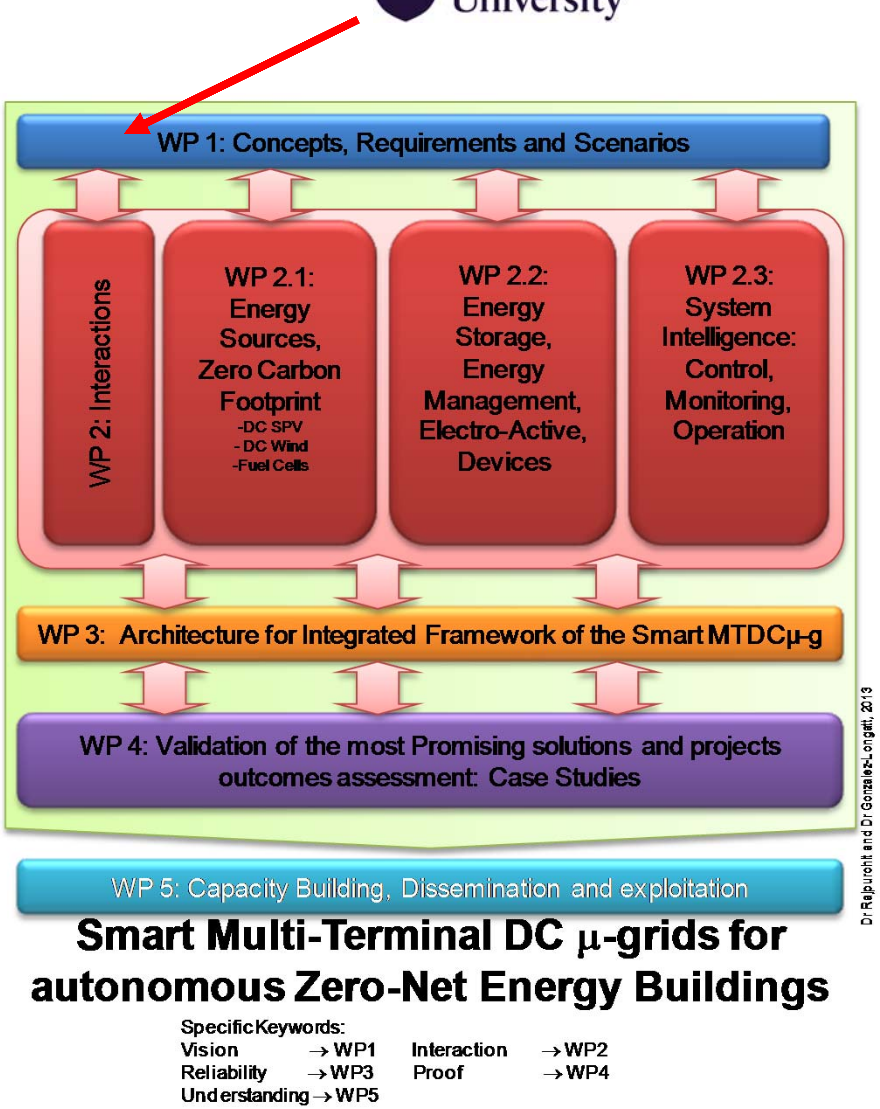
Specific Keywords:

Vision	→ WP1	Interaction	→ WP2
Reliability	→ WP3	Proof	→ WP4
Understanding	→ WP5		

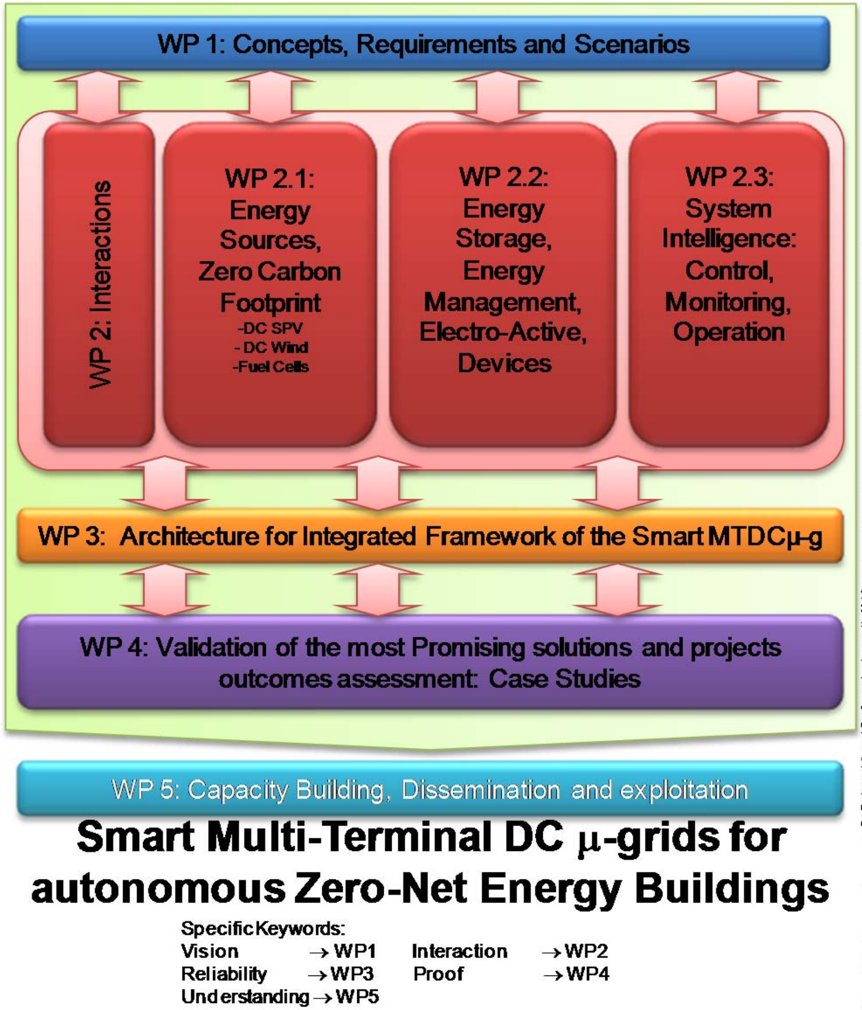
WP 1. Concept, Requirements and Scenarios –VISION



- **Task 1.1:** Develop the project concepts.
- **Task 1.2:** Define the requirements of a MTDCμ-g system to enable an aZNEB.
- **Task 1.3:** Define and select 4 scenarios to reflect different rural and urban representative areas in UK and India.

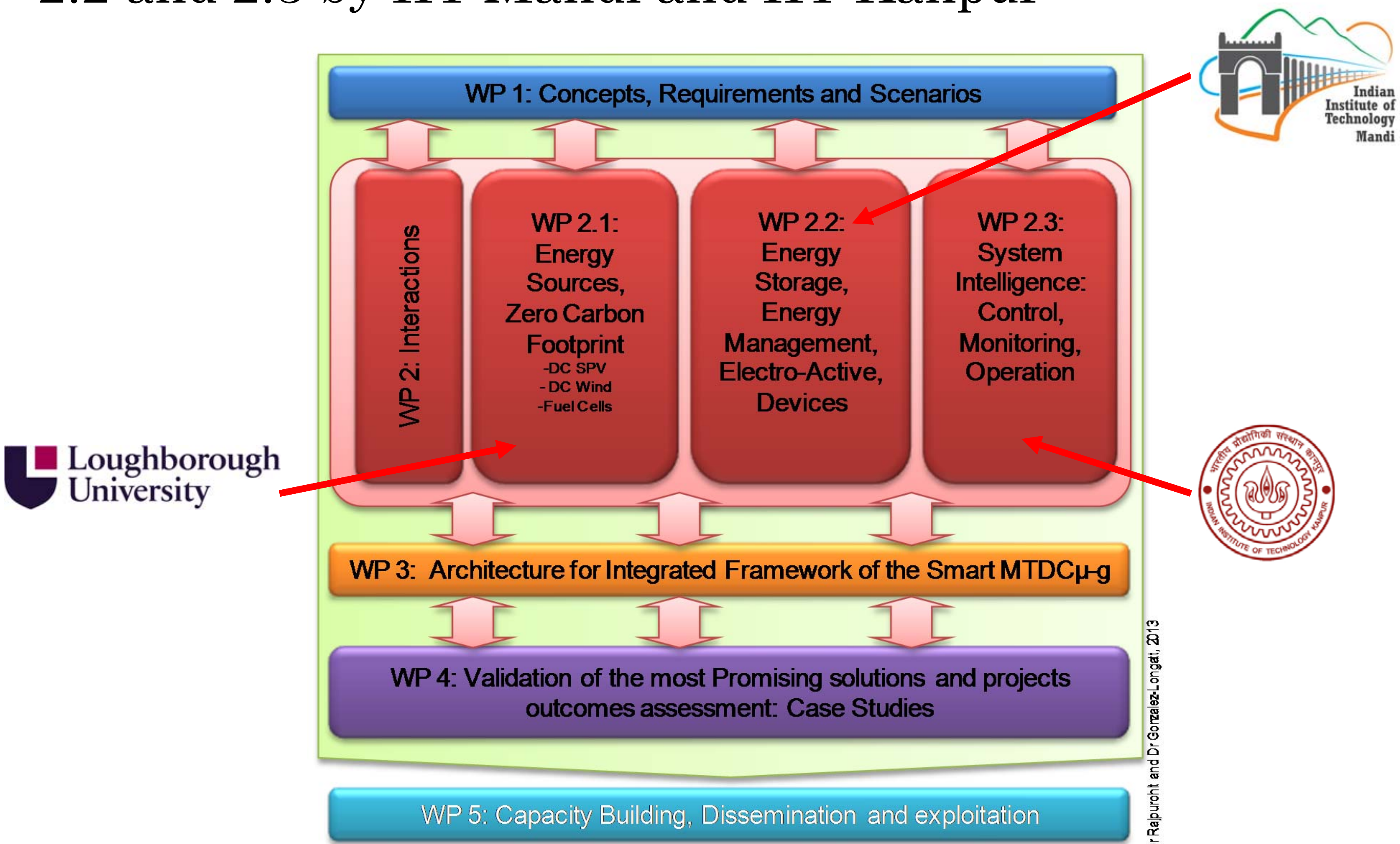
WP 2. Integration between Sub-system –INTERACTION

- (a) Developing strategies, algorithms and models in order to define interactions of technologies, resources, communication systems and stakeholders in smart MTDCμ-g and
- (b) Developing strategies, algorithms and models in order to define interactions of technologies, resources, communication systems and stakeholders in smart MTDCμ-g.



WP 2. Integration between Sub-system –INTERACTION

- WP 2.1 will be lead by Loughborough University and WP 2.2 and 2.3 by IIT Mandi and IIT Kanpur



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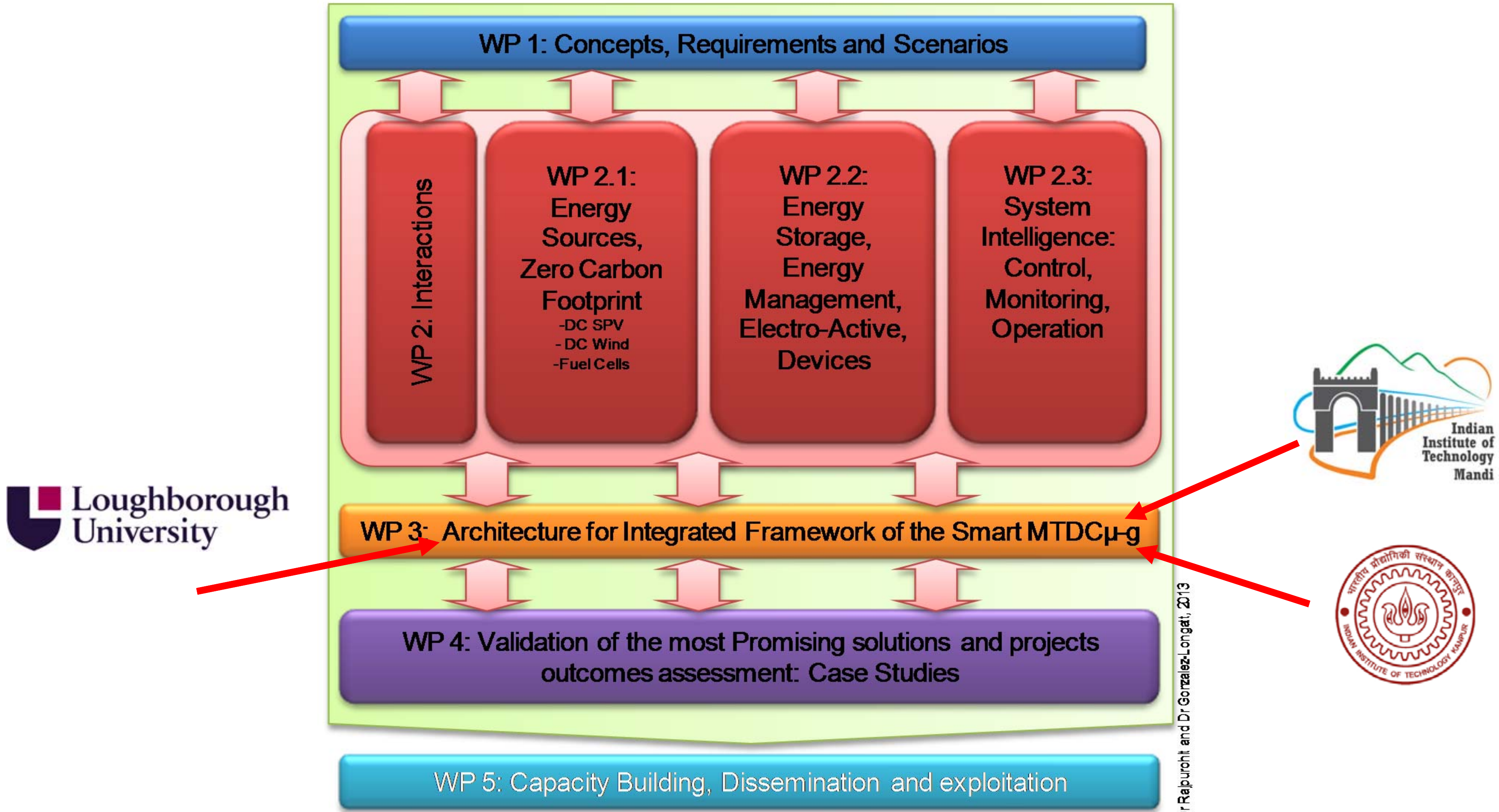
WP 3. Architecture of Integrated Framework of the smart MTDCμg – RELIABILITY

- **Task 3.1: Develop an appropriate architecture to integrate the subsystem of the smart MTDC-μg concept.** The issues of inter-connections, control, communication, operation and management of the systems will be considered at the technical level. The economic implications will be analysed in terms of pricing issues, investment requirements and market functioning.
- **Task 3.2: Develop a prototype for the integrated framework the proposed smart MTDCμg concept**.
- **Task 3.3: Evaluate the internal consistency and coherency the developed prototype in order to ensure the capability of aZNEBs.**

WP 3. Architecture of Integrated Framework of the smart MTDCμg – RELIABILITY

- The WP 3.1 will be lead by Loughborough University and WP 3.2 and 3.3 by IIT Mandi.



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WP 4. Testing and Validation of the most promising solution –PROOF

- **Task 4.1: Data collection preparation.** A suitable number of cases will be considered to develop a reasonable, representative picture. The initial data collection will run in parallel to the framework development which will be **led by the Indian teams**.
- **Task 4.2: Preparing the representative Indian and UK test cases.** Two case studies will be prepared by the Indian teams for the Indian rural and urban area.
- **Task 4.3: Carry out test and validation simulations. The validation of the model will be carried out laboratory facilities at IIT Mandi and IIT Kanpur** equipped with Real Time Digital Simulator and Opal-RT facilities, funded by DST, GoI, India.

WP 5. Dissemination and Exploitation of Results–UNDERSTANDING

- **Task 5.1: Research capacity building**. This development will be achieved through researcher training and undergraduate and post-graduate student training both in India and in the UK.
- **Task 5.2: Internet Presence and Website Development.** The website will survive the project and will be hosted at IIT Mandi.
- **Task 5.3: Publications in Conference and Journals.** The project will use publications for dissemination: 1) Academic peer-reviewed papers, book chapters and edited books; 2) Conference papers; 3) Workshops in the participating countries in India and UK, 4) Capacity building exercises.

WP 5. Dissemination and Exploitation of Results–UNDERSTANDING

- **Task 5.4: Presentations on international committees and working groups**
- **Task 5.5: Recommendation for standard committees, future R&D etc.**

Thanks
Any Question?

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1. **Project Concepts**
    - **Smart**
    - **Multi-Terminal**
    - **Micro-Grid**
    - **Autonomous**
    - **Zero Net Energy Building**
2. **Defining Requirements**

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Developing the project concepts

Developing the Concepts

1. Smart
2. Multi Terminal DC
3. Micro-grid
4. Autonomous
5. Zero-Net Energy Building

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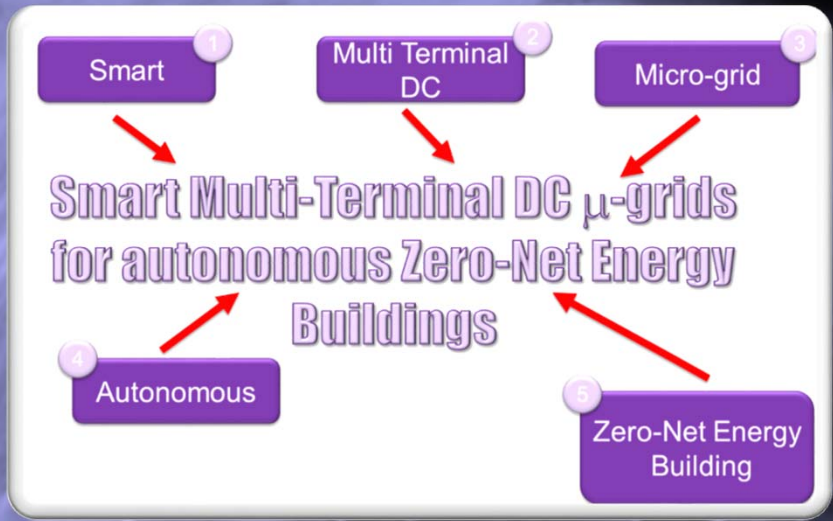
1. Smart



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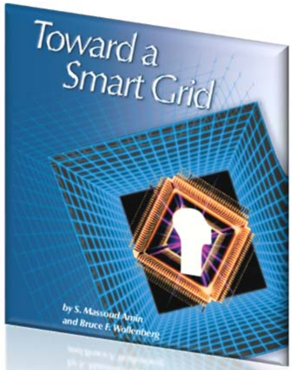
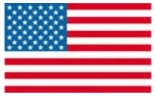
1. Smart

Smart



The term smart grid has been in use since at least 2005, when it appeared in the article "Toward A Smart Grid" by Amin and Wollenberg.



"Smart Grid / Department of Energy"

http://energy.gov/oe/technology-development/smart-grid

Smart Grids European Technology Platform

http://www.smartgrids.eu/

Department of Energy & Climate Change and Ofgem

https://www.gov.uk/government/policies/maintaining-uk-energy-security--2/supporting-pages/future-electricity-networks

A smart electricity grid that develops to support an efficient, timely transition to a low carbon economy to help the UK meet its carbon reduction targets, ensure energy security and wider energy goals while minimising costs to consumers

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/285417/Smart_Grid_Vision_and_RoutemapFINAL.pdf

Self-Healing to correct problems early
Interactive with consumers and markets
Optimized to make best use of resources
Predictive to prevent emergencies
Distributed assets and information
Integrated to merge all critical information
More Secure from threats from all hazards

Massive deployment in ICT
Intelligent systems
Distributed intelligent systems.

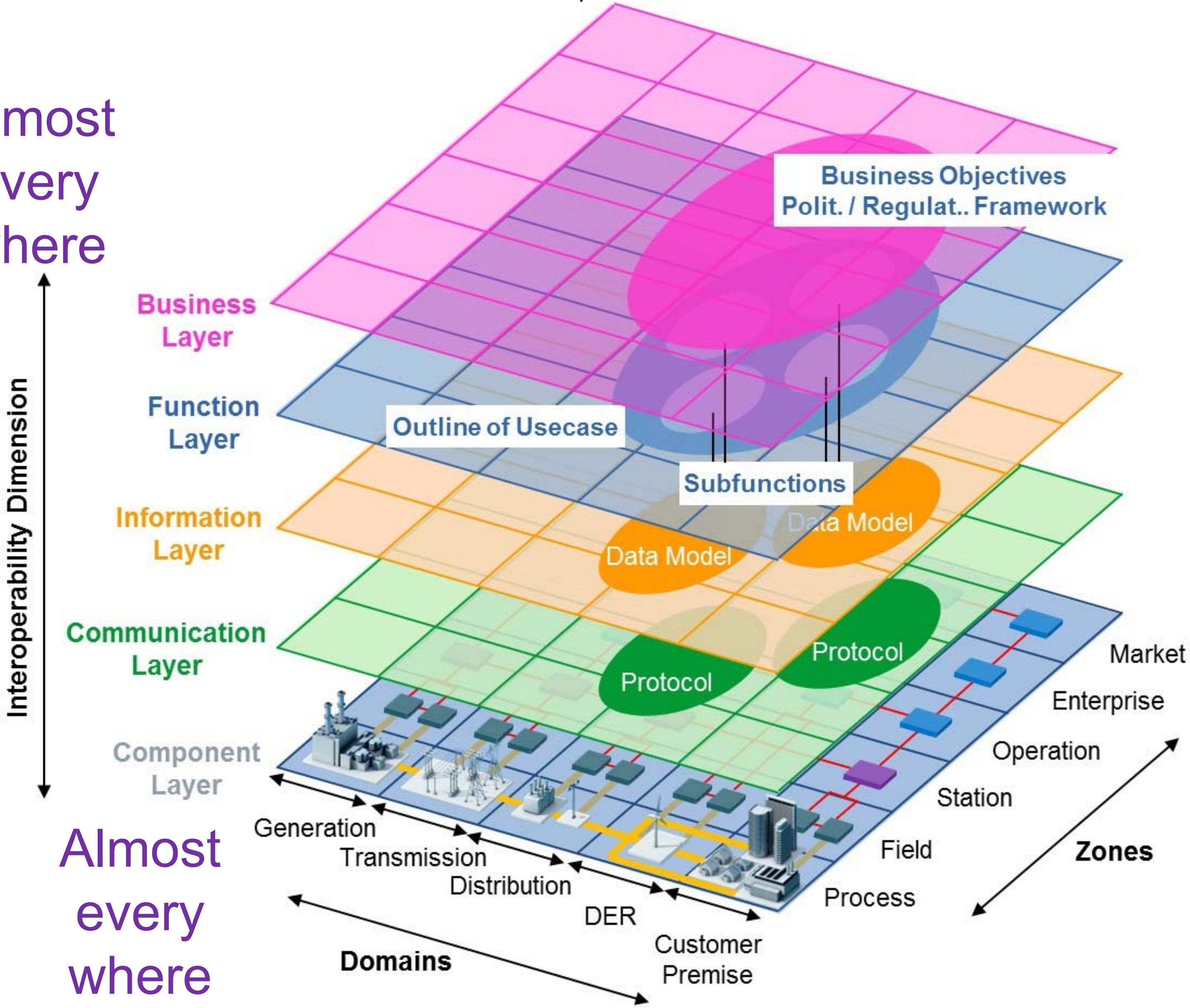
Feasible

Features of a Smart Grid

Smart grid: dimensions, domains and zones

• Source: EC Smart Grid Standardisation Reference Group

Almost every where



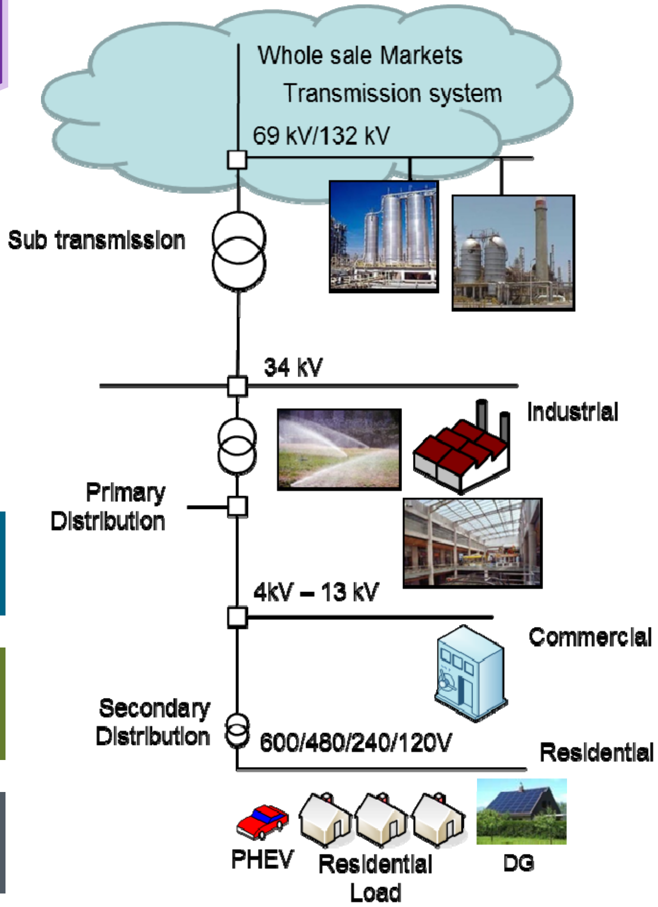
Almost every where

Almost every where

Smart Grids: Challenges/Solutions

Great Challenges

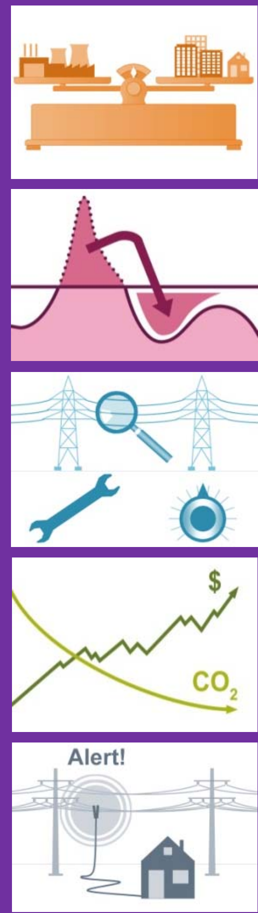
- Distributed and renewable energy
- Limited generation and grid capacity
- Aging and/or weak infrastructure
- Cost and emissions of energy supply
- Revenue losses, e.g. non-technical losses



Smart Grid

Solution

- Balancing generation & demand, new business models
- Load management & peak avoidance
- Reliability through automatic outage prevention and restoration
- Efficient generation, transmission, distribution & consumption
- Full transparency on distribution level and automated loss prevention



Smart Grid Advantages

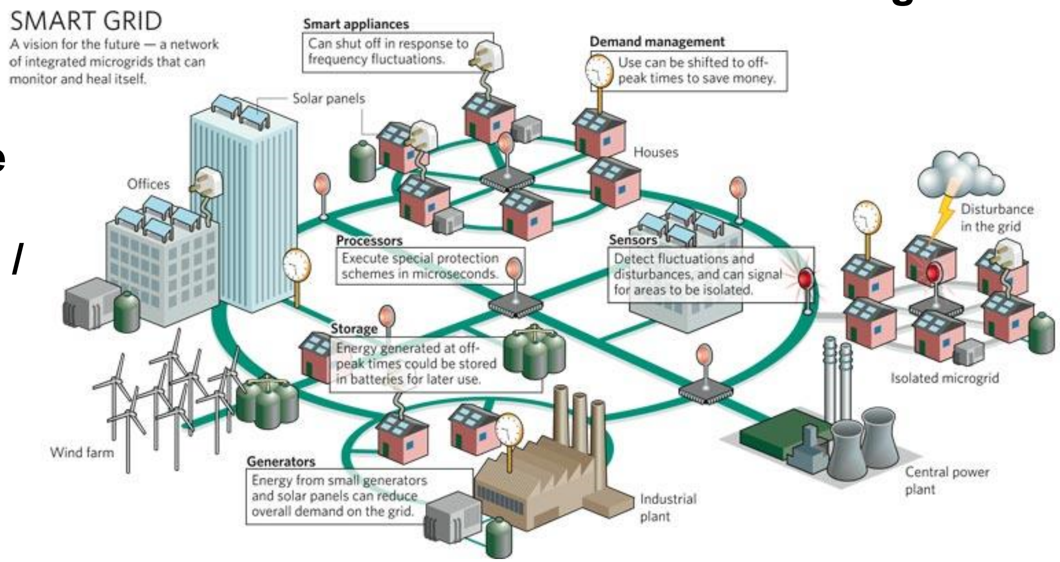
Operational Efficiency

Reduced Onsite Premise Presence / Field Work Required
Shorter Outage Durations
Optimized Transformer Operation
Standards & Construction
Improved Network Operations
Reduce Integration & IT maintenance cost
Condition-based Asset Maintenance / Inspections

Energy Efficiency

Reduced Energy Losses

Active/Passive Demand-side Management



Customer Satisfaction

Enable Customer Self-Service / Reduce Call Center Inquiries

Improved Revenue Collection

Environmental Impact

4. Autonomous

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4. Autonomous

Autonomous

- It is a system designed **to be operated <u>independently</u> from <u>infrastructural support services</u>***

* Examples of Support services:

  - **<u>Power grid</u>**
  - Gas grid
  - Municipal water systems
  - Sewage treatment systems
  - Storm drains
  - **<u>Communication services</u>**

in some cases, public roads.

Eliminating dependence on the electrical grid is relatively simple but growing all necessary food is a more demanding and time-consuming proposition.

Feasible

There is conflict with Smart grid concept

Smart

Must be!

Going fully off-grid

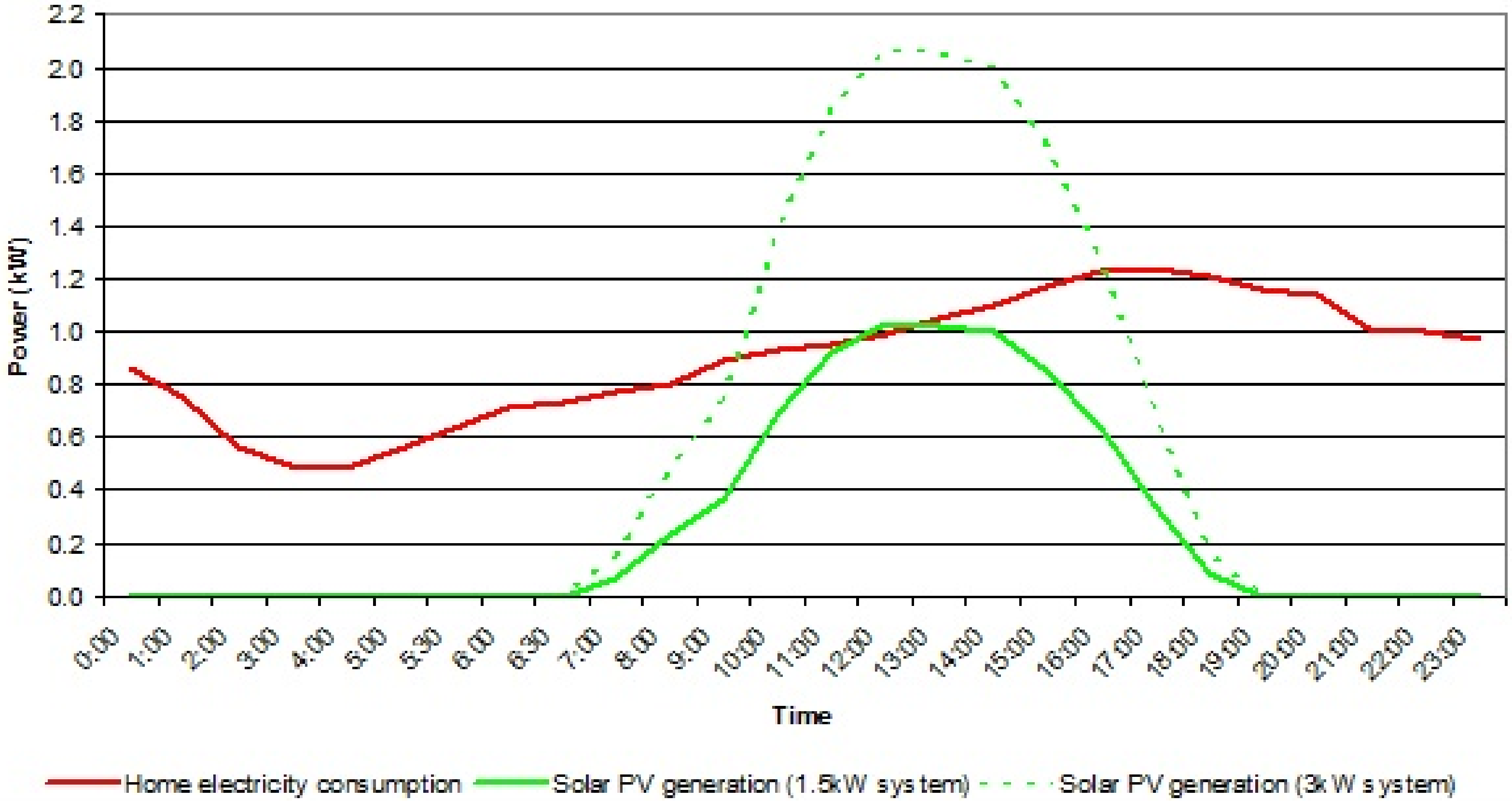
Autonomous

- **First condition for going off- grid:**
- *To be sure that the* **energy supply** *over a long period of time to cover the* **energy load** dur*ing this period of time* (or at least if it is not the case, to be able to get additional electrical energy to your microgrid without connecting to the grid (e.g., backup generator, good neighbours, etc)).
- **Second condition:**
- **To have adequate flexibility means in the microgrid** (e.g., modulation of the demand, storage devices, etc) for being able to **balance** at any time production of electricity with consumption.

Four Possible Options to... (1/4)

Autonomous

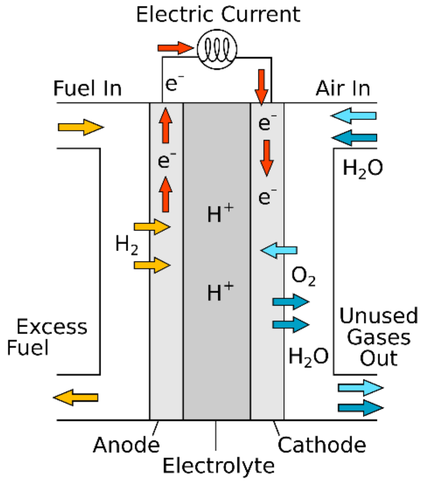
- **Over-dimension of Energy Supply:** The PV installation could be sized for producing during the less sunny periods of the year, an amount of energy equal to the energy consumed during these periods)
- → **Decrease in storage costs.**



Four Possible Options to... (2/4)

Autonomous

- **Hydrogen-based storage devices** that use electrolysis to produce hydrogen and **fuel cells** to generate electricity from hydrogen are much less expensive than batteries in smoothing out long-term fluctuations.
- Indeed, the price of the hydrogen reservoir only grows slowly with its capacity.



While barely the size of a tractor-trailer, Los Angeles' John Ferraro Building Fuel Cell Power Plant provides enough energy for 250 homes.

Prospects for hydrogen storage in graphene

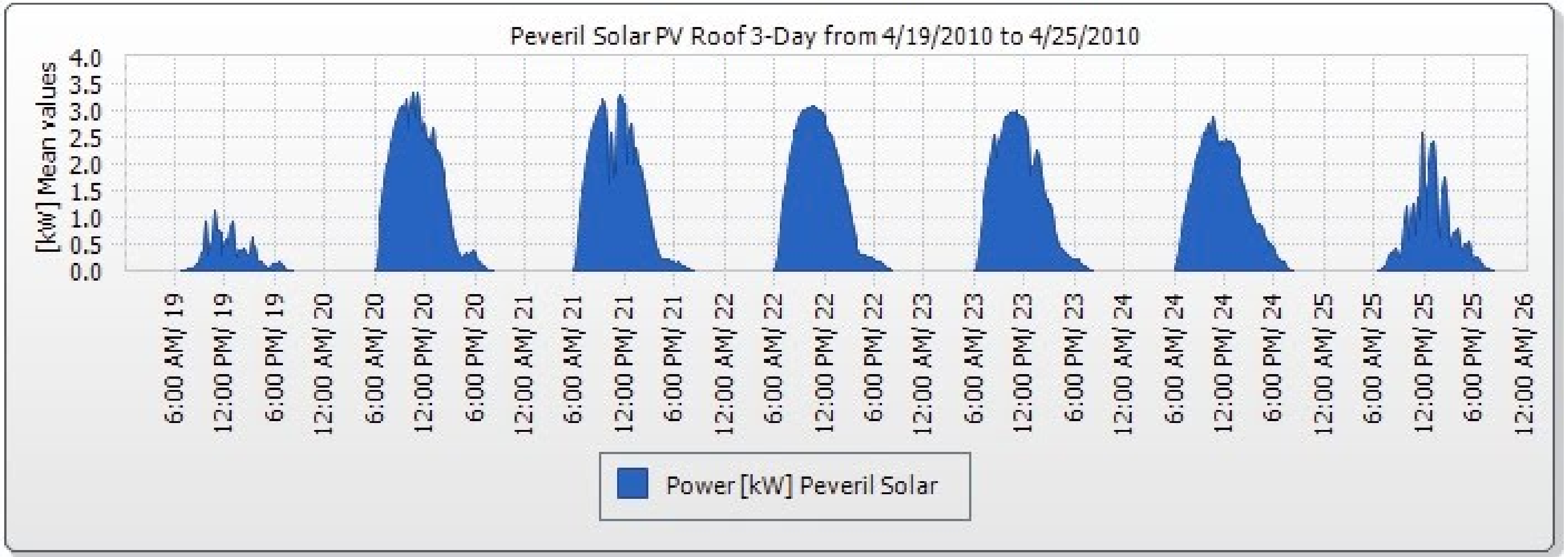
Valentina Tozzini* and Vittorio Pellegrini

NEST-Istituto Nanoscienze – Cnr and Scuola Normale Superiore, Piazza San Silvestro 12, 56127 Pisa Italy.

Four Possible Options to... (3/4)

Autonomous

- **Reduce inter-seasonal fluctuations…**
- The closer you get from the equator, the less this problem of interseasonal flucuctuation of PV energy production is marked.
  - For example, while in Belgium PV panels produce 3 times as much energy in the six most sunny months of the years than during the rest of the year, this factor drops to 1.8 in South of Spain.



http://chargingtheearth.blogspot.co.uk/2010_05_01_archive.html

Four Possible Options to... (4/4)

Autonomous

- **Outsourcing mobile consumptions:** During the less sunny months, off-grid microgrids' owners could **charge their electrical car at work** to reduce their consumption or even transfer energy at night from their car to the microgrids' batteries.

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2. Multi-Terminal DC System

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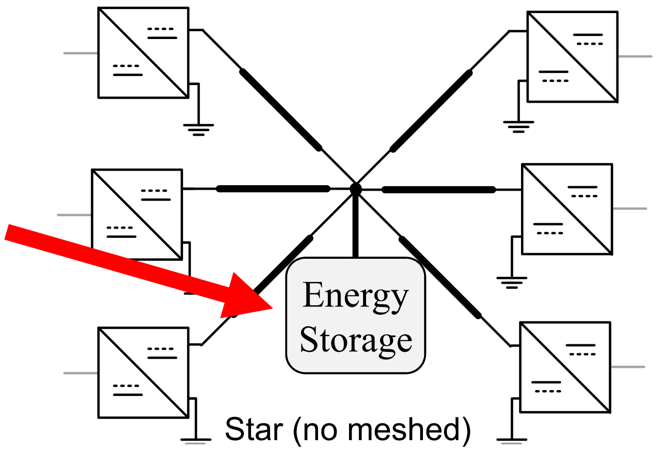
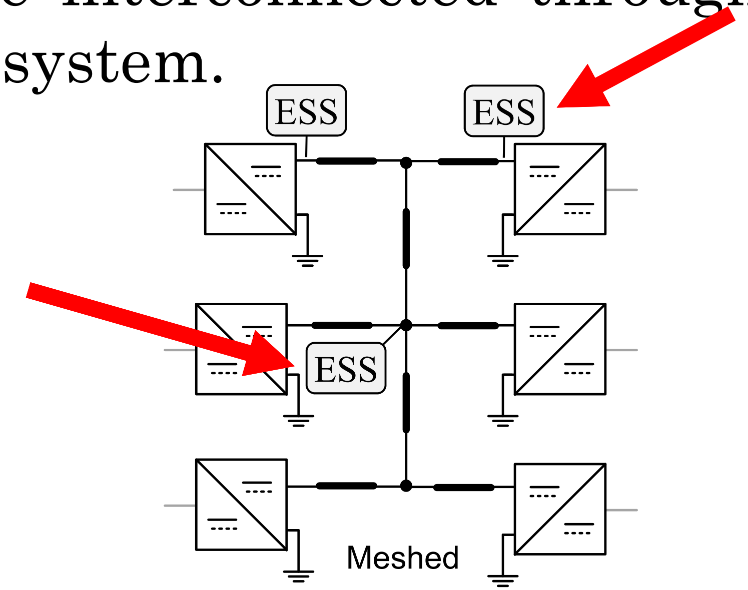
2. Multi-Terminal DC Systems

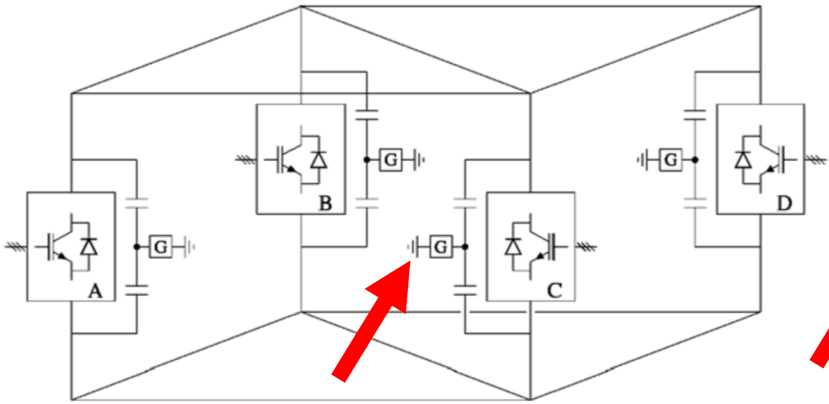
- MTDC systems are characterised when **three or more converter stations** become interconnected through the DC side of the transmission system.



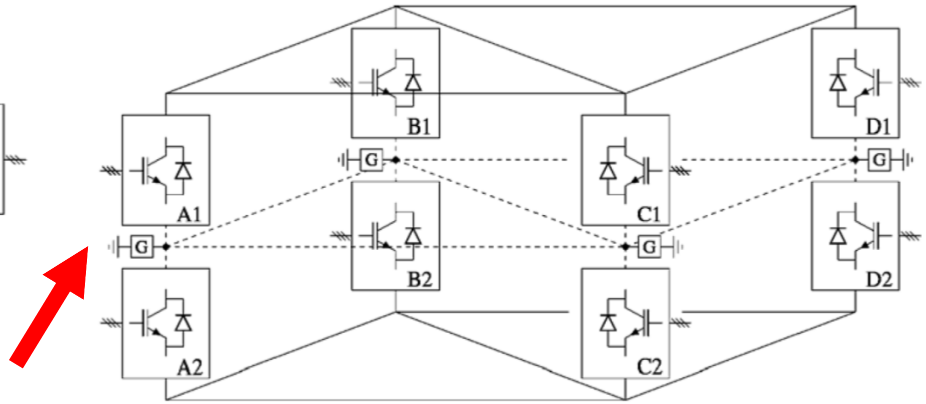
Star (no meshed)



Meshed



Symmetric monopolar grid.

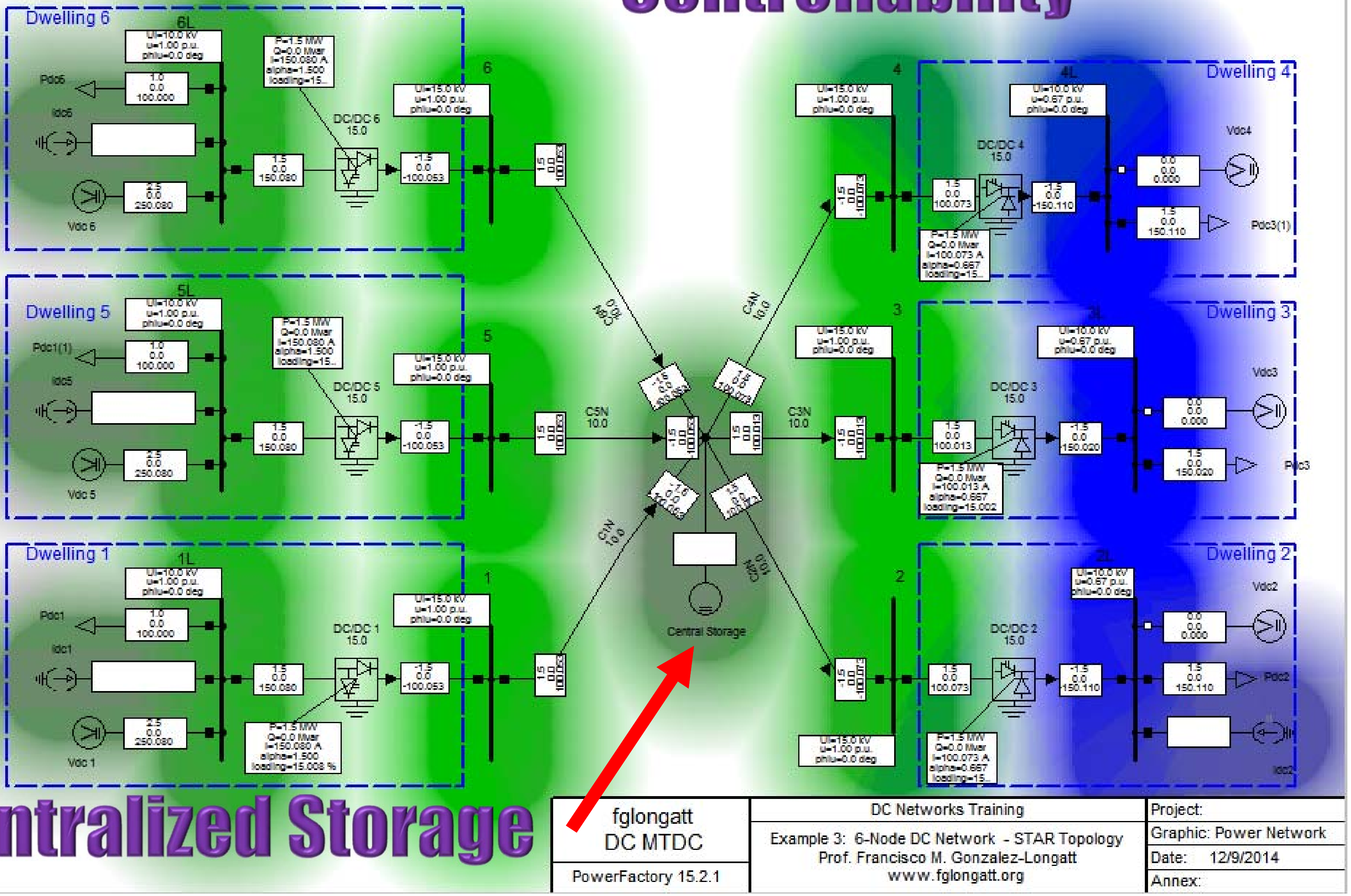


Bipolar grid with metallic return

DC-μg – STAR Topology –No Meshed

Multi Terminal DC

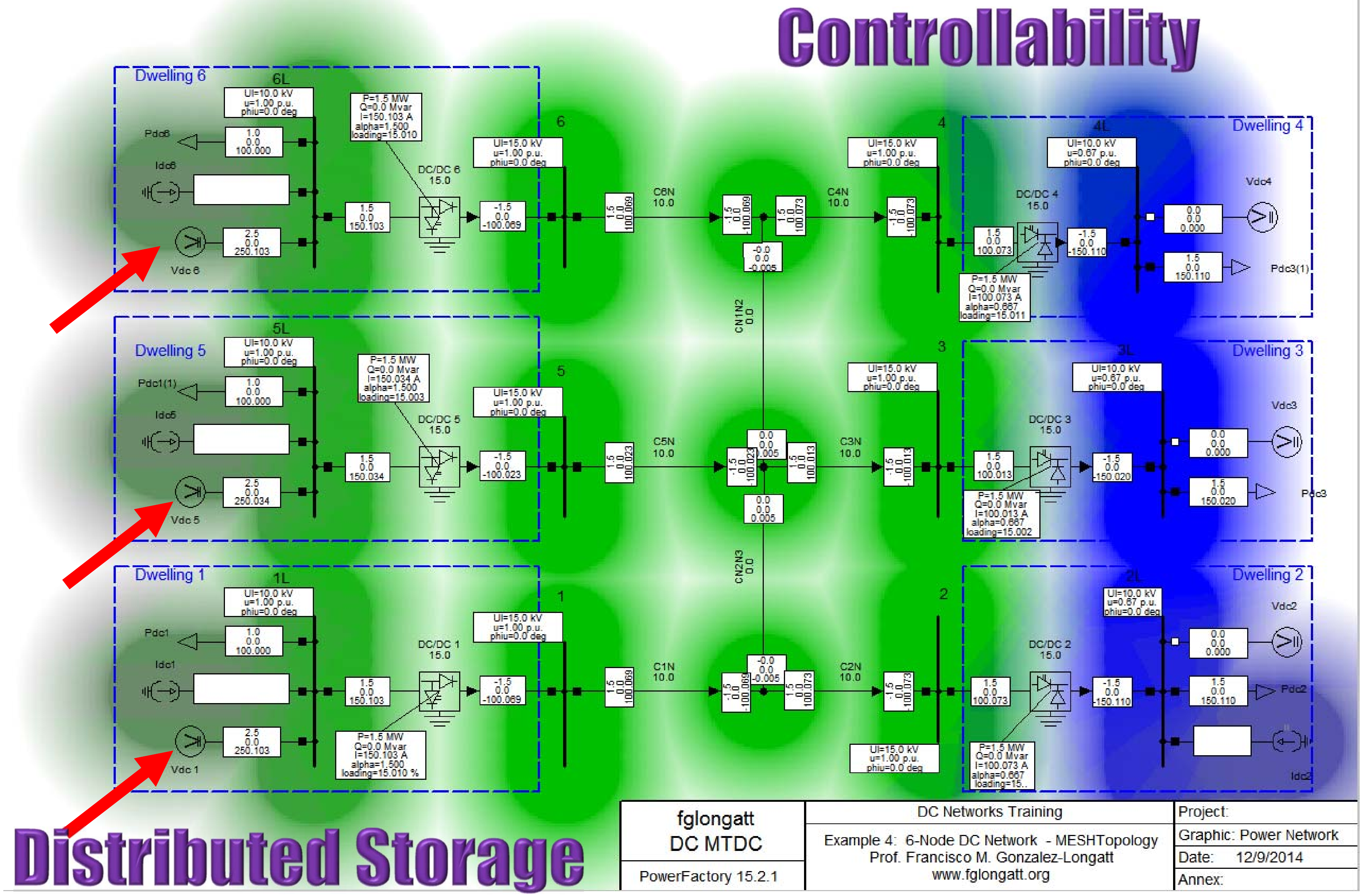
Controllability



Centralized Storage

DC-µg – MESHED Topology

Multi Terminal DC



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3. Micro-Grid

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3. Micro-Grid

Micro-grid

- It consists of interconnected **distributed energy resources** capable of providing **sufficient** and **continuous energy** to a significant portion of internal load demand.
- It possesses **independent controls**, and **intentional islanding takes place with minimal service interruption** (seamless transition from grid-parallel to islanded operation

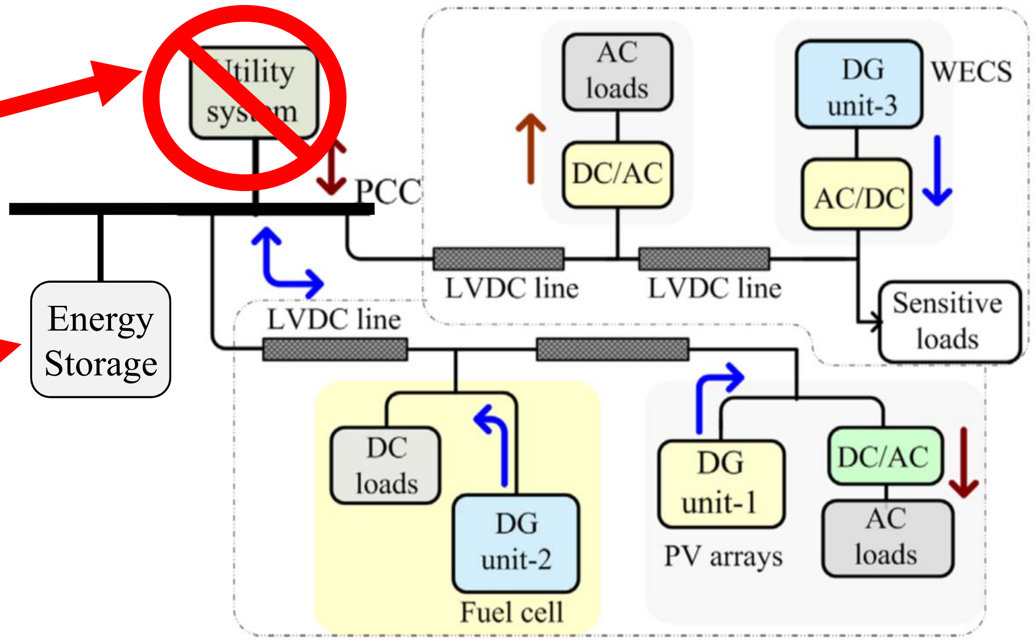
Autonomous

There is conflict with Autonomous concept

Energy storage systems must be included in order to enable Autonomous cooperation

Discussion:

- **Distributed**
- **Centralized**
- **Combined**



Justo, J. J., et al. (2013). "AC-microgrids versus DC-microgrids with distributed energy resources: A review." Renewable and Sustainable Energy Reviews **24**(0): 387-405.

5. Zero Net Building

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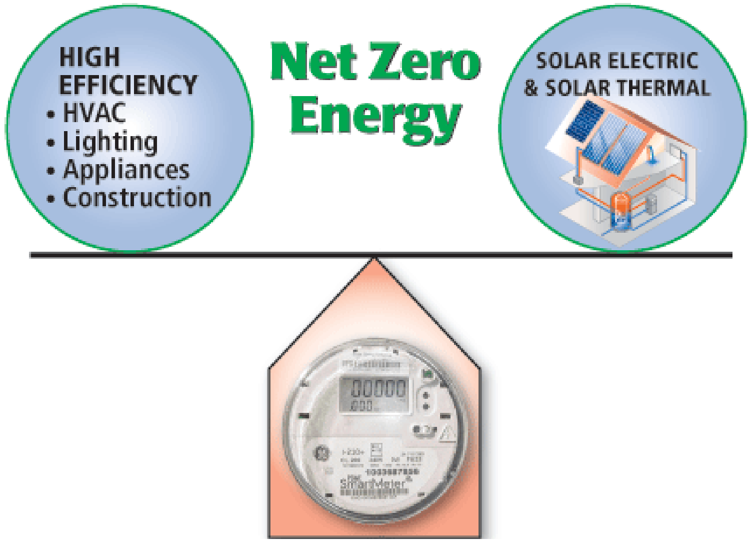
5. Zero-Net Energy Building

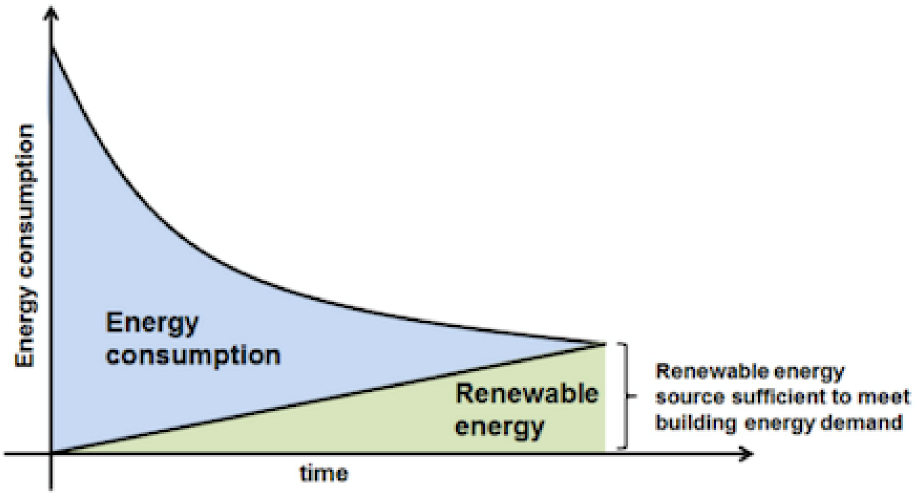
Zero-Net Energy Building

ISSUE:

- Depending on the ZEB definition, the results can vary substantially.

- The way the **zero energy goal is defined** affects the choices designers make to achieve this goal and whether they can claim success





Torcellini, P., et al. (2006). Zero Energy Buildings: A Critical Look at the Definition. ACEEE Summer Study on Energy Efficiency in Buildings. Pacific Grove, CA, USA, National Renewable Energy Laboratory.

NEAR Zero-Net Energy Buildings:

- *Directive 2010/31/EU* (EPBD recast) Article 9 requires that "*Member States shall ensure that by 31 December 2020 all new buildings are **nearly zero-energy buildings (NZEB)**...*"

- A **nearly zero-energy building** (NZEB) is defined in Article 2 of the EPBD recast as "**a building that has a very high energy performance**. The nearly zero or **very low amount of energy** required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources **produced on-site** or **nearby**".

DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL: Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF

Zero-Net Energy Buildings:

- The **lack of a commonly agreed ZEB definition** is already widely discussed on the international level [A]
- **Aspects** involved in the definition:
  1. The **metric** of the balance,
  2. The balancing **period**,
  3. The **type of energy** use included in the balance,
  4. The **type of energy balance**,
  5. The accepted **renewable energy supply** options,
  6. The **connection to the energy infrastructure** (**NO!!!**)
  7. The requirements for the **energy efficiency**, the indoor climate and in case of gird connected ZEB for the building–grid interaction

[A] A.J. Marszal, P. Heiselberg, J.S. Bourrelle, E. Musall, K. Voss, I. Sartori, A. Napolitano, Zero energy buildings: a review of definitions and calculation methodologies, *Energy and Buildings* (2011) 971–979

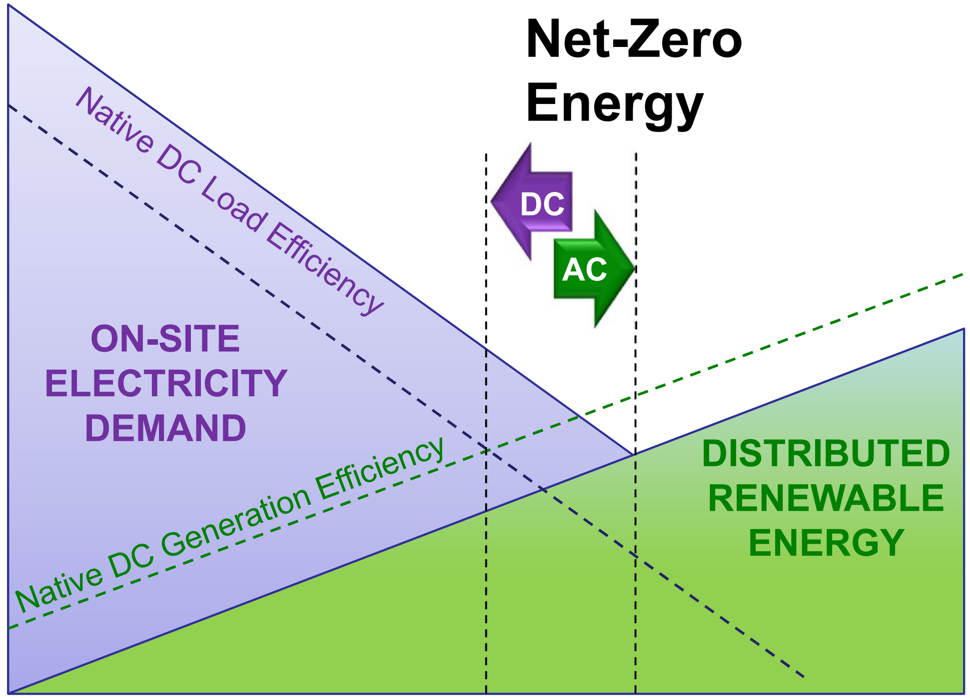
Net Zero Energy Building Model

- Buildings that produce as much energy as they consume

1. Integrated design and operations planning
2. Site renewable strategies get optimized using dc
3. Energy Storage in DC allow Grid independence
4. System Intelligence control, monitor, verify

U.S. DEPARTMENT OF ENERGY

ZERO ENERGY COMMERCIAL BUILDINGS CONSORTIUM

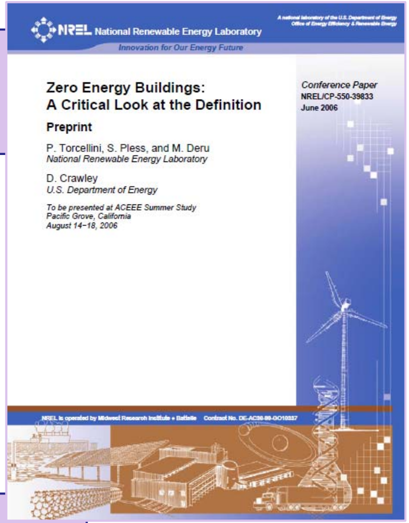


Types of Net-ZEB Buildings

$$\sum_{i=1}^{year} E_{production}(t_i) = \sum_{k=1}^{year} E_{comsumption}(t_k)$$

A site ZEB produces at least as much energy as it uses in a year, when accounted for at the site.

Net-Zero Site Energy


NREL National Renewable Energy Laboratory
Innovation for Our Energy Future
A national laboratory of the U.S. Department of Energy Office of Energy Efficiency & Renewable Energy

Zero Energy Buildings: A Critical Look at the Definition

Preprint

P. Torcellini, S. Pless, and M. Deru
National Renewable Energy Laboratory

D. Crawley
U.S. Department of Energy

To be presented at ACEEE Summer Study
Pacific Grove, California
August 14–18, 2006

Conference Paper
NREL/CP-550-39833
June 2006

NREL is operated by Midwest Research Institute • Battelle Contract No. DE-AC36-99-GO10337

Net-Zero Energy Costs

The amount of money the **utility pays** the building owner for the energy the building exports to the grid is at least **equal to the amount the owner pays the utility** for the energy services

$$\sum_{i=1}^{year} Total_{export}(t_i)[\$] = \sum_{k=1}^{year} Total_{import}(t_k)[\$]$$

A source ZEB produces at least as **much energy as it uses in a year**, when accounted for at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site. To calculate a building's total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers.

Net-Zero Source Energy

$$\sum_{i=1}^{year} E_{production}(t_i) = \sum_{k=1}^{year} E_{comsumption}(t_k)$$

$$\sum_{i=1}^{year} Emissions(t_i) = 0$$

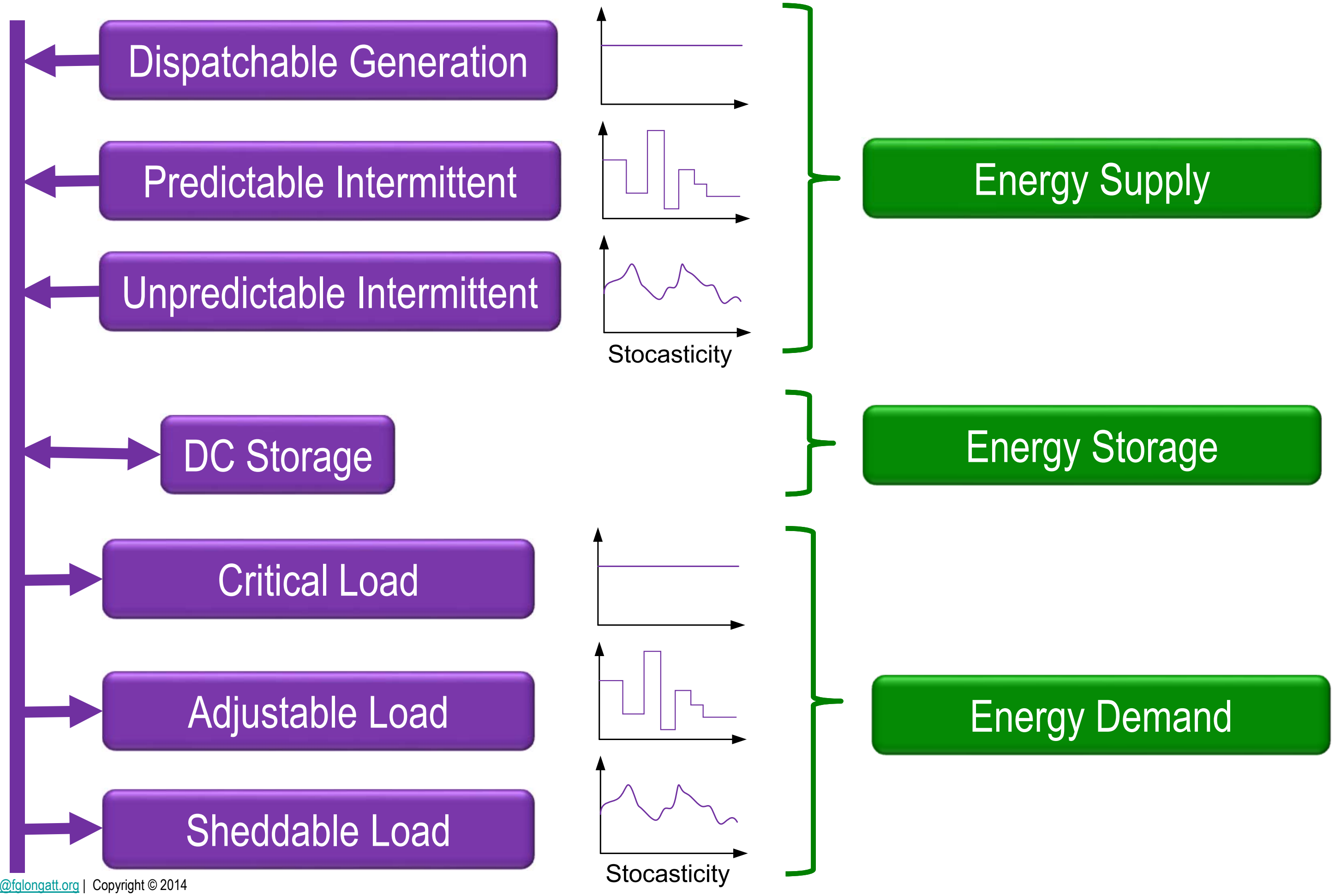
Net-Zero Energy Emissions

A net-zero emissions building produces at least as **much emissions-free renewable energy** as it uses from emissions-producing energy sources

Torcellini, P., et al. (2006). Zero Energy Buildings: A Critical Look at the Definition. ACEEE Summer Study on Energy Efficiency in Buildings. Pacific Grove, CA, USA, National Renewable Energy Laboratory.

Balancing Supply and Demand

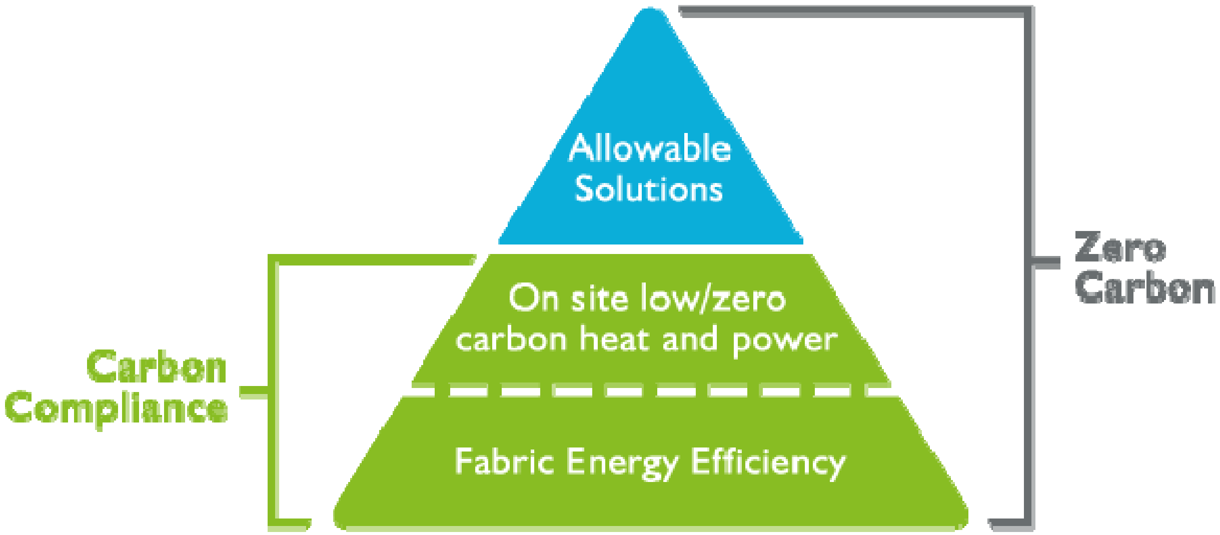
- Micrgrids have the ability to maintain a **balance** between **available supply** and **desirable load demand** through careful marriage of supply and demand combined with **intelligent control of any imbalance**.



UK: Context

New Build Homes

- In December 2006, the UK Government announced that all new homes would be '**zero carbon**' from 2016 [1].
- The **Zero Carbon** Buildings policy forms part of Government's wider strategy to achieving **the Climate Change Act 2008 (CCA) target***, while at the same time assists in tackling other important issues including energy security and fuel poverty



* The Act mandates an 80% reduction in CO_2 from the 1990 levels, which are used as a baseline, by 2050.

[1] http://www.ukgbc.org/content/new-build-homes

UK: Context

- There are three core requirements which must all be met for a home to qualify as zero carbon:
  - The fabric performance must, at a minimum, comply with the defined standard known as the **Fabric Energy Efficiency Standard (FEES)** and
  - Any CO2 emissions that remain after consideration of heating, cooling, fixed lighting and ventilation, must be less than or equal to the **Carbon Compliance* limit established for zero carbon homes**, and
  - Any remaining CO2 emissions, from regulated energy sources (after requirements 1 and 2 have been met), must be reduced to zero.

Recommended levels are:
- 10 kg CO2(eq)/m2/year for detached houses.
- 11 kg CO2(eq)/m2/year for attached houses.
- 14 kg CO2(eq)/m2/year for low rise apartment blocks (up to 4 storeys).

*Carbon Compliance limit is the maximum permitted amount of CO_2

http://www.zerocarbonhub.org/zero-carbon-policy/carbon-compliance-target

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Defining the requirements of a MTDC -g system to enable an aZNEB.

III International Workshop
Smart Multi-Terminal DC μ-grids for autonomous Zero-Net Energy Buildings
Indian Institute of Technology Mandi
14-15st December 2014

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System Requirements

Smart (1)

Multi Terminal DC (2)

Micro-grid (3)

Smart Multi-Terminal DC μ-grids for autonomous Zero-Net Energy Buildings

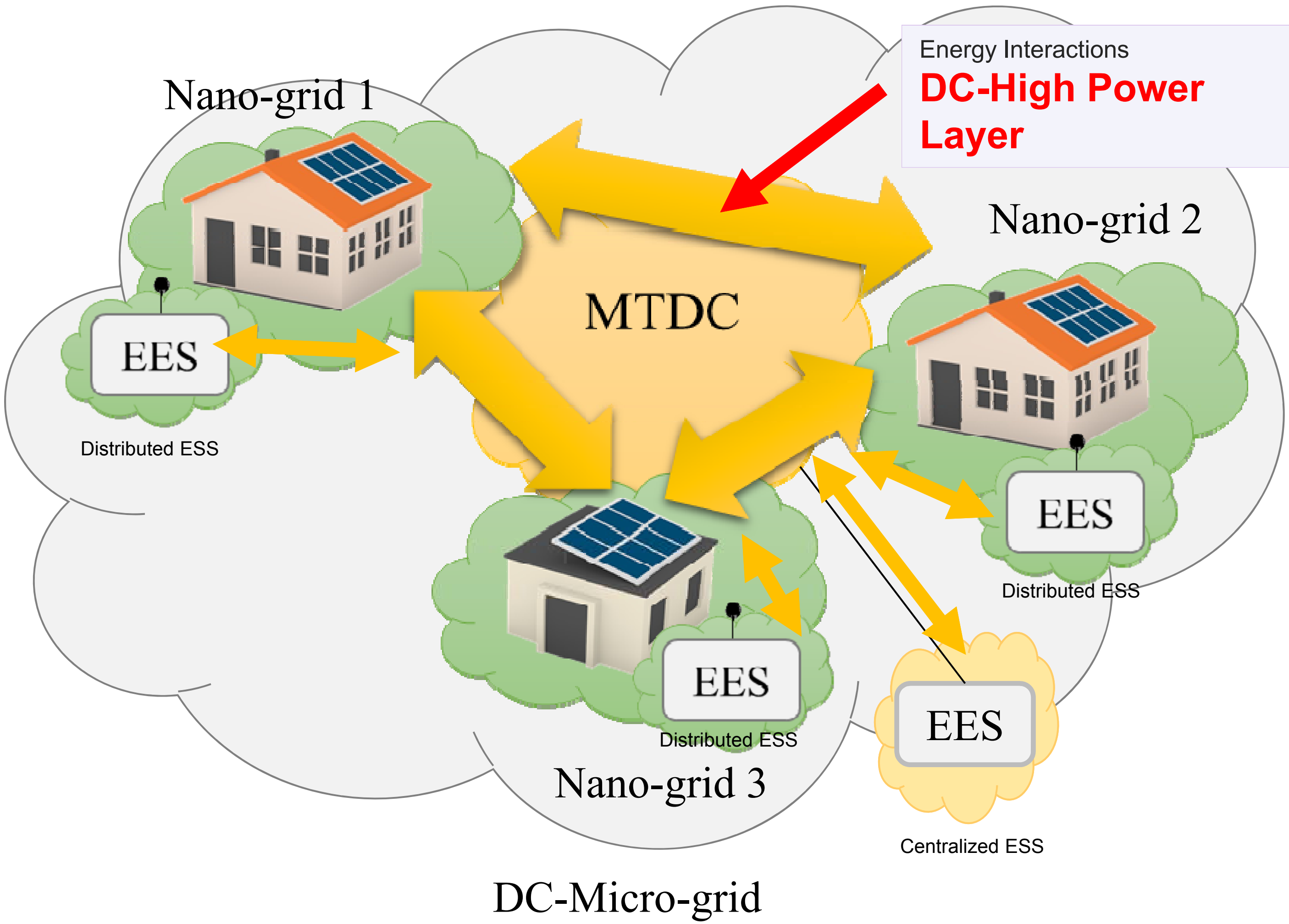
Autonomous (4)

Zero-Net Energy Building (5)

Task 1.2: Define the requirements of a MTDC micro-g system to enable a ZNEB.

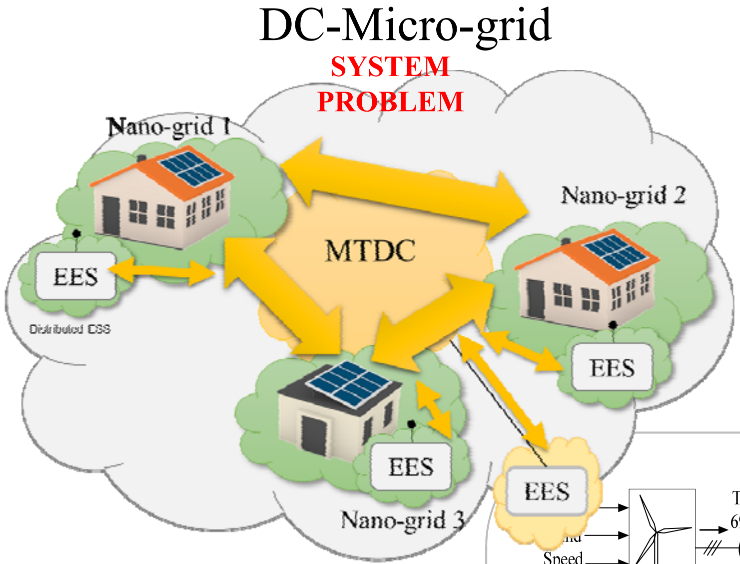
System Requirements

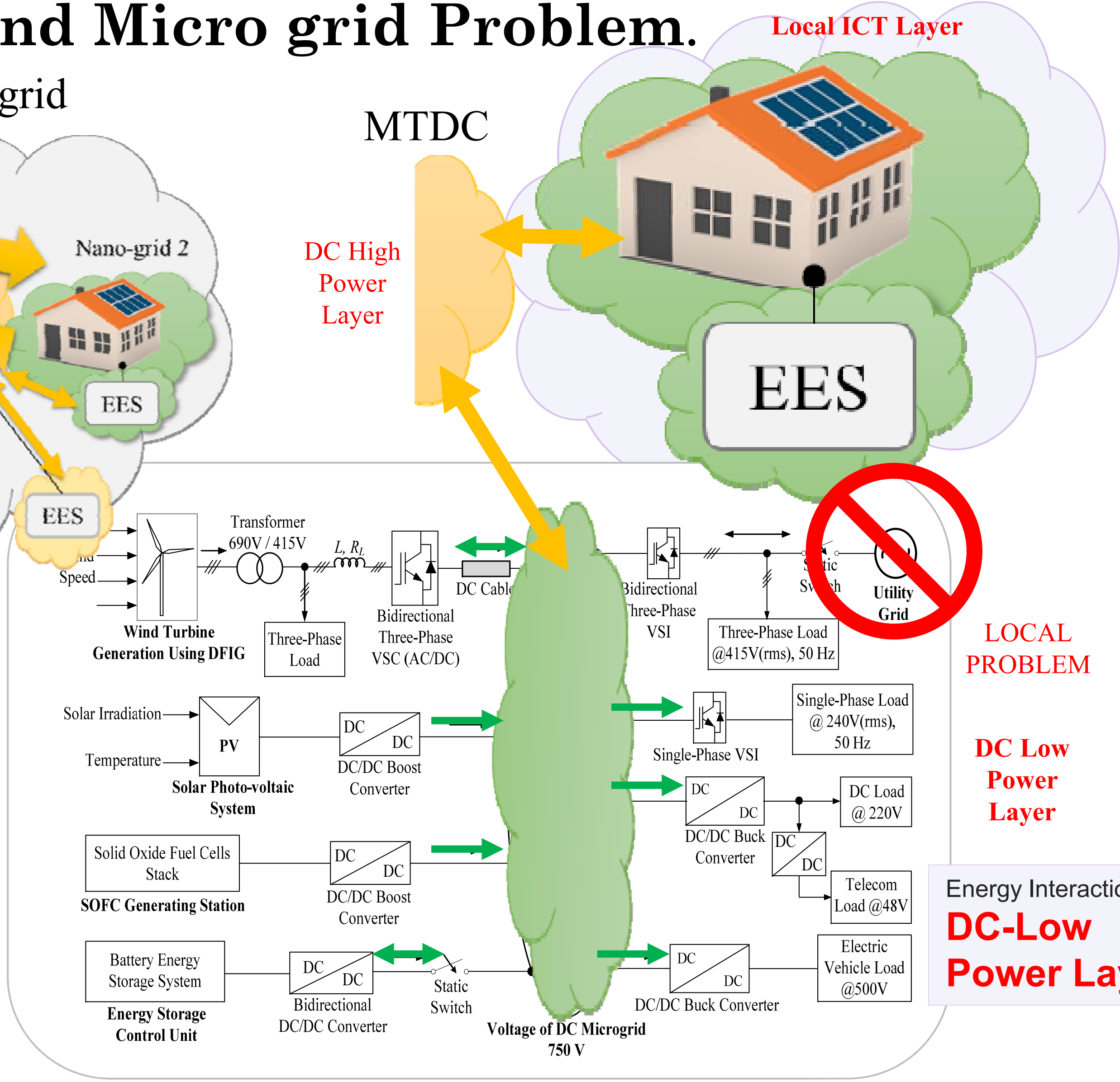
- **Nanogrids** (n-g) are small microgrids, typically serving a single building or a single load.



System Requirements

- **Nanogrids and Micro grid Problem.**





Problem of Nano-grid

Fully Studied by Indian Partners

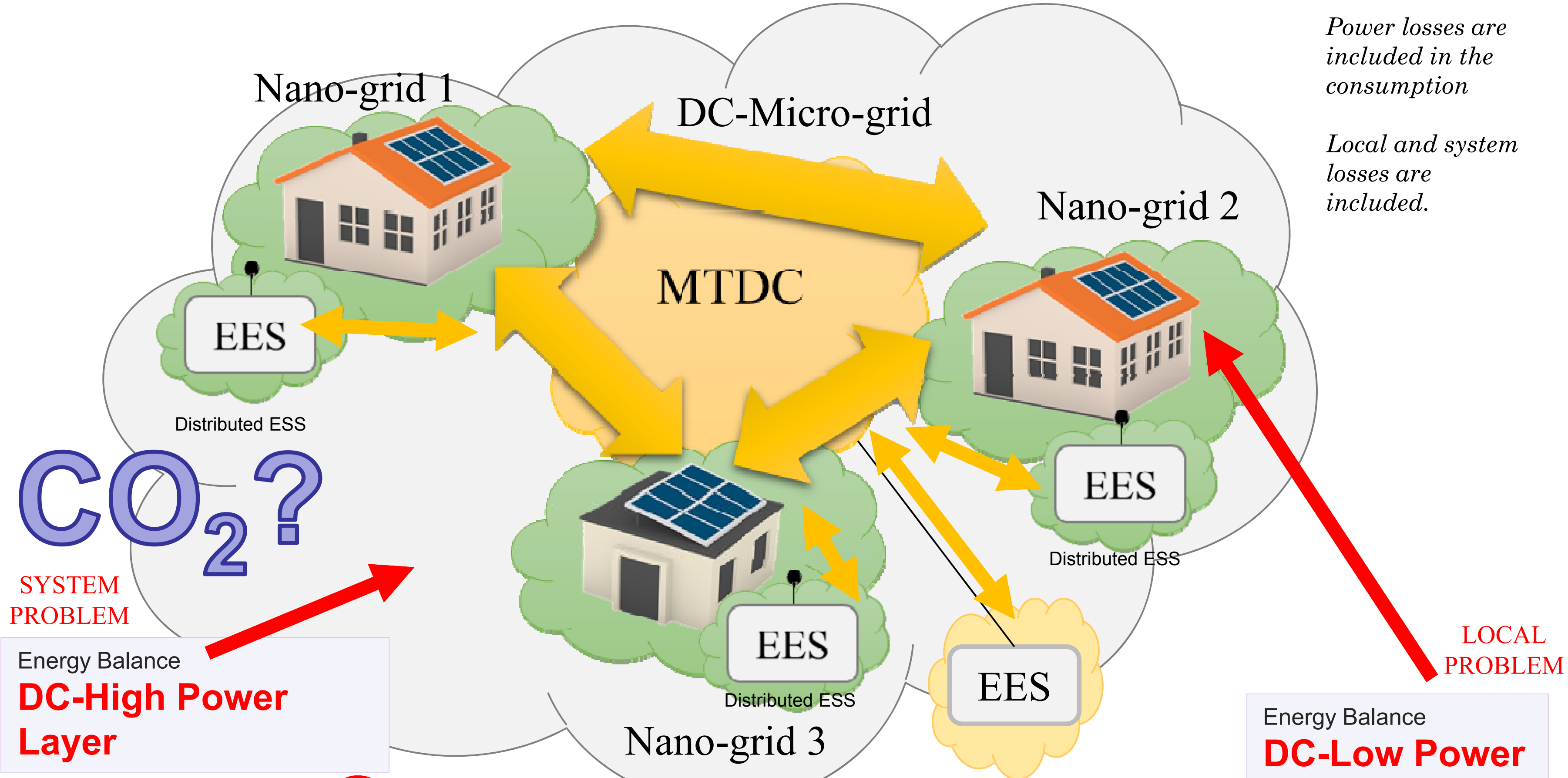
Energy Interactions
DC-Low Power Layer

System Requirements

- **Energy Balance Problem(?): Local Versus System**

Power losses are included in the consumption

Local and system losses are included.



$$\sum_{i=1}^{T} E_{production}^{MTDC}(t_i) - \sum_{k=1}^{T} E_{consumption}^{MTDC}(t_k) = 0$$

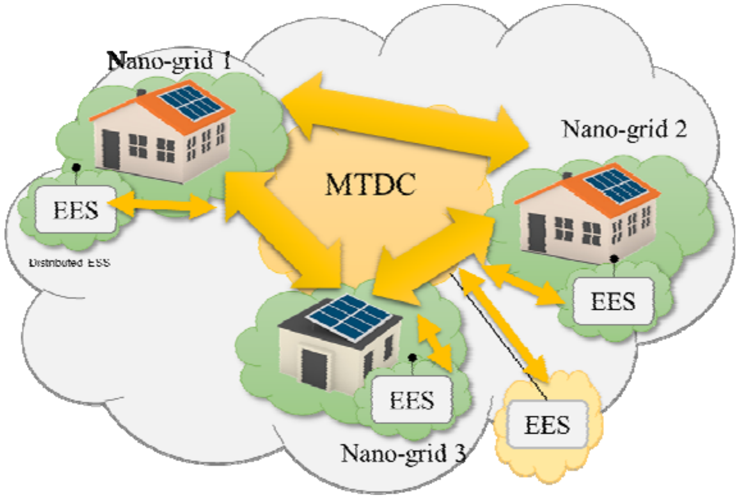
$$\sum_{i=1}^{T} E_{production}^{nano,j}(t_i) - \sum_{k=1}^{T} E_{consumption}^{nano,j}(t_k) < \xi$$

$j = 1, 2, 3$

***T* : Horizon of the Balancing**

***ξ* : Imbalance can be positive or negative**

Balancing Horizon



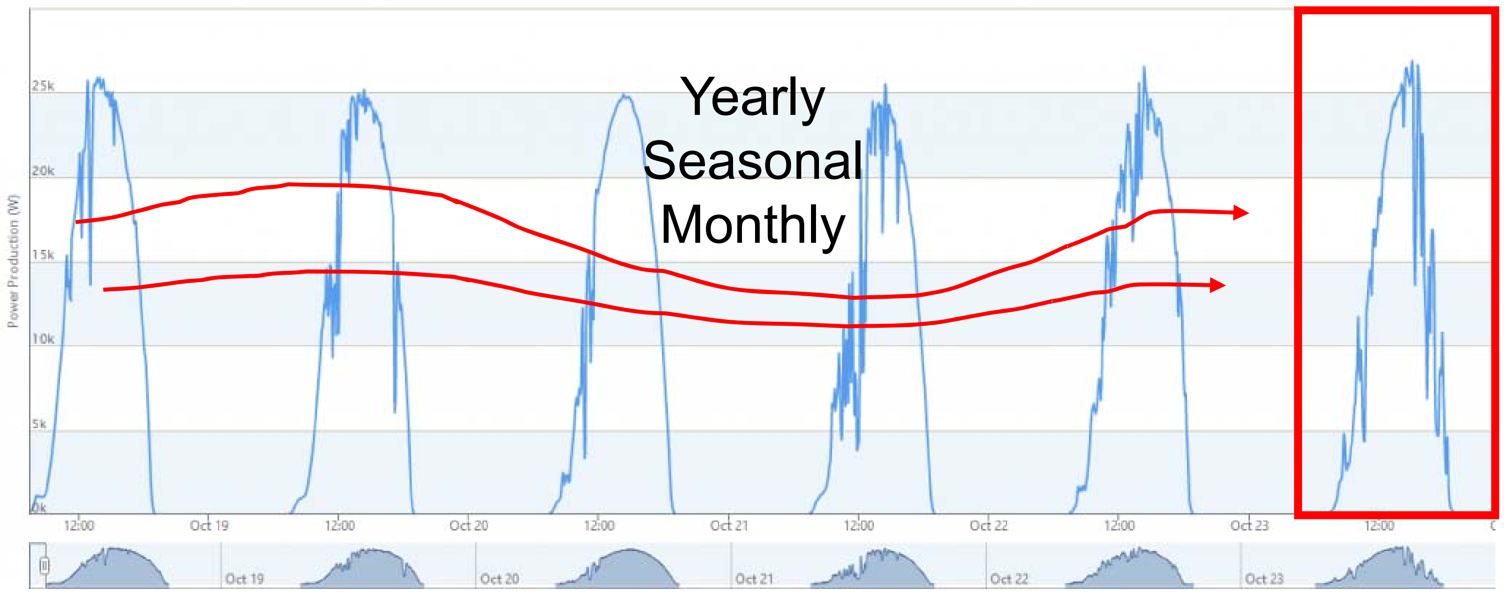
Centralized ESS 🙂

$$\left\{\begin{array}{l}\sum_{i=1}^{T} E_{production}^{MTDC}(t_i) - \sum_{k=1}^{T} E_{consumption}^{MTDC}(t_k) = 0 \\ \sum_{i=1}^{T} E_{production}^{nano,j}(t_i) - \sum_{k=1}^{T} E_{consumption}^{nano,j}(t_k) < \xi \\ \qquad\qquad j = 1,\ 2,\ 3\end{array}\right.$$

🙂 De-centralized ESS

🙁 Distributed Renewable Energy Sources

DC-Load : Energy Management System 🙂



Time Resolution
5 mins
15 mins
30 mins

24-hour horizon

Thanks
Any Question?

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