Integration Experience of Photovoltaic Power Systems in Sub-Urban and Remote Mini-grids

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PVPS

Presentation Plan

1. IEA Photovoltaic Power Systems Program
2. New IEA PVPS Task 11 program
3. PV integration experience to date
4. Next steps
5. Conclusion

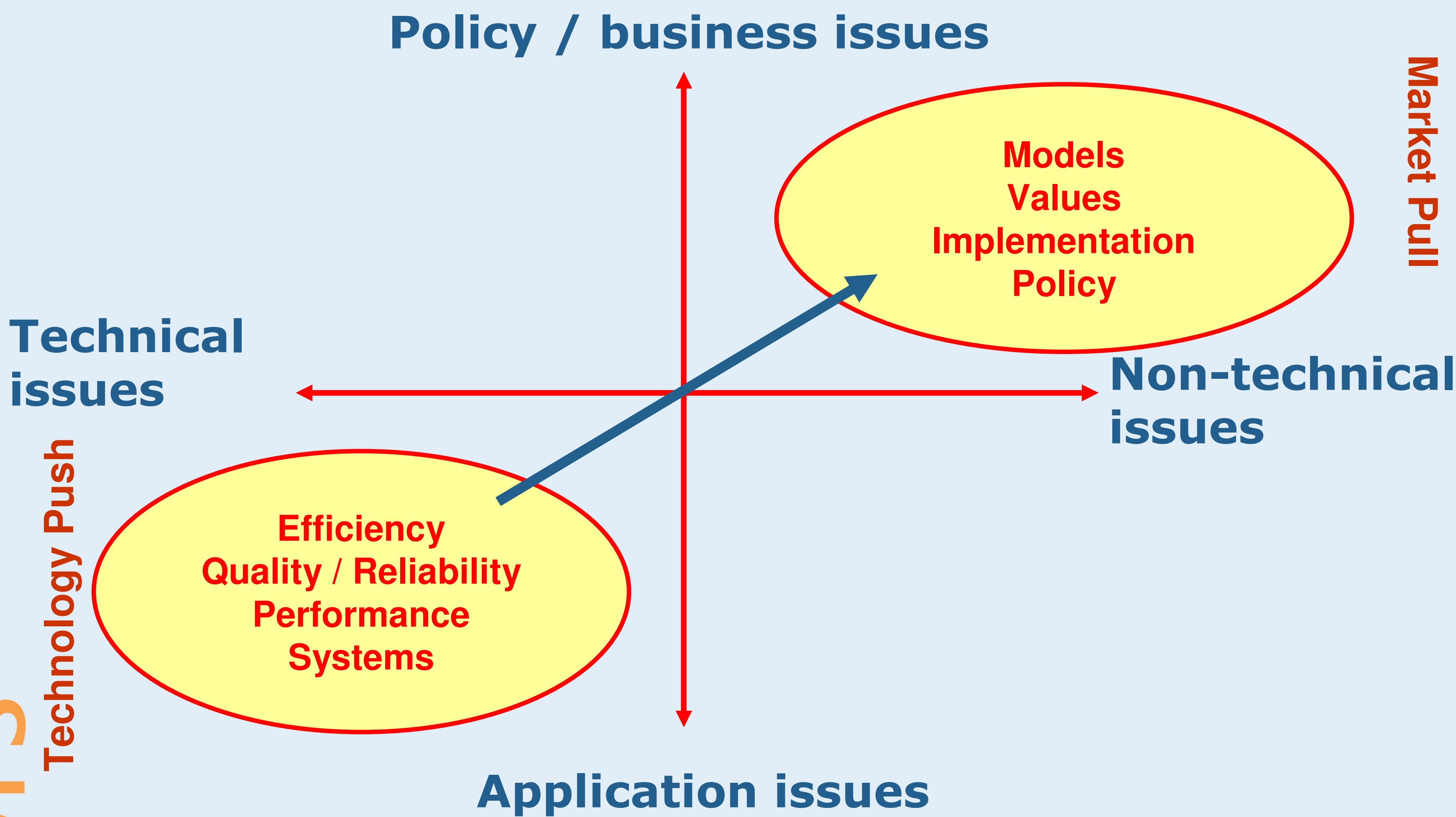
IEA Photovoltaic Power Systems Program

- International Energy Agency (IEA)
  - Cooperation on energy policy and R&D among 24 OECD countries
- IEA Photovoltaic Power Systems (PVPS) Implementing Agreement
  - Collaborative R&D projects (Tasks) on application of PV power systems
  - Participation on a national basis by member nations of the IEA PVPS
  - Activities within Tasks usually carried out on a task-sharing basis among participating countries

PVPS features

- Global network of expertise
- Broad variety of stakeholders
- Independent, objective, neutral
- Country based, task-shared
- Analysis
- Recommendations
- Communication & interaction
- Broad dissemination of results

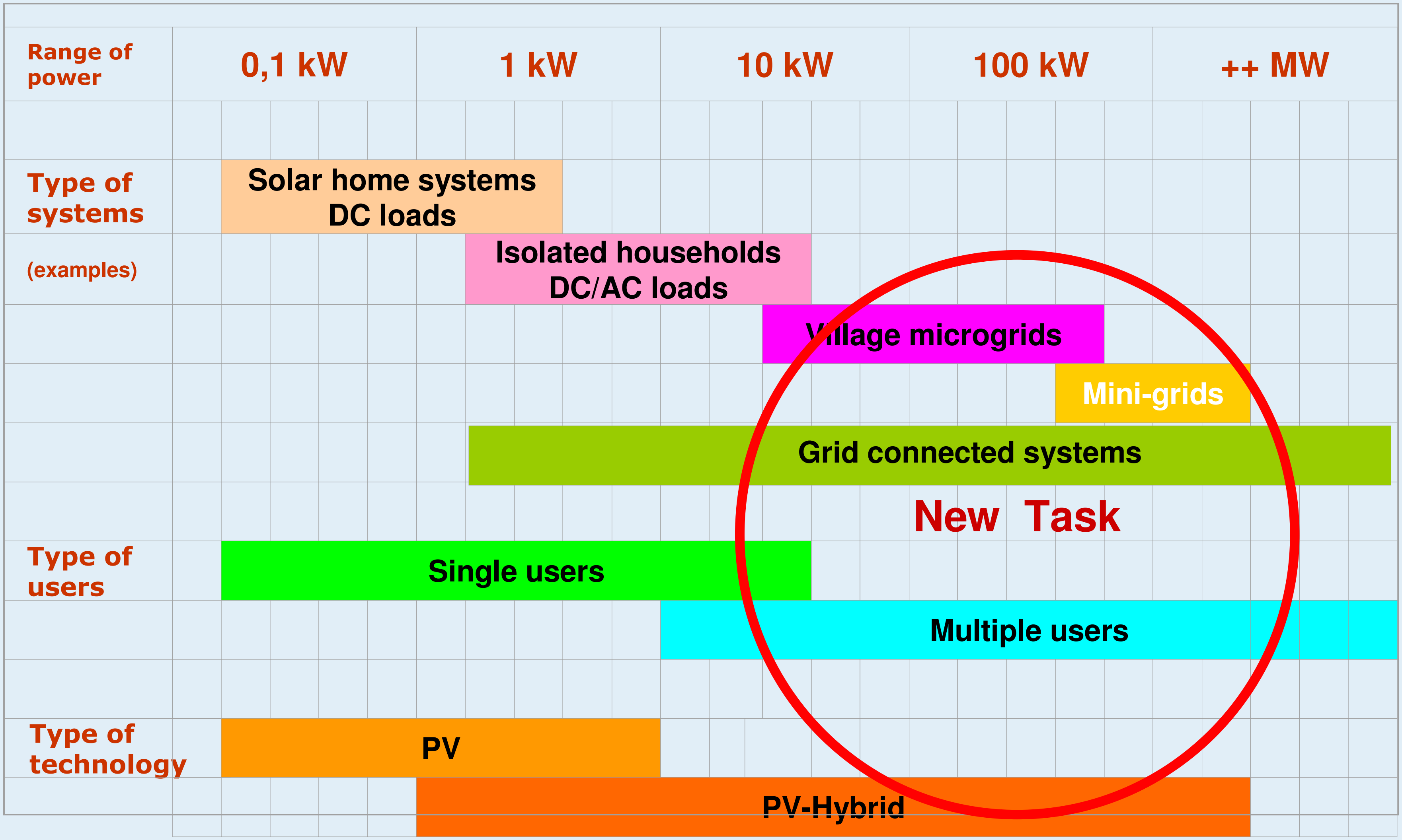
PVPS strategy dimensions



IEA PVPS – pioneering grid integration studies

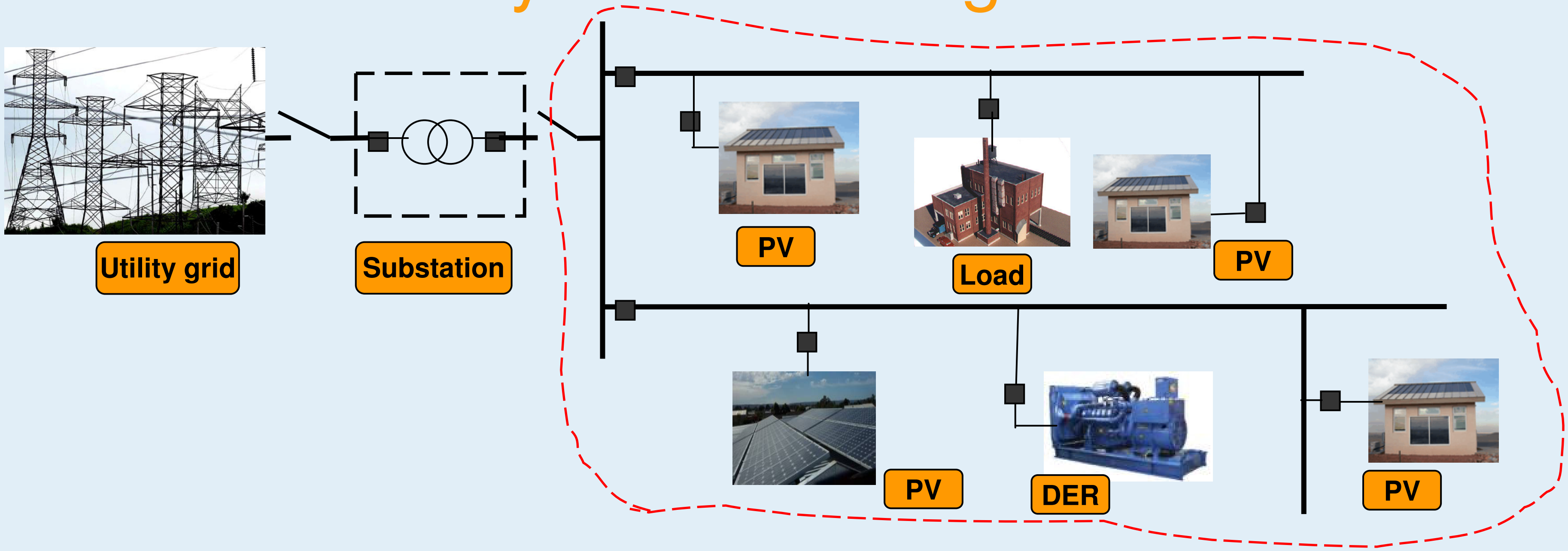
- Task 5 1993 – 2002
  - Utility aspects of grid connected PV [1]
    - harmonics
    - grounding
    - reclosing of protection devices
    - isolation transformers and dc injection
  - Effects of high penetration of PV [2]
  - Islanding issues [3,4,5]

New IEA PVPS Task 11



PVPS

Task 11 - PV hybrids in mini-grids



PV + other DER + multiple loads connected by a mini-grid that operates in:

- **autonomous** (islanded) mode,
- **grid-connected** mode,
- **ride-through** mode (between the above modes).

IEA PVPS Task 11 work plan

Subtask 10: Design Issues

- Activity 11: Current architecture: state of the art & trends
- Activity12: Design Methodology and Tools
- Activity 13: Best Practices

Subtask 20: Control Issues

- Activity 21: Mini-grid Stability
- Activity 22: Communication
- Activity 23: High level control, supervisory control
- Activity 24: Storage
- Activity 25: Interconnection and island issues

Subtask 30: PV Penetration in Mini-Grids

- Activity 31: Performance indicators
- Activity 32: Strategies for energy management

Subtask 40: Sustainability

- Activity 41: Social and political framework
- Activity 42: Financial and economic issues
- Activity 43: Environmental considerations

Task 11 flowchart

2006 → **2011**

Review and Assess Current Knowledge About PV Hybrids in Mini-grids

Where can we find experience on integrating PV hybrids into mini-grids???

Report on Current Best Practices. Provide Design Guidance.

Identify Specific Issues for Further Study & Research

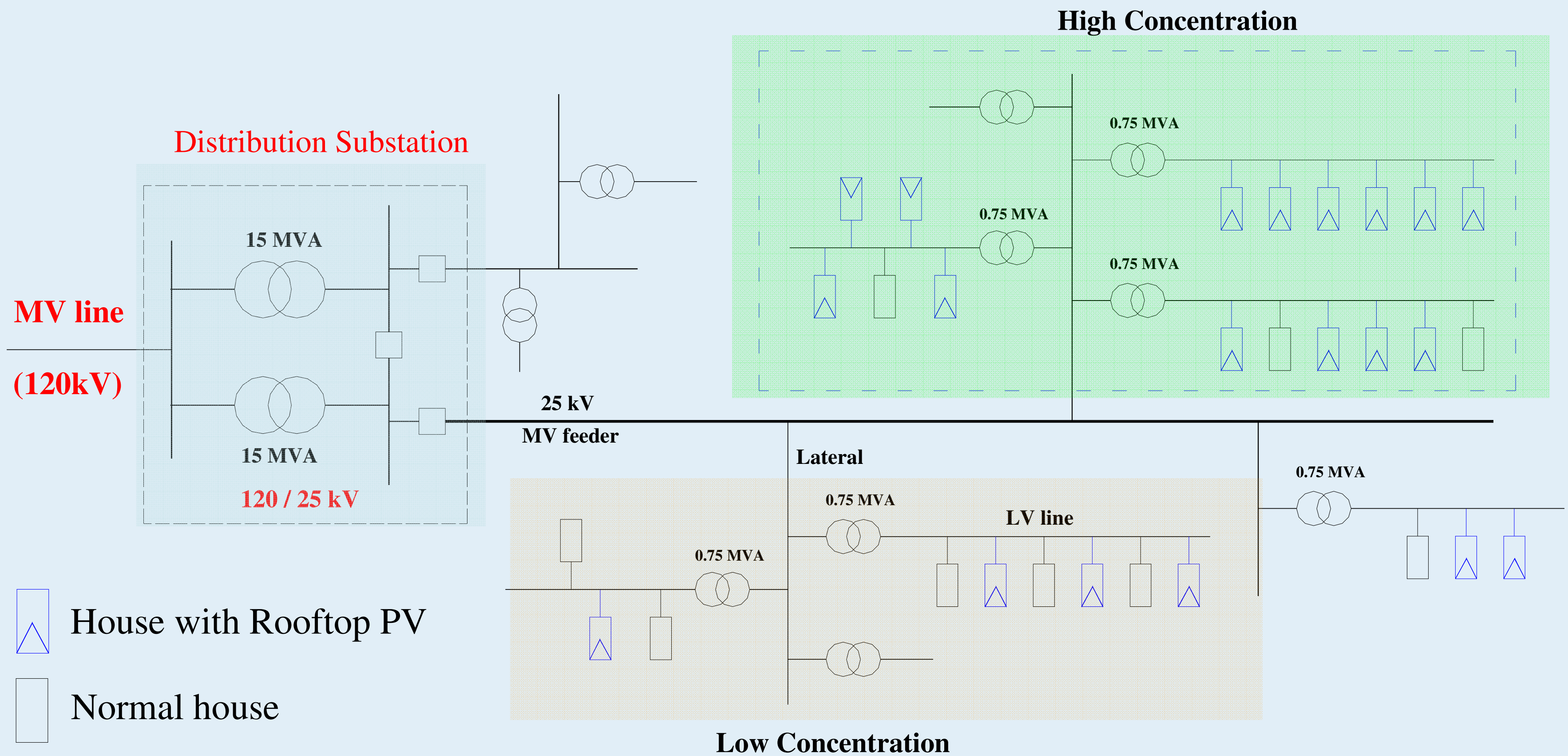
Interim Reports and Papers

Further Studies and Research. Monitor Progress on Mini-grids

Final Reports, Design Guides and Recommendations

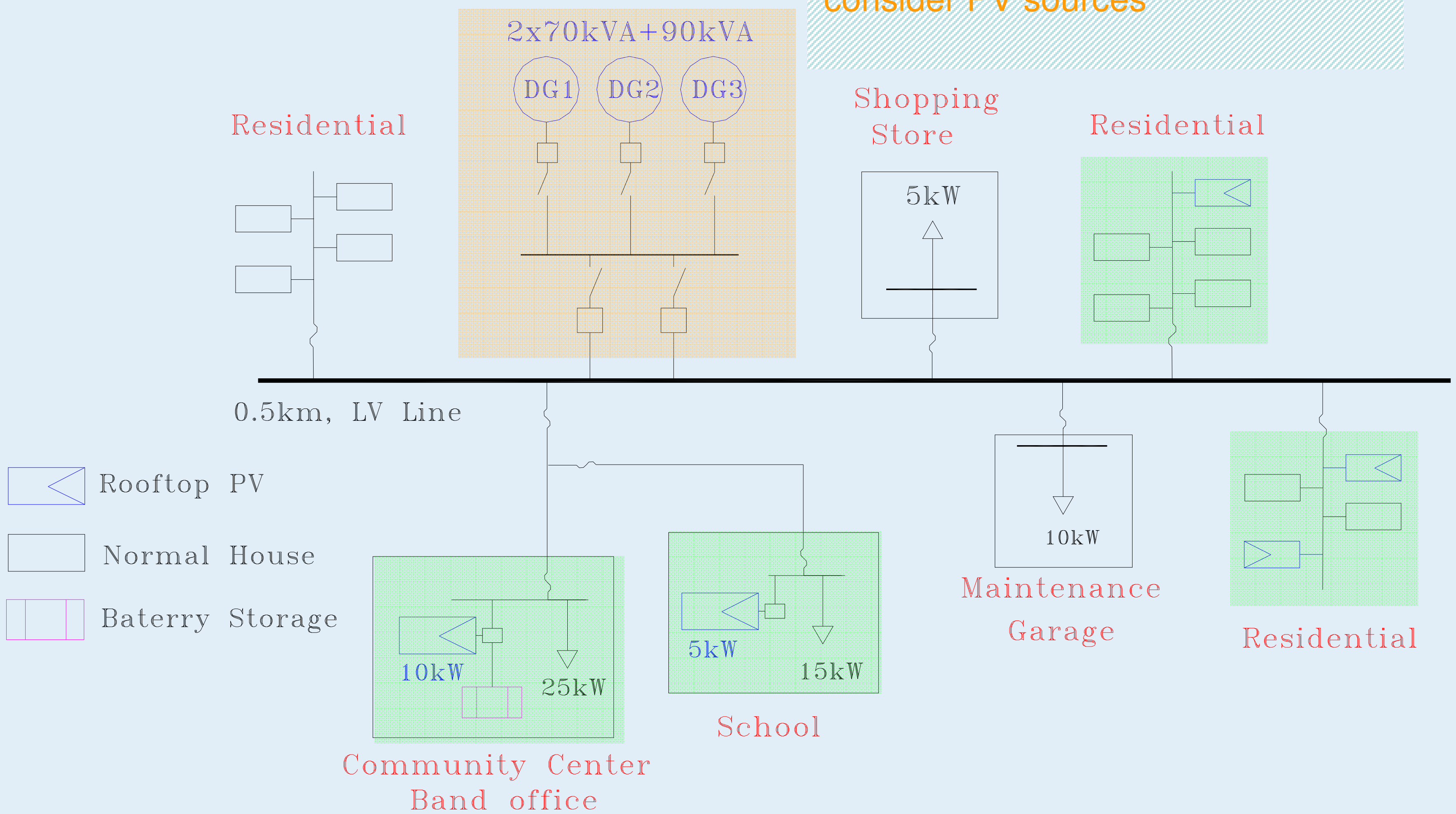
PV cluster

- Suburban locations
- PV capacity up to several MW
- High penetration of PV on some laterals
- PV added to existing distribution grid



Autonomous PV mini-grid

- Remote communities, islands
- Typical PV capacity up to 100 kW
- Distribution network design may consider PV sources



Characteristics of clusters and mini-grids

	PV clusters	Autonomous PV Mini-Grid
Connection	Grid-connected only	Isolated grid only
Generation source	PV + main grid	PV + other DER (usually Diesel genset)
Grid stiffness	Medium or strong grid	Weak grid
Energy storage	Not necessary (Grid acts as an Energy Buffer)	May be required (normally, battery storage)
Technical concerns	Power quality (Voltage rise, Harmonic distortion)	Grid stability (frequency and voltage fluctuations), power quality
Operating requirements	- Bidirectional power-flow capability for the network - Islanding detection and disconnection for PV-inverters	- Short-term: Power dispatch strategies - Long-term: Energy management

Reported data from PV clusters

- Demonstration project in Gunma, Japan (>500 houses, 2.2 MW PV) [6,7]
- PV settlement of "Schlierberg", Germany (50 units, 300 kW PV) [8]
- Sydney Olympics Solar Village, Australia (629 units, >600kW PV) [9]
- PV suburb networks, Netherlands

  (> 500 houses, > 500 kW PV) [10]
- No recent North American data found
  - Task 11 is seeking more data from California PV clusters (e.g. Premier Gardens project).

PV clusters
Reported effects on power quality

PQ Concern	Observation	Consideration	Impact
Voltage variation	1 to 2% increase at light load and high solar irradiation	•Network configuration •Number of feeders •Voltage regulation method	May exceed the standard limit
Unbalance Voltage	1 to 2% variation due to uneven distribution of PV-inverters on three phases and shading effect	Geographical and electrical distributions of PV installations in the area	Minor impact
THD voltage	5th, 7th, and 11th harmonics slightly increase	•Harmonic content of the grid voltage •Series impedance of the grid	Normally below the standard limit
THD current	Harmonic distortion could increase at low solar generation	•PV-inverter topology (filter impedance) •Design of current control loop •Grid stiffness	May exceed the standard limit; Undesirable switch-off of PV-inverters
Flicker	May occur at fast alternations of clouds and sunshine	Grid impedance	No noticeable impact
Stress on distribution transformer	•Transformer may operate at very low power factor by increase in PV generation •Moderate increase in transformer temperature	•Type of household appliances (power factor) •Local means of reactive power compensation •PV-inverter technology	May increase the transformer loss and temperature

Reported data from autonomous PV mini-grids

- Greek island systems (Arki, Antikythera, and Kythnos) [11, 12, 13]
  - PV–Diesel mini-grid
  - PV-Wind-Diesel mini-grid
  - Some data on power quality and system stability
- Other reports focus on performance of energy resources (PV, battery) - not on network performance (power quality, frequency of outages, voltage and frequency stability)
- More field data is needed.
- Task 11 plans to gather more data

Autonomous PV mini-grids
Reported effects on power quality

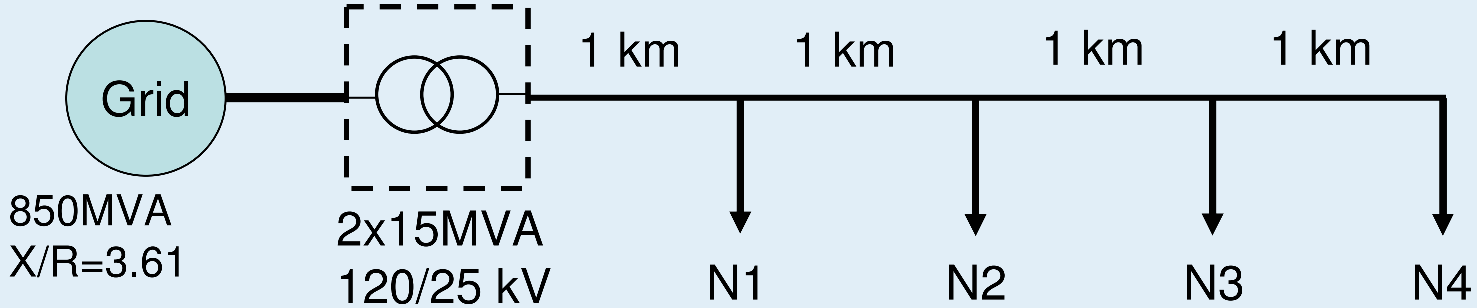
PQ Concern	Observation	Considerations	Impact
Voltage & frequency variation	Not reported	•Network configuration •Mini-grid voltage and frequency regulation method	May exceed the standard limit. No operating impact reported.
Unbalance Voltage	Not reported	Geographical and electrical distributions of sources and loads in the mini-grid	Minor impact – no observation reported.
THD voltage	1.25% - 5.3% THD	•Harmonic content of the DER interfaces •Series impedance of the grid •Effects of non-linear loads	Normally below the standard limit. No operating impact reported.
THD current	Up to 24% current distortion (Inverter in system does not meet present standards for current distortion)	•PV-inverter topology •Grid stiffness	May exceed the standard limit; No operating impact reported.
Flicker	May occur at fast alternations of clouds and sunshine • Not reported	Grid impedance	No noticeable impact reported.
Stress on distribution transformer	Transformer may operate at very low power factor by increase in PV generation • Not reported	•Type of household appliances (power factor) •Local means of reactive power compensation •PV-inverter technology	May increase the transformer loss and temperature – no observation reported.

Observations

- Field data suggests that there are few serious integration issues. Primary integration issue for high penetration PV is voltage rise – consistent with previous IEA PVPS studies.
- Effects are very dependent on network configuration. Distribution network architectures vary substantially in IEA countries and so studying systems in different countries is important.
- Mitigation methods can be inverter based (eg.Gunma demonstration) or network based.
- Limited power quality data available for autonomous mini-grids. Cluster data is a useful indicator but field data from mini-grids is needed.

Next steps

- Seek more field data from both clusters and autonomous mini-grids
- Use simulation tools to evaluate scenarios where field data isn't available.



Canadian PV cluster simulation study in progress:

- A 10 MVA feeder that supplies 4 suburb neighbourhoods of 300 houses each.
- Canadian distribution network parameters.
- Uniform distribution of load and PV generation
  - 2kW rooftop PV per house
  - House load: 7.5kW (peak), 4.0kW (ave.)
  - Load and PV generation varies during day (summer profile)

Conclusion

- The new IEA PVPS Task 11 offers a forum for experts from all IEA countries to share knowledge on mini-grid systems incorporating PV.
- The IEA PVPS mechanism supports collaborative R&D efforts. Current Task 11 participating countries: Australia, Austria, Canada, France, Germany, Japan, Korea, Norway, Spain, Switzerland. Participation and data from other countries is welcome.

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