Automated Quantification of PV Hosting Capacity in Distribution Networks under User-defined Control and Optimization Procedures

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Outline

Hosting capacity
- Definition
- Thresholds and power system criteria evaluation

PVHC (developed PowerFactory plugin)
- Presentation
- The algorithm behind

User-defined control strategies
- Smart inverter control
- Smart load shifting

Simulation results

Conclusion
PV hosting capacity

“Hosting capacity is a feeder’s ability to accommodate PV without adversely impacting reliability or power quality issues.” Rylander et al. (2016)
PV hosting capacity

Power system criteria

PV hosting capacity limited by feeder thresholds and power quality standards

EPRI’s evaluation criteria

- Thermal
- Power quality/voltage
- Protection
- Reliability/safety

- Substation transformer
- Primary conductor
- Service transformer
- Secondary conductor
- Sudden (fast) voltage change
- Steady-state voltage
- Relay reduction of reach
- Sympathetic tripping
- Unintentional islanding
- Operational flexibility
- Load tap changer impact
- Voltage regulator impact
- Element fault current
- Element fault current

EN 50160 standards*


Developed a tool (PVHC) capable of:

- Estimating the PV hosting capacity, **rapidly and accurately**
- **Evaluating** current state of grid in terms of power quality under chosen PV configurations
- **Detecting** power system criteria and standards’ violations and their location
- Being **highly expandable** and **portable**

How:

- PyQt for the GUI (PowerFactory-inspired)
- PowerFactory for the electrical grid simulation
- Python scripting for automation of tasks
Developed add-on

Presentation

**Setup**

**GUI**

**PVHC computation**

**Results**

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**DigSILENT**

**PowerFactory 2017**

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High portability
Free download

PVHC is an open-source tool.

Access the source code and documentation at:

www.csem.ch/PVHC

PVHC can be expanded to adjust to your project’s needs
Tool validation

Performed on the CIGRE benchmark low-voltage microgrid*

Load consumption
generated by a behavior simulator

Overhead lines
forming a radial network

High PV penetration
irradiance time series from real measurements

Behind the algorithm

Step 1 – select PV systems
Behind the algorithm

Step 2 – configure PV systems

![Diagram showing PV systems configuration](image)
Behind the algorithm

Step 3 – reorder PV systems

![Diagram showing PV systems reordering](image-url)
Behind the algorithm

Step 4 – gradually increment power

kVA

PV 5  PV 4  PV 1  PV 2  PV 3
Step 5 – stop at power criterion fail

Behind the algorithm

- e.g. overvoltage at PV 4
Behind the algorithm

Step 6 – freeze failing PV system

e.g. overvoltage
at PV 4
Step 7 – continue incrementing power and freeze PV systems accordingly

Behind the algorithm

e.g. overvoltage at PV 4
Behind the algorithm

1-panel precision convergence

- PV 5
- PV 4
- PV 1
- PV 2
- PV 3

kVA

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Behind the algorithm

1-panel precision convergence

User input:
- Min. and Max. panel
- Increment step size

Start incrementing power

Identified failure:
- Stop incrementing
- Apply bisection method

Convergence:
- 1-panel precision
Behind the algorithm

Output and results

Excel sheet containing:

- Recap of program settings and selected network elements
- State of PV systems (panel number, output power)
- Location and cause of failed power criteria
- Total feeder PV generation
- Power quality report (coming soon)

Automatic plotting on PowerFactory:

- Voltage profiles
- Thermal loadings
- Transformer tap changes
- ....
Implementation of user-defined control strategies

Control strategies

Input → Create PowerFactory objects → Setup algorithm → for PV in PV systems:

Turn PV off → False

Turn PV (min panel) on → Violates criteria → False

PV = ø? → True

Set PV (num panel) → False

Apply bisection method → Violates criteria → False

num panel = panel start → True

Set new initial parameters → False

Remove PV from PV systems → False

for PV in PV systems:

Turn PV (min panel) on → True

PV = ø? → False

Set PV (num panel) → True

Apply bisection method → False

num panel = panel step → True

Remove PV from PV systems → False

for PV in PV systems:

PV = ø? → False

Set PV (num panel) → True

Apply bisection method → False

output results of hosting capacity → False

New capacity > Old capacity? → True

End

End

Hosting capacity computation
Control strategies

**Smart inverter control (I)**

Development of a smart inverter control strategy:

- Based on **Volt/VAR control**
- Find **optimal control parameters**
- Based on **regular update** of parameters
- Guarantee grid stability / **power quality**
- Assist in **voltage support**
- Increase **PV hosting capacity**

![Graph showing VARs generated vs. Measured voltage at PCC (p.u.)]
Control strategies

Smart inverter control (II)

Objective function:

$$\min \ C(x, \lambda) = \frac{\lambda V^2(x) + (1 - \lambda)L^2(x)}{V(x) + L(x)}$$

Trade-off between:

Voltage deviation

$$V(x) = \sum_{n=1}^{N} \sqrt{\frac{1}{K} \sum_{k=1}^{K} (10u_{k,n}(x) - 10)^2}$$

Max. line loading

$$L(x) = \sum_{n=1}^{N} \sqrt{\frac{1}{K} \sum_{k=1}^{K} (0.01l_{k,n}(x))^2}$$
Smart appliance scheduler

Control strategies

No load shifting:
- Suboptimal self-consumption
- Possible reverse power flows
- Possible over-voltages and under-voltages
- Solar leakage
- Expensive storage systems needed
Control strategies

Smart appliance scheduler

**Load shifting:**
- Done by solving a MILP*
- Self-consumption maximized
- Peak-to-average ratio reduced
- Reverse power flows avoided
- Cost of supply reduced
- Voltage deviation improved
- Possible increase of hosting capacity

*V. Kaczmarczyk, et al. “Simulator for optimal scheduling of domestic appliances [4]"
Simulated results

Rules for the sizing of PV systems are **very different from one another**

+ **19.7%** hosting capacity with smart inverter control.

+ **53.9%** hosting capacity with direct load control.

+ **57.1%** hosting capacity with both methods combined
Conclusion

Automated quantification of PV hosting capacity:

- Under specific grid configuration and user-defined settings
- Fast and Accurate
- Easily expandable and portable

Ability to compare, evaluate, and combine various control strategies

Results on CIGRE’s benchmark grid show:

- A 377% difference in hosting capacity between DACHZ and EN 50160
- A total increase of 57.1% in hosting capacity with smart control strategies
Free download

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