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Design optimization of Aalborg-type transformerless PV inverters with focus on power quality

Georgios Orfanoudakis
HELLENIC MEDITERRANEAN UNIVERSITY (HMU), GREECE

Eftychios Koutroulis
TECHNICAL UNIVERSITY OF CRETE (TUC), GREECE

Georgios Foteinopoulos
TECHNICAL UNIVERSITY OF CRETE (TUC), GREECE

Weimin Wu
SHANGHAI MARITIME UNIVERSITY (SMU), CHINA

Introduction – Motivation

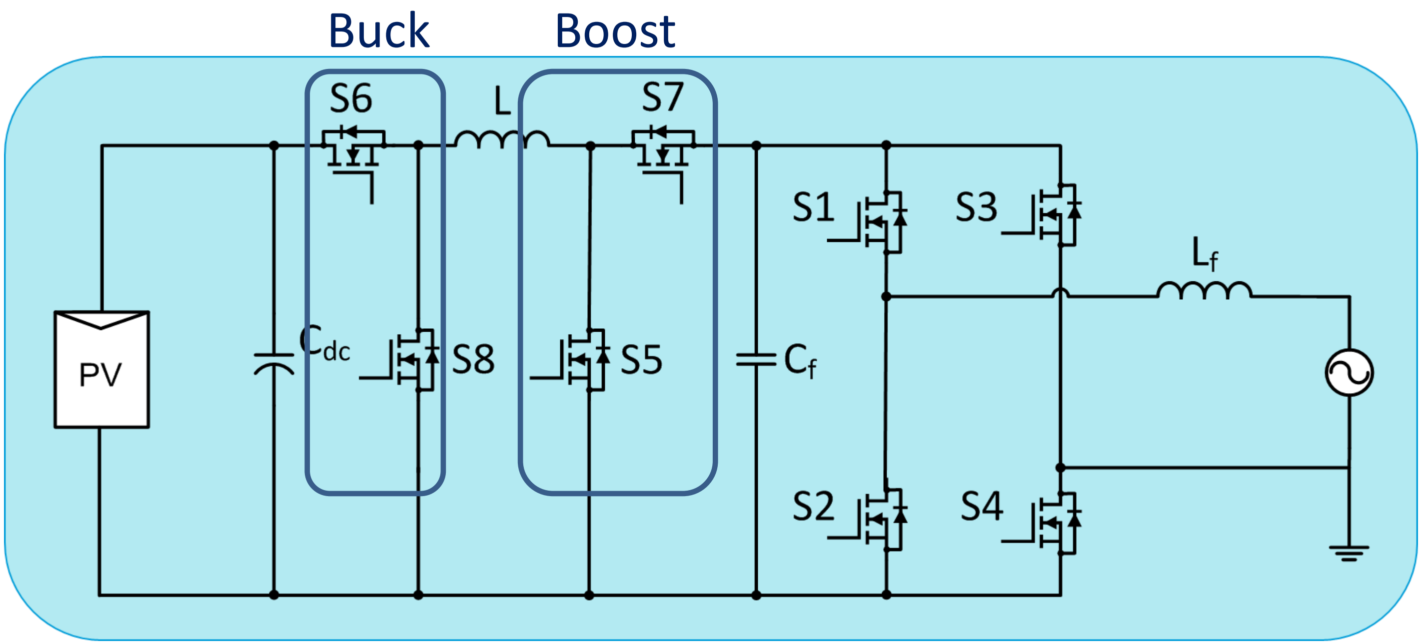
- **Single-phase transformerless photovoltaic (PV) inverters**
  - High efficiency
  - Power quality
- **Operating range varies widely**
  - Daily and seasonal variations
  - Solar irradiance and ambient temperature
- **Power quality standards**
  - Limit grid current Total Demand Distortion (TDD) below 5%
- **Conventional filter design methods**
  - Do not apply to topologies with current-source characteristics
- **Need for optimized selection of switching frequency and filter parameters**

Summary – Contribution

- **Method**
  - Powerful simulator
  - Metaheuristic optimization algorithm
- **Aim**
  - Maximize the European efficiency …
  - under given design constraints …
  - obtaining TDD < 5% for the entire operating range
- **Strengths**
  - Considers the PV array, the inverter with its controller, and the grid
  - Applicable to topologies that exhibit both voltage- and current-source characteristics

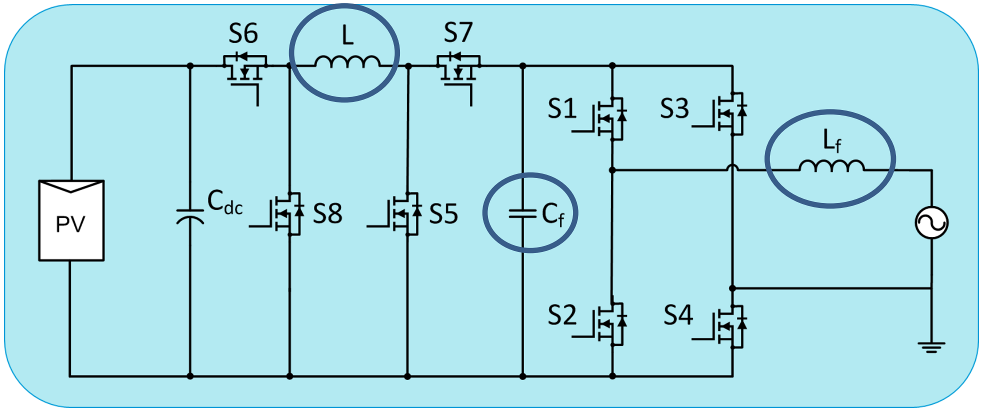
Transformerless PV inverter

- **Full-bridge Aalborg PV inverter**
  - Only one power stage, Buck (S6/S8) or Boost (S5/S7), switches at high frequency at each moment
  - Requires custom current control technique



Proposed method

- **Design variables**
  - Buck/Boost stage switching frequency (f_{sw})
  - Buck/Boost inductor (L)
  - Output filter inductor (L_f)
  - Buck/Boost output capacitor (C)



- **Particle Swarm Optimization (PSO)**

$$\underset{\substack{\boldsymbol{X}=[f_{sw},L,L_f,C] \\ TDD<5\%}}{\text{maximize}} \; \eta_{eu}(\boldsymbol{X})$$

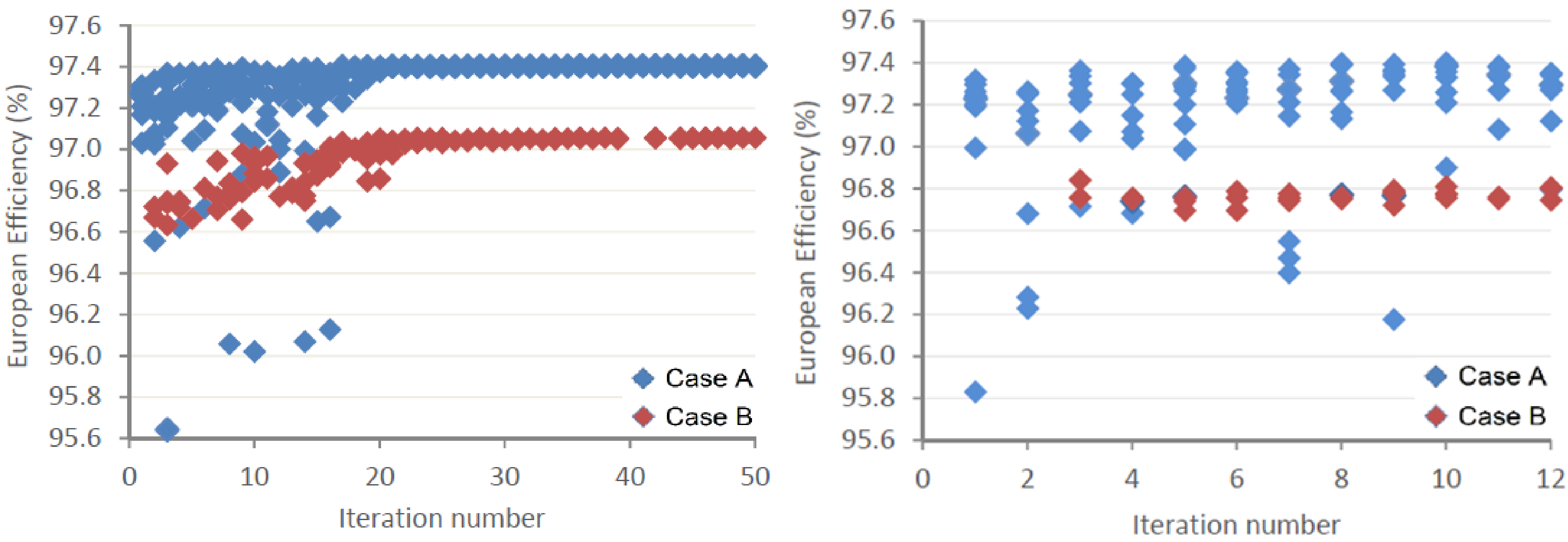
$$\eta_{eu} = 0.03 \cdot \eta_{5\%} + 0.06 \cdot \eta_{10\%} + 0.13 \cdot \eta_{20\%} + 0.10 \cdot \eta_{30\%} + 0.48 \cdot \eta_{50\%} + 0.20 \cdot \eta_{100\%}$$

- **Loss estimation**
  - Derivation of analytical loss expressions not required.
  - Calculations by MATLAB-Simulink / Simscape^{TM} Physical System (PS) blocks.

Results

- **Two sets of constraints:**
  - **Case A**: Considering only the boundary values in the table.
  - **Case B**: Also, $(4 \cdot L + L_f) < 3$ mH

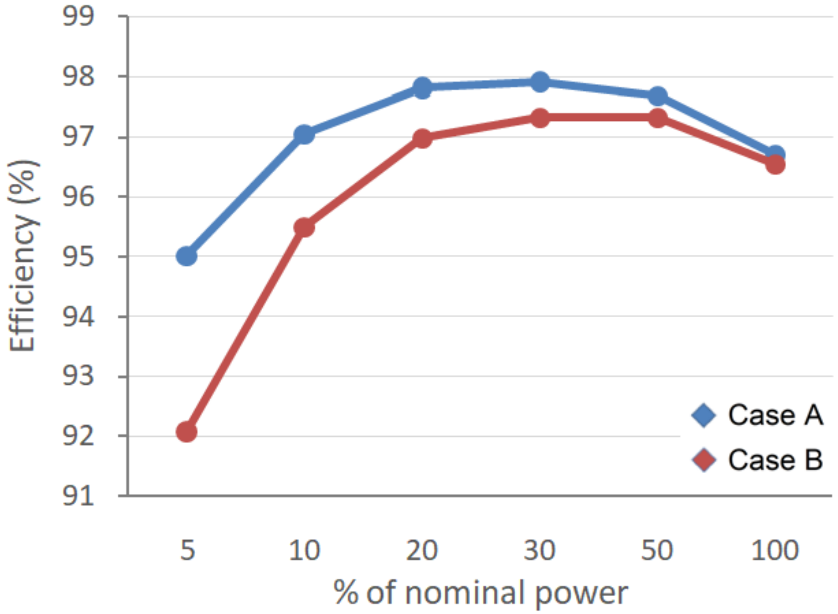
Symbol	Description	Min / Max	Unit
f_s	Buck/Boost switching freq.	10 / 20	kHz
L	Buck/Boost inductor	0.5 / 2.5	mH
L_f	Output filter inductor	0.02 / 1.5	mH
C	Buck/Boost output capacitor	2 / 5	μF

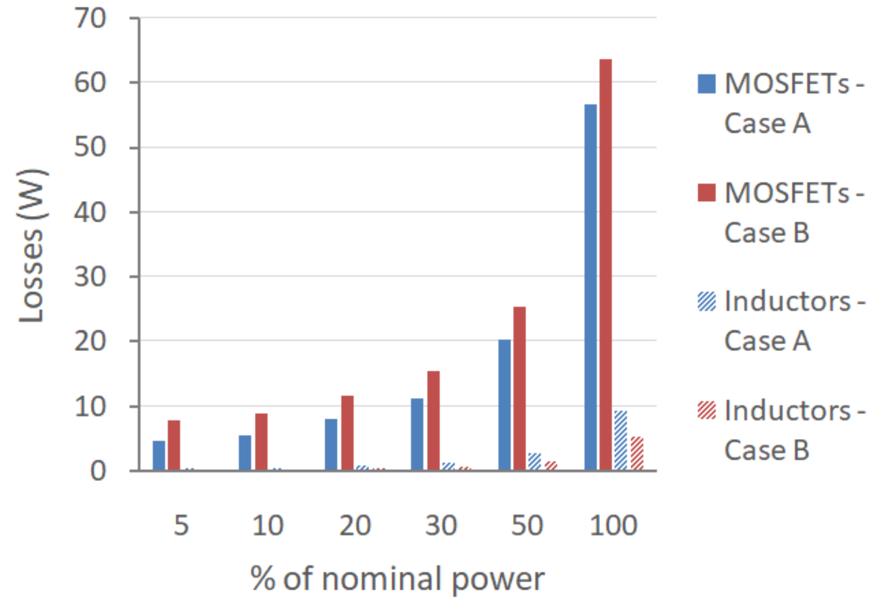


(a) (b)

Results (2)

- **Two sets of constraints:**
  - **Case A**: Minimum switching frequency (10 kHz) selected to minimize overall losses – obtained η_{eu} = 97.4%
  - **Case B**: Inductor values selected under given constraint to allow for minimum possible switching frequency (14.2 kHz) – obtained η_{eu} = 96.8%





Conclusion

- **Concept**
  - Complete system simulation (PV array, inverter, controller, grid).
  - Executed only a limited number of times.
  - Heuristically selected sets of design parameters.
- **Advantages**
  - Applicable to unconventional converter topologies and/or modulation and control strategies.
  - Not requiring derivation of analytical expressions for semiconductor and passive component losses.
  - Can operate with different loss models and constraints.
  - Can be extended to multi-objective optimization.

Acknowledgement

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Thank you for your attention !