Synthesis of Solar Photovoltaic Systems: Optimal Sizing Comparison

Alessandro Trindade[1] and Lucas Cordeiro[2]

[1]Federal University of Amazonas (UFAM), Brazil
[2]The University of Manchester (UoM), UK

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Agenda

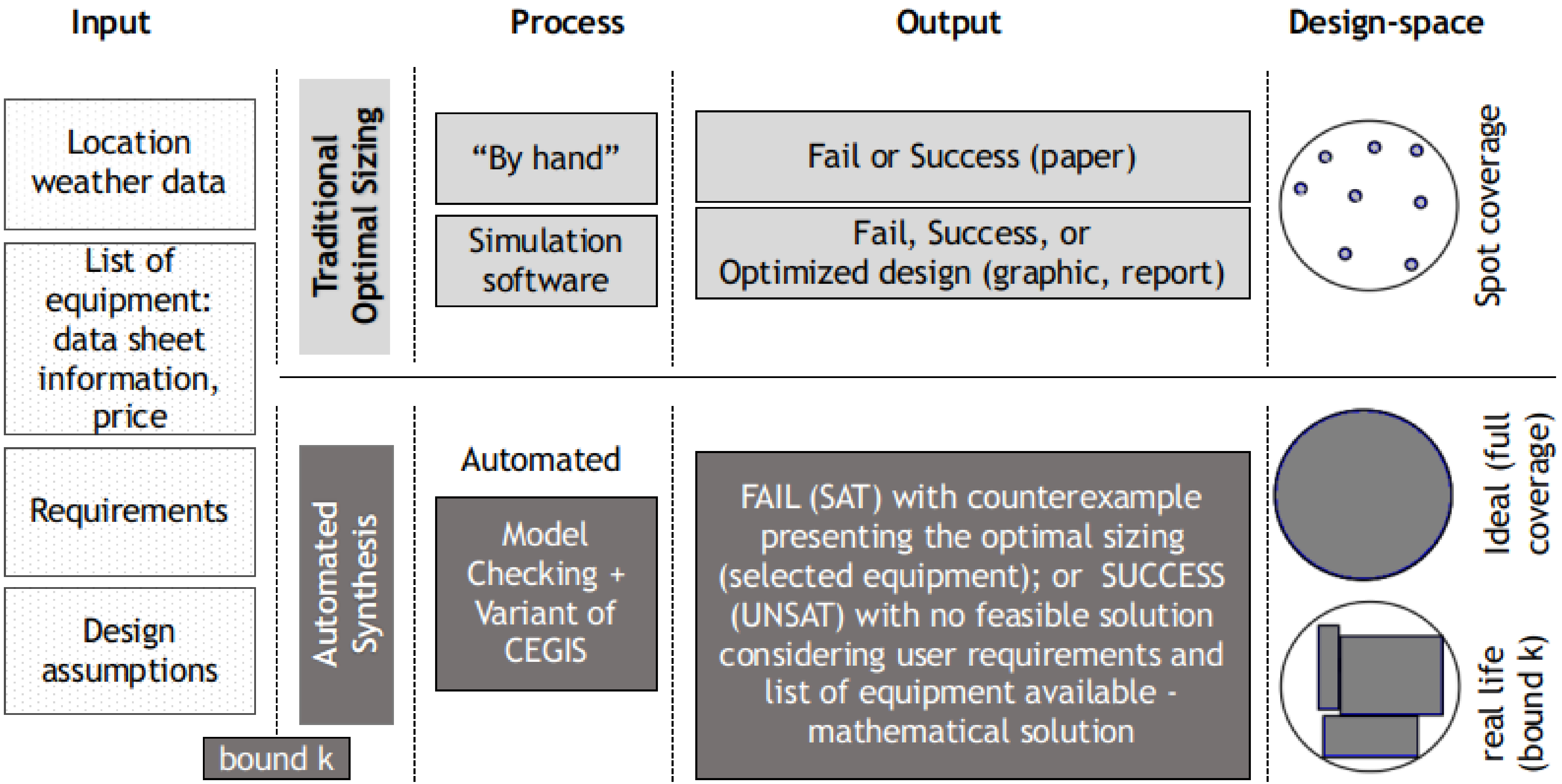
- Motivation
- Problem
- Objectives
- Methodology
- Results
- Conclusions

Source: https://smallbusinessforum.co/why-i-quit-taking-notes-and-you-should-too-ee94c2c725f8

Motivation

- From a PhD Thesis
- Future cities? But there are 850 million people without electricity
- Use of formal synthesis to size a stand-alone solar PV system
- Optimal PV sizing
  - Feasible solution with the lowest equipment cost, including installation and maintenance in a 20-years horizon
- To create a tool
- Evaluate different software verifiers
- Compare the technique with commercial simulation tool

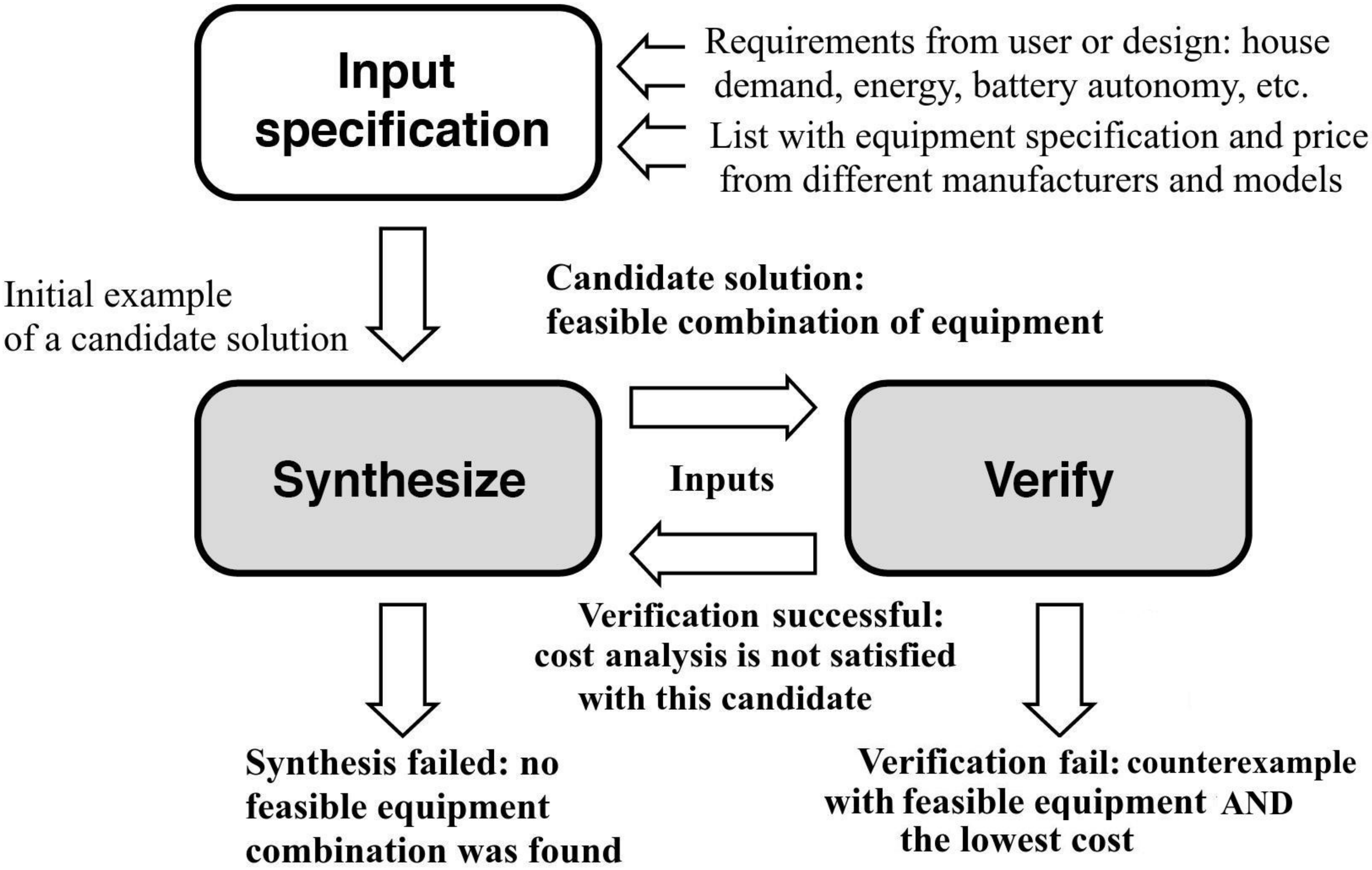
Problem

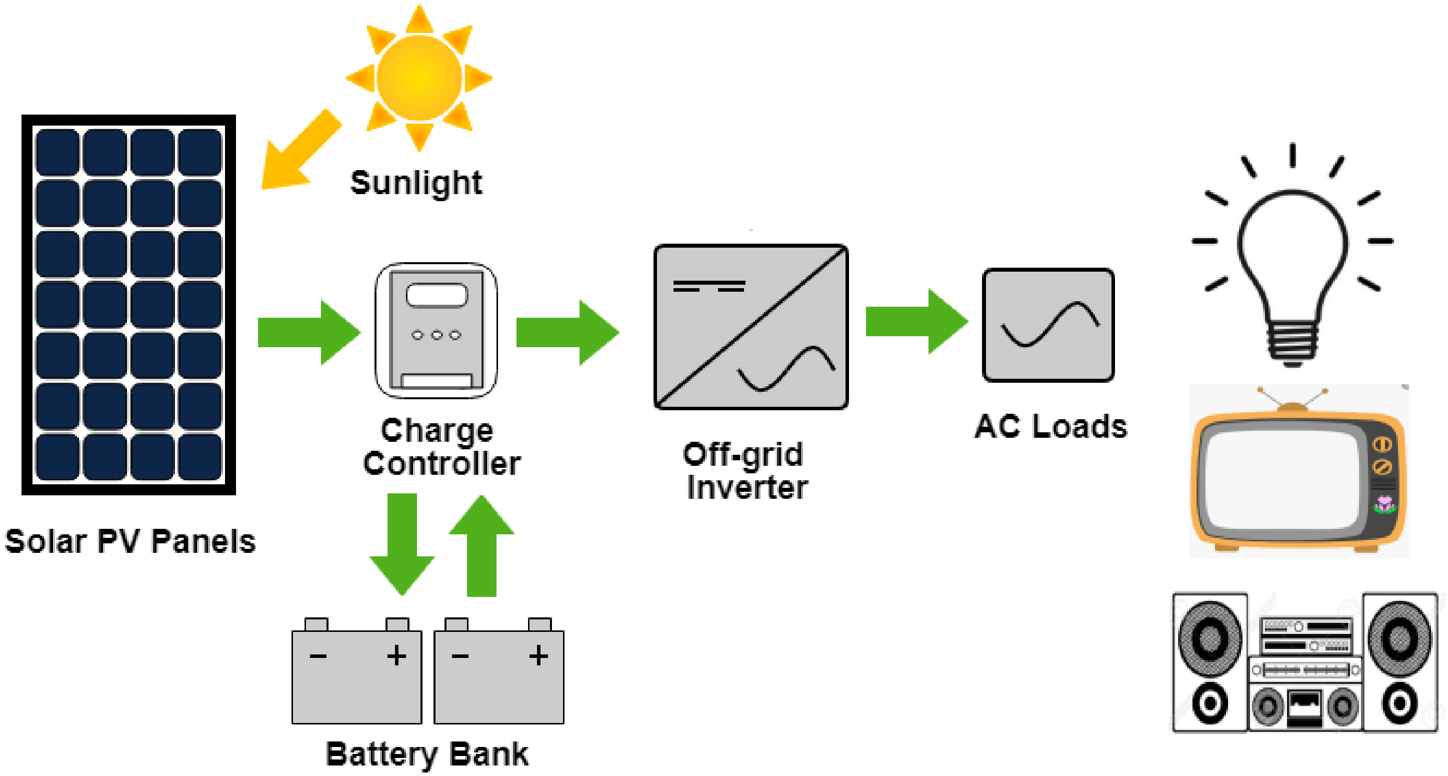

Input
Process
Output
Design-space
Location weather data
List of equipment: data sheet information, price
Requirements
Design assumptions
bound k
Traditional Optimal Sizing
"By hand"
Simulation software
Fail or Success (paper)
Fail, Success, or Optimized design (graphic, report)
Spot coverage
Automated Synthesis
Automated
Model Checking + Variant of CEGIS
FAIL (SAT) with counterexample presenting the optimal sizing (selected equipment); or SUCCESS (UNSAT) with no feasible solution considering user requirements and list of equipment available - mathematical solution
Ideal (full coverage)
real life (bound k)

Objectives

- General:
  - To obtain the optimal sizing of solar PV systems using synthesis
- Specifics:
  - To use formal method to model the PV system
  - To use automated synthesis approach to obtain the optimal PV sizing solution: CEGIS-like technique
  - Use of commercial equipment items (40 in our case)
  - To use 7 case studies, 3 software verifiers, and a specialized optimization PV system tool: comparative

Methodology

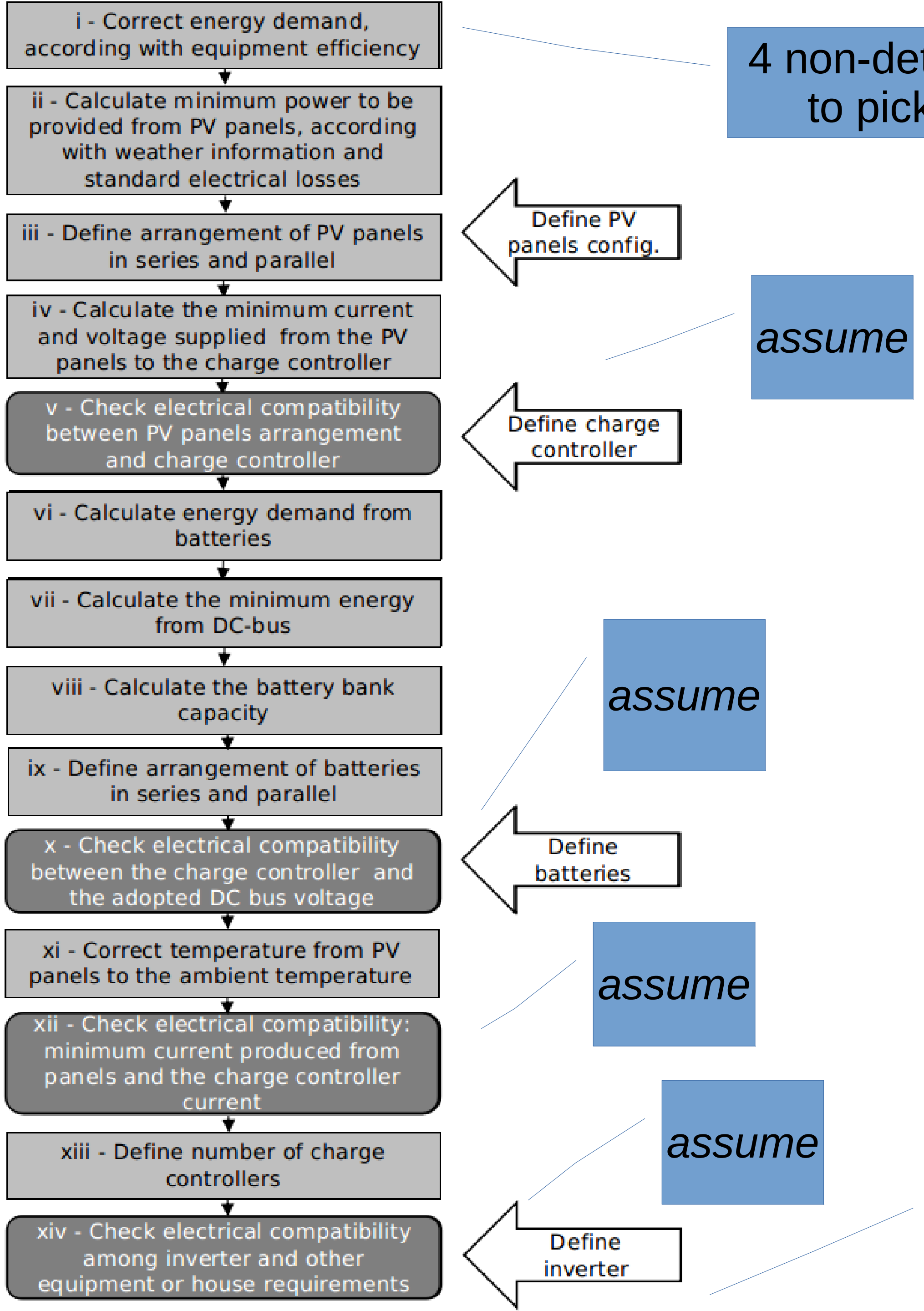




Source: http://texcorgroup.co.ke/project/supply-deliver-installation-of-pv-solar-power-system-to-primary-schools-in-off-grid-areas-of-narok-county-19-schools/

$$LCC = C_{PV} + C_{bat} + C_{charger} + C_{inv} + C_{installation} + C_{batrep} + C_{PWO\&M}$$

4 non-deterministic variables and 4 matrices: to pick candidates for every component



Phase 2: VERIFY

Linear search for the lowest LCC, incrementally until FAIL (SAT) or SUCCESS (UNSAT)

Feasible solution: **SYNTHESIS phase 1**

Results

- Evaluation goals: **soundness and performance**
- Configuration: Intel Xeon CPU E5-4617 (8-cores) with 2.90 GHz and 64 GB RAM, running Ubuntu 16.04 LTS 64-bits.
- Specialized optimization tool: HOMER Pro
- Simulation software for optimal sizing validation: PVsyst
- Predefined time out of 660 minutes
- 7 case studies (5 deployed in rural area of Manaus, Amazonas, Brazil)
  - Power demand from 263 W to 1, 586 W
  - Energy demand from 2.5 kWh/day to 14 kWh/day
  - Battery autonomy from 12h to 48h

Case Study	CBMC 5.11 (MiniSat 2.2.1)	ESBMC 6.0.0 (Boolector 3.0.1)	CPAchecker 1.8 (MathSAT 5.5.3)	HOMER Pro 3.13.1
Case 1: Power Peak: 342W Energy: 3.9 kWh/day Battery autonomy: 48h	Out of Memory	SAT (620 min), LCC: US$ 10,214 6 panels x 330 W (3S-2P) 16 batteries x 105 Ah (2S-8P) Controller 35 A/145 V Inverter 700 W/48 V	SAT (548 min), LCC US$ 10,214 6 panels x 330W (3S-2P) 16 batteries x 105 Ah (2S-8P) Controller 35A/145V Inverter 700W/48V	SUCCESS (< 1 min), LCC: US$ 7,808 2.53 kW of panels 12 batteries x 83.4 Ah (2S-6P) 0.351 kW inverter
Case 2: Power Peak: 814 W Energy: 4.88 kWh/day Battery autonomy: 48h	Out of Memory	Time Out	Time Out	SUCCESS (< 1 min), LCC: US$ 12,861 3.71 kW of panels 20 batteries x 83.4 Ah (2S-10P) 0.817 kW inverter
Case 3: Power Peak: 815 W Energy: 4.88 kWh/day Battery autonomy: 12h	Out of Memory	SAT (63 min), LCC: US$ 9,274 14 panels x 150 W (7P-2S) 6 batteries x 105 Ah (2S-3P) Controller 35A/145 V Inverter 700 W/48 V	Time Out	Not possible (autonomy < 24h)
Case 4: Power Peak: 253 W Energy: 3.6 kWh/day Battery autonomy: 48h	Out of Memory	SAT (147 min), LCC: US$ 9,678 6 panels x 330 W (7P-2S) 16 batteries x 105 Ah (2S-8P) Controller 35A/145 V Inverter 280 W/48 V	SAT (605 min), LCC: US$ 9,678 6 panels x 330 W (7P-2S) 16 batteries x 105 Ah (2S-8P) Controller 35A/145 V Inverter 280 W/48 V	SUCCESS (< 1 min), LCC: US$ 7,677 2.42 kW of panels 12 batteries x 83.4 Ah (2S-6P) 0.254 kW inverter
Case 5: Power Peak: 263 W Energy: 2.5 kWh/day Battery autonomy: 48h	Out of Memory	SAT (36 min), LCC: US$ 8,900 4 panels x 330 W (2P-2S) 14 batteries x 80 Ah (2S-7P) Controller 35A/145V Inverter 280 W/24 V	SAT (254 min), LCC: US$ 8,900 4 panels x 330 W (2P-2S) 14 batteries x 80 Ah (2S-7P) Controller 35A/145V Inverter 280 W/24 V	SUCCESS (< 1 min), LCC: US$ 6,175 1.59 kW of panels 10 batteries x 83.4 Ah (2S-5P) 0.268 kW inverter
Case 6: Power Peak: 322 W Energy: 4.3 kWh/day Battery autonomy: 48h	Out of Memory	SAT (380 min), LCC: US$ 9,678 6 panels x 320 W (2P-3S) 18 batteries x 105 Ah (2S-9P) Controller 35A/145V Inverter 400 W/24 V	Time Out	SUCCESS (< 1 min), LCC: US$ 9,112 3.15 kW of panels 14 batteries x 83.4 Ah (2S-7P) 0.328 kW inverter
Case 7: Power Peak: 1,586 W Energy: 14 kWh/day Battery autonomy: 48h	Out of Memory	UNSAT (< 1 min)	Time Out	SUCCESS (< 1 min), LCC US$ 41,878 12.5 kW of panels 66 batteries x 83.4 Ah (2S-33P) 1.6 kW inverter

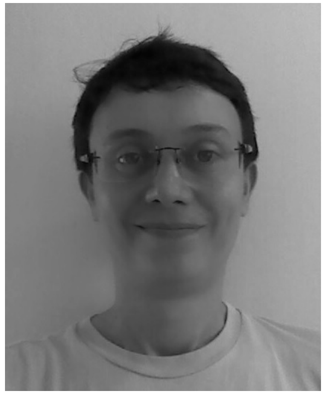
Results: optimal sizing validation (PVsyst)

- Case Studies 1, 4, 5 and 6:
  - Formal synthesis sizing: no error found, availability > 95%
  - HOMER Pro: no error found, oversize of PV panels and batteries
- Case Study 2
  - Without formal synthesis sizing (TO)
  - HOMER Pro: no error found, oversize of PV panels and batteries
- Case Study 3:
  - PVSyst and HOMER Pro can’t analyze autonomy < 24 h
  - Only formal synthesis presented sizing
- Case Study 7:
  - UNSAT for formal synthesis sizing
  - HOMER Pro: no error found, oversize of PV panels and batteries

Conclusions

- Our technique is promising: qualitative results
- ESBMC with Boolector presented the best overall results
- Our solution is far more detailed and closer to commercial reality than the solution given by the commercial tool. Plus, it considers autonomy < 24h
- Our CEGIS-like approach for the synthesis has the VERIFY phase linear and <u>lingering</u>: future work is to improve the search for solution
  - Parallel binary search
  - Using a solver that is specific to perform optimization with model checking (νZ)

- Alessandro Trindade
  - Federal University of Amazonas (Brazil)
  - alessandrotrindade@ufam.edu.br



- Lucas Cordeiro
  - University of Manchester (UK)
  - lucas.cordeiro@manchester.ac.uk