Development of a heuristic algorithm to design stand-alone microgrids for rural electrification projects considering distributed generation

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Agenda

1. **Introduction**
   a. Motivation
   b. Input – Output
   c. Considerations
2. **Architecture of the algorithm**
   a. Phase I: Initial solution construction
   b. Phase II: Distributed generation incorporation
   c. Phase III: Microgrids expansion
3. **Results – Case Study**
4. **Conclusions and future steps**

Motivation

45% of rural areas electrified through mini-grids by 2030 (IEA, 2011)

1. Generation technology
2. Topology of electrical network

Up-front costs of the electrification project

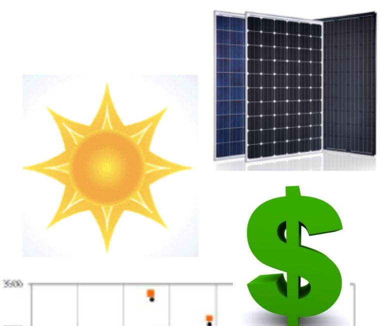
Key
Optimal use of resources and design

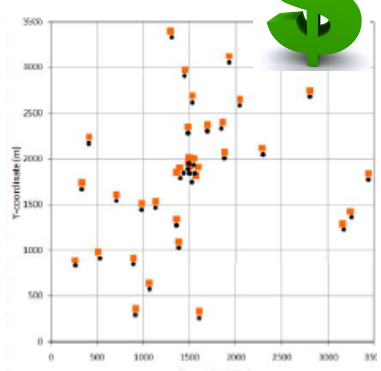
Input - Output

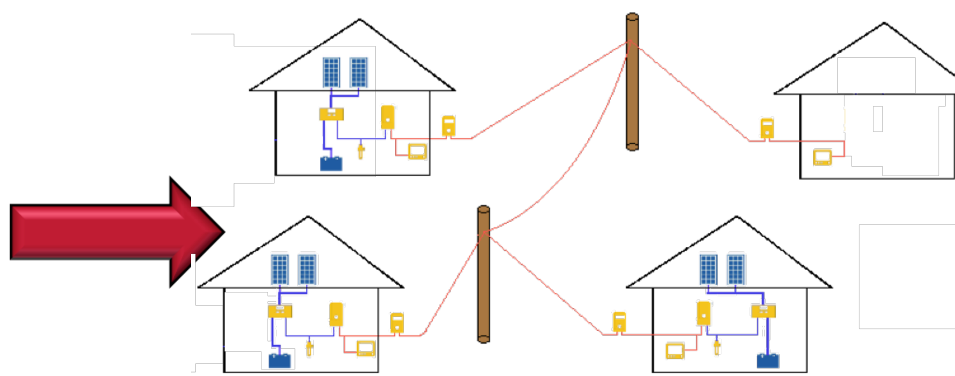
1) Consumers' location,
2) Consumers' power and energy demand,
3) Cost and electrical characteristics of potential equipment,
4) Electrical constraints.
5) Local solar radiation.

→ **ALGORITHM** →

1) Electrical network design
2) Number and location of DGs
3) Electrical design of DGs
4) Investment cost of the project



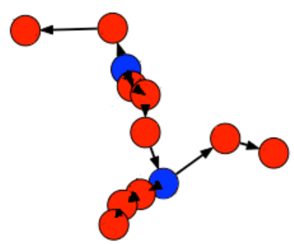




Considerations

- AC microgrids,
- Radial network,
- Generation points located at consumption points,
- Generation based on RE (Solar)
- Minimization of upfront investment
- All generation points with similar power capacities.

Scenario A

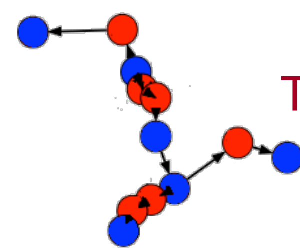


Total power Req: 1.2 kW

Number Generation points: 2

Power capacity per GP ≈ 0.6 kW

Scenario B



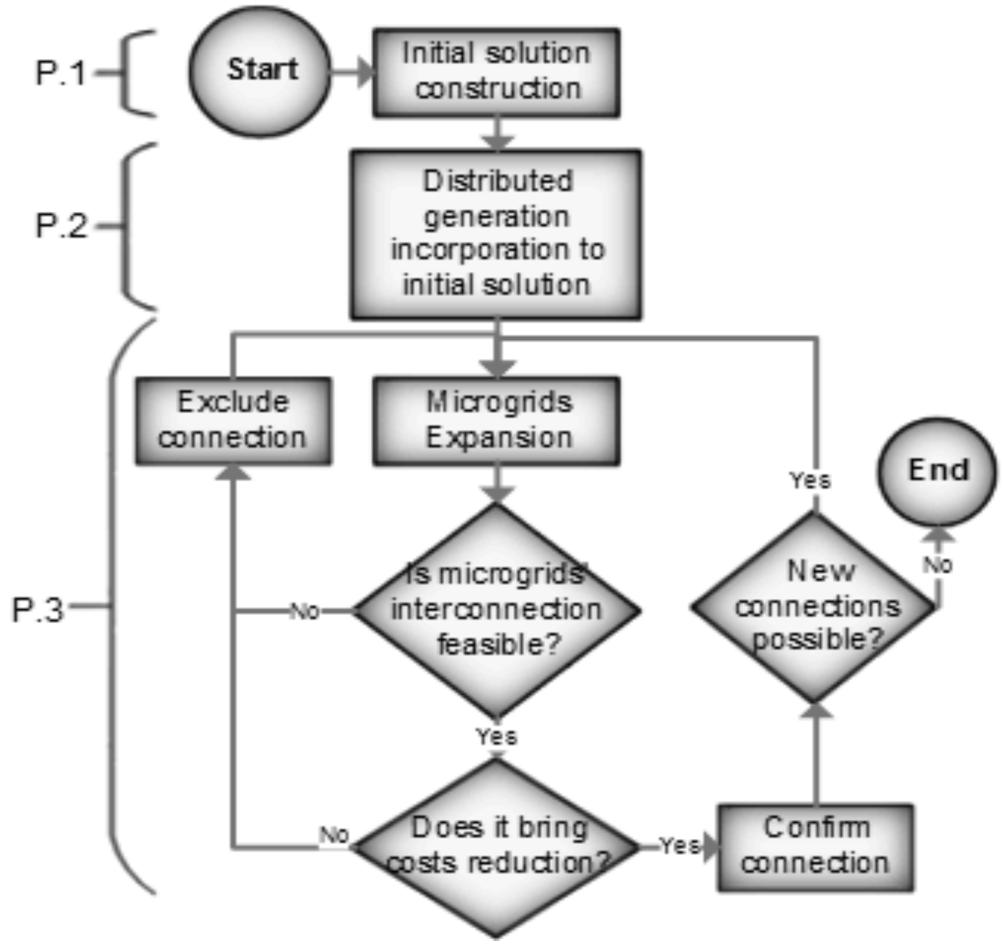
Total power Req: 1.2 kW

Number Generation points: 6

Power capacity per GP ≈ 0.2 kW

Architecture of the algorithm

Overview: Main phases



Architecture of the algorithm

Phase I: Initial solution construction

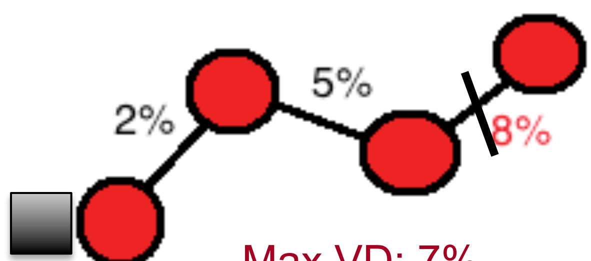
Demand concentration index

$$DI_j = \sum_{j \in N_i} \frac{ED_j}{\max(L_{ij}, L_{min})}$$

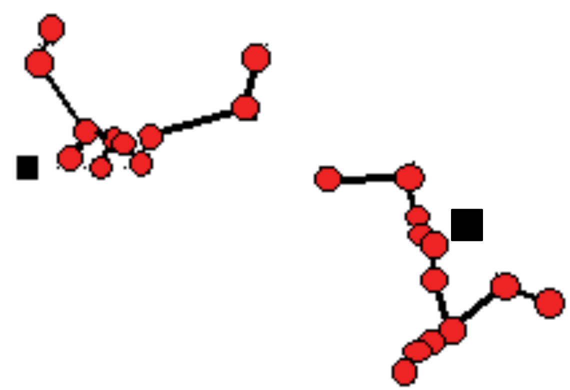
(Ranaboldo, 2013)

Initial point selection

Electrical network construction



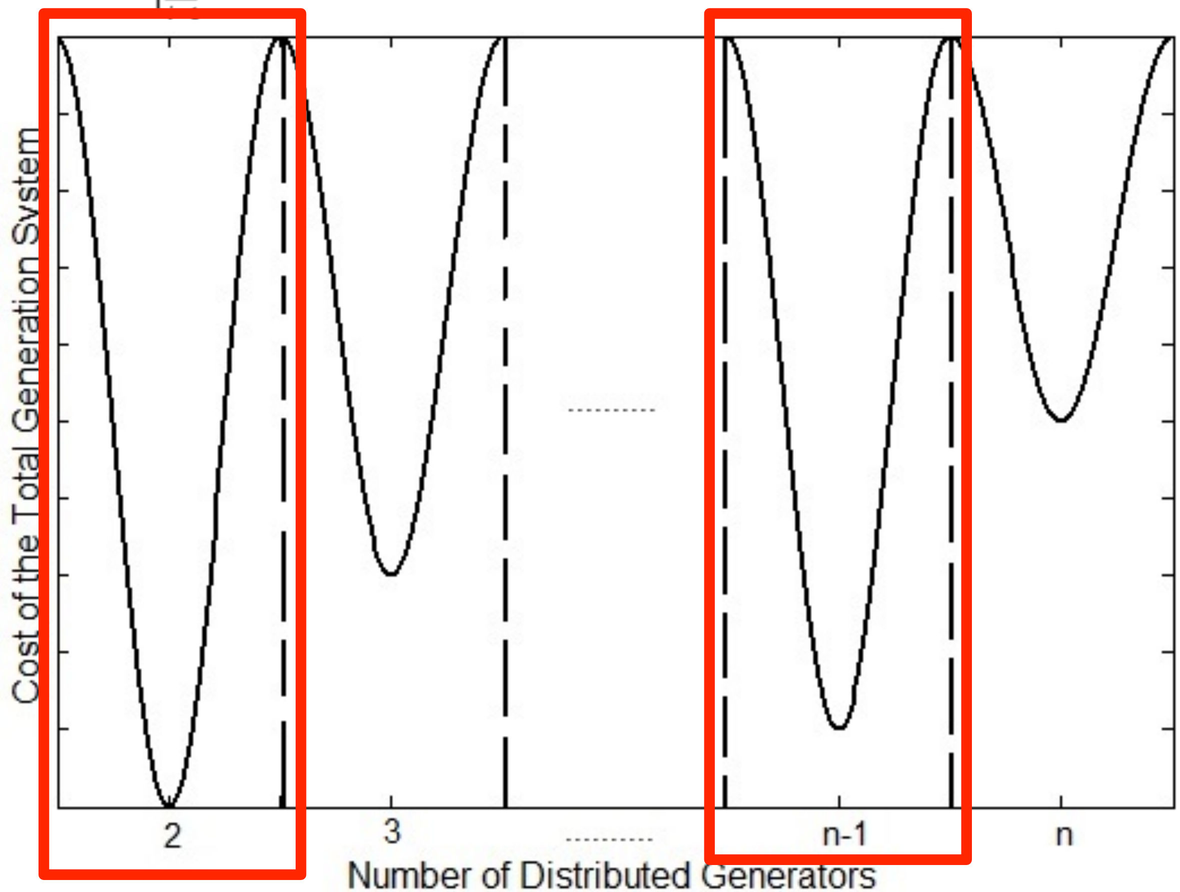
Max VD: 7%



Architecture of the algorithm

Phase II: Distributed generation incorporation

$$Cost = min\left|\sum^{m}(NG_{Gi}\cdot CostG_{Gi} + NB_{Bi}\cdot CostB_{Bi} + NCC_{CCi}\cdot CostCC_{CCi} + NI_{Ii}\cdot CostI_{Ii} + NC_{Ci}\cdot CostC_{Ci})\right|$$



Architecture of the algorithm

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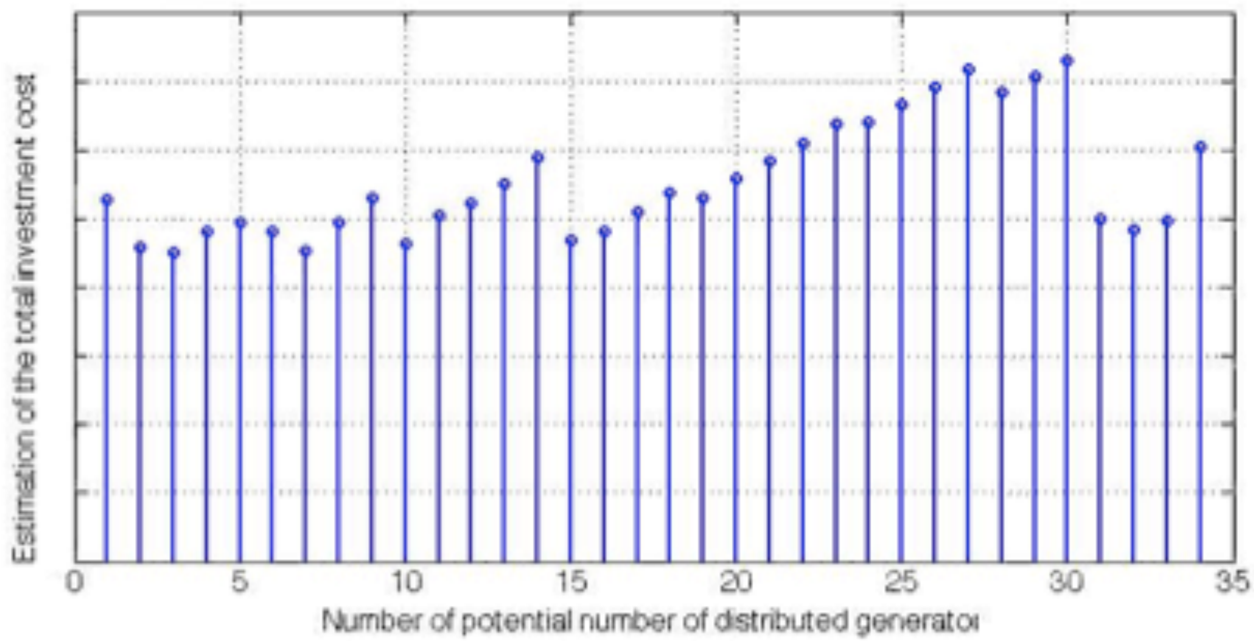
Phase II: Distributed generation incorporation

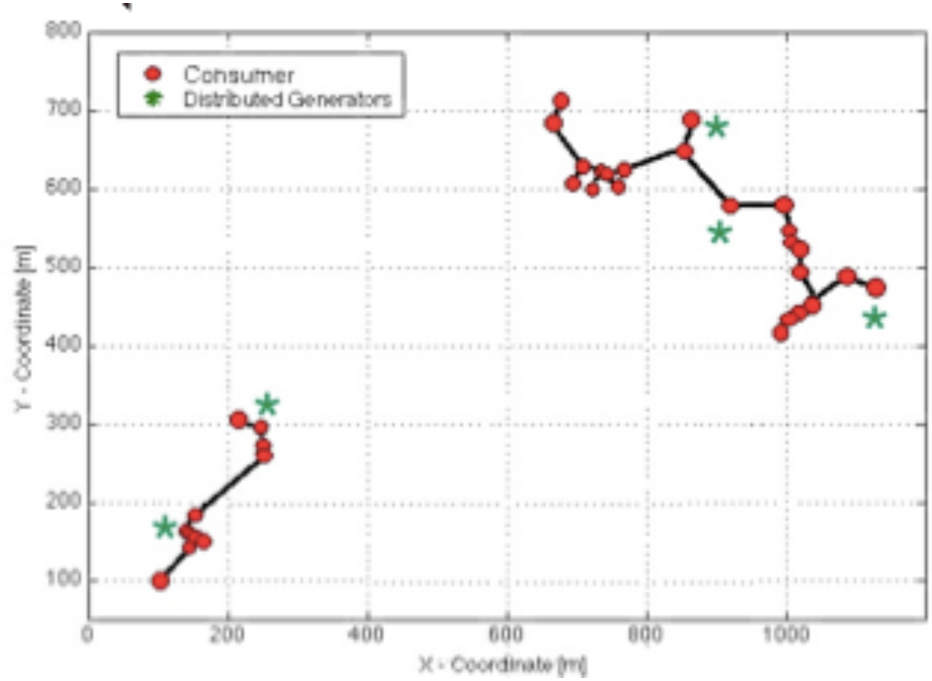
Selection of cheapest scenarios - Estimation



Architecture of the algorithm

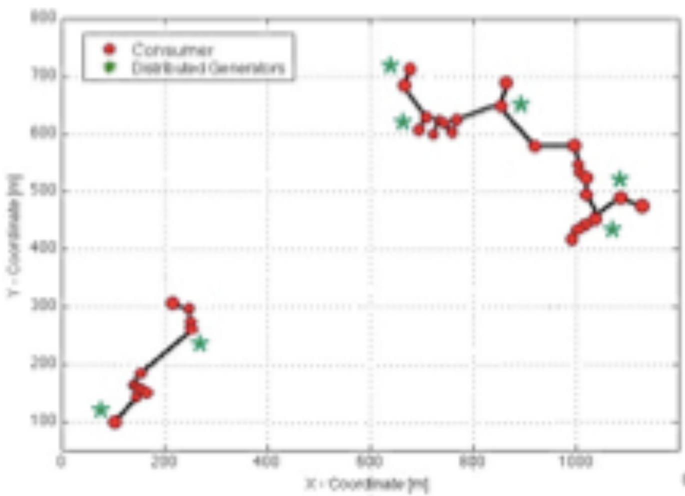
Phase II: Distributed generation incorporation

Simulation of scenarios → Improved Backwards/ Forward Sweep → Sizing and cost estimation → **Selection of cheapest solution**



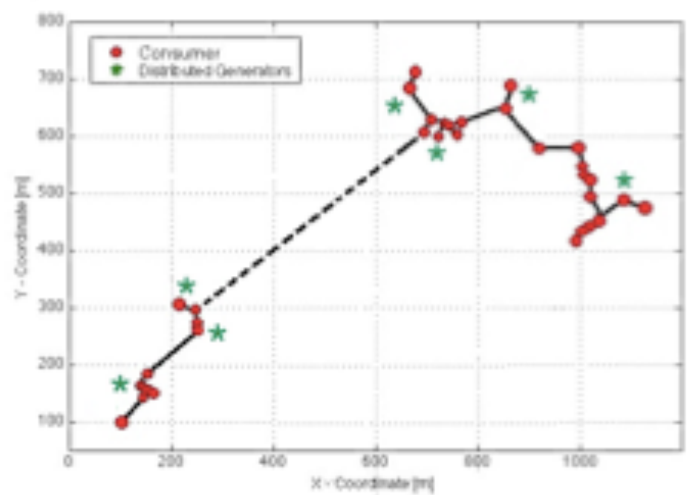
Architecture of the algorithm

Phase III: Microgrids Expansion



Case A

Case B

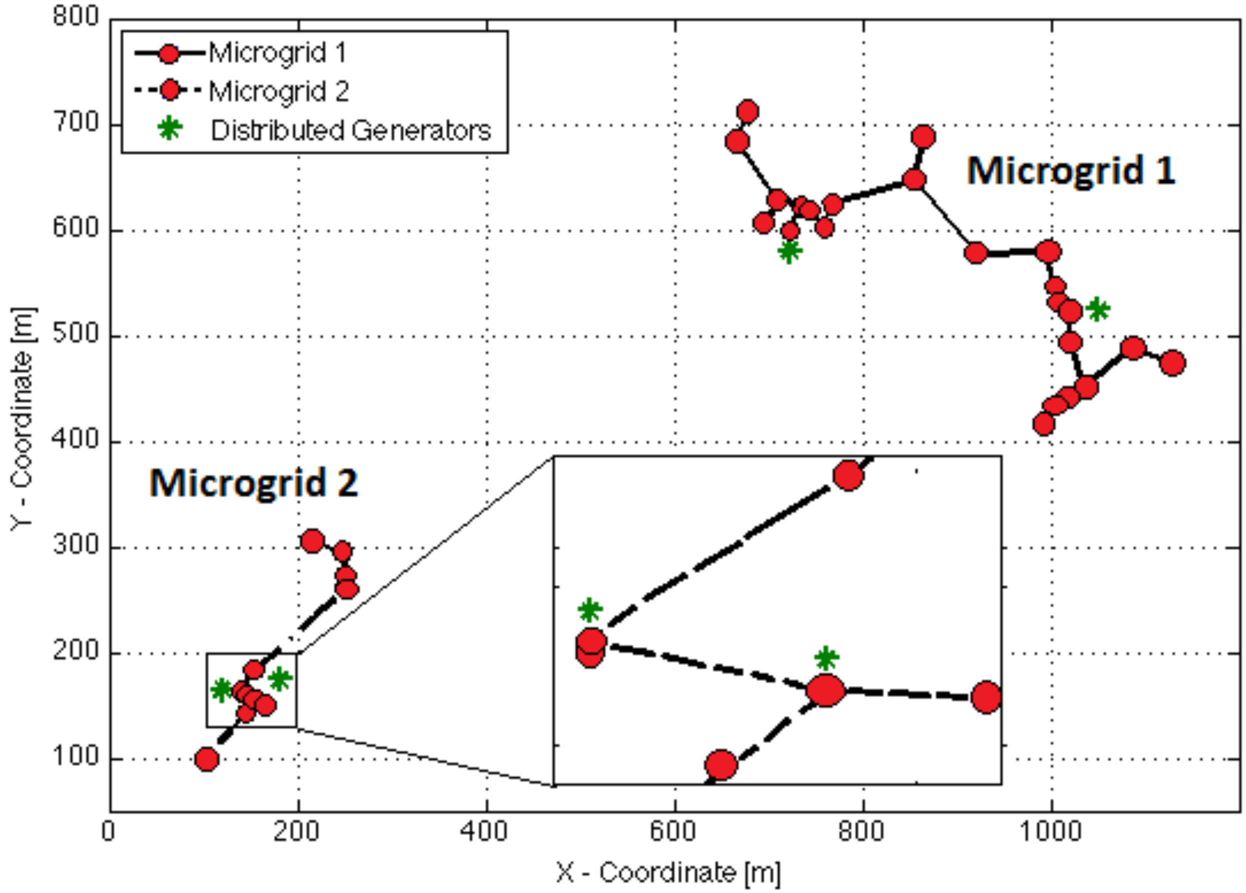


Cost A < Cost B?

Selection of final solution

Results – Case Study

Sonzapote (Nicaragua)



Results – Case Study

Sonzapote (Nicaragua)

Cost comparison
SHS – Centralized approach – Proposed Algorithm

Reference Scenarios	SHS	Centralized Generation
Cost [USD]	73,221	63,364
Cost of Algorithm [USD]	61,510	
Difference between Algorithm and References	**-19%**	**-3%**

Cost comparison
Proposed Algorithm – HOMER Pro

Total real HOMER Pro:	*59,431 USD*
Total Algorithm:	*61,510 USD*

Difference: 3.7%

Results – Case Study

- Gap in the design models/software of off-grid systems considering generation and distribution network.
- Use of design algorithms greatly simplify the design process of the electrification process, while achieving investment reductions.
- Similar investment costs found for centralized and distributed generation solutions.
- Implementation of multiple smaller microgrids rather than a bigger one – *Investment reduction*
- Selection of amount of generation points can be solved from a technical/economical perspective.

Future Steps

- Inclusion of additional configurations as part of the potential solutions:
  - DC microgrids,
  - SHS,
  - Microgrids with a single generation point.

Goal: Electrification projects exploiting the benefits of each possible configuration

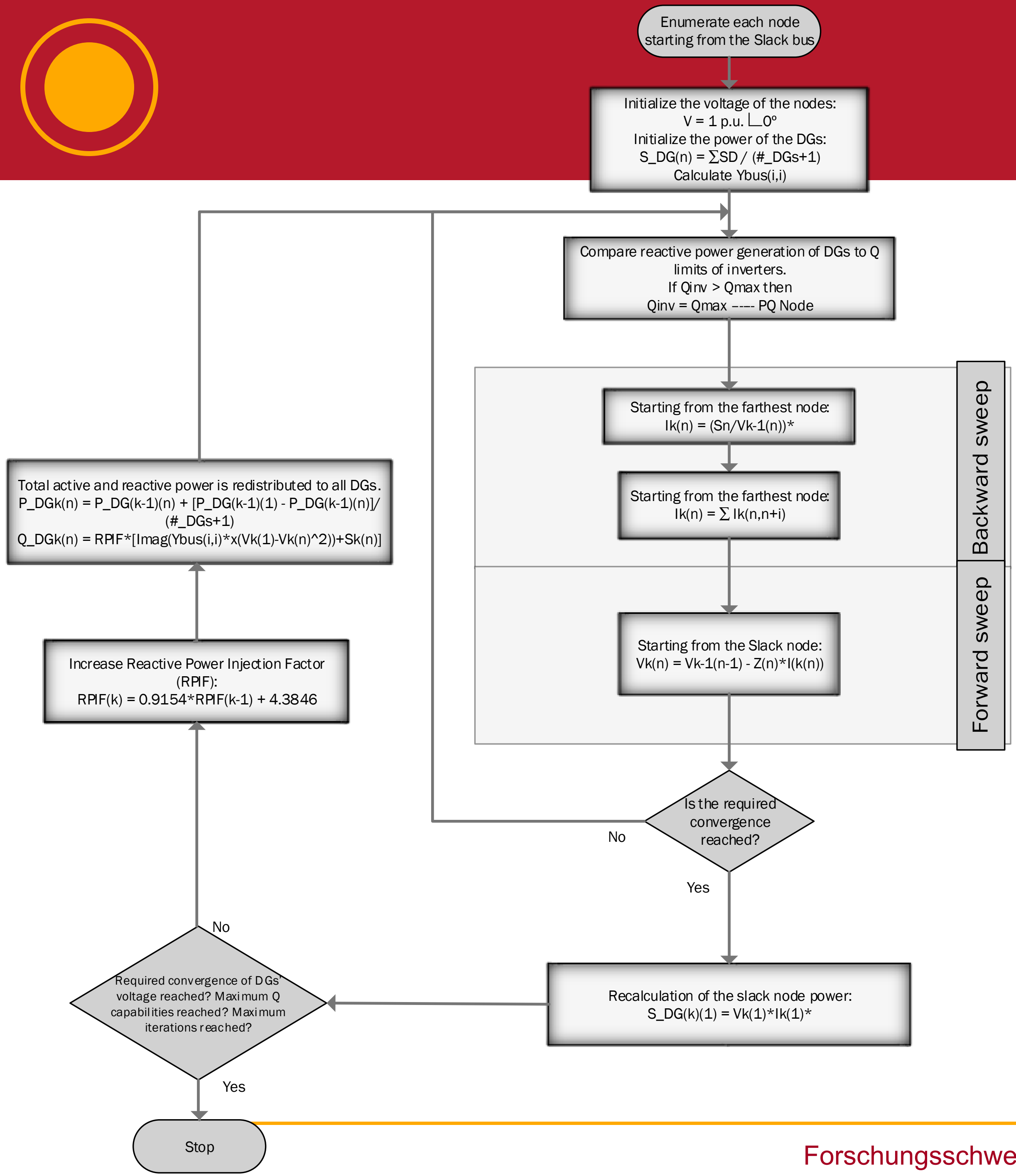
- Optimization of the type of cable used for the electrical network.
- In general, increase the efficiency of the algorithm.

Thanks for your attention!

ESMAP – Voltage drop estimation

U. World Bank, *Mini-Grid Design Manual*, vol. ESMAP Technical Paper 007. 2000. pp. 228 - 231

$$\%VD \approx 2 \cdot (r \cdot \cos\emptyset + x \cdot \sin\emptyset) \cdot \frac{\sum_{n=1}^{N} L_n\,(km) \cdot P_{n\,(kW)}}{E^2 \cdot \cos\emptyset} \cdot 10^5\%$$

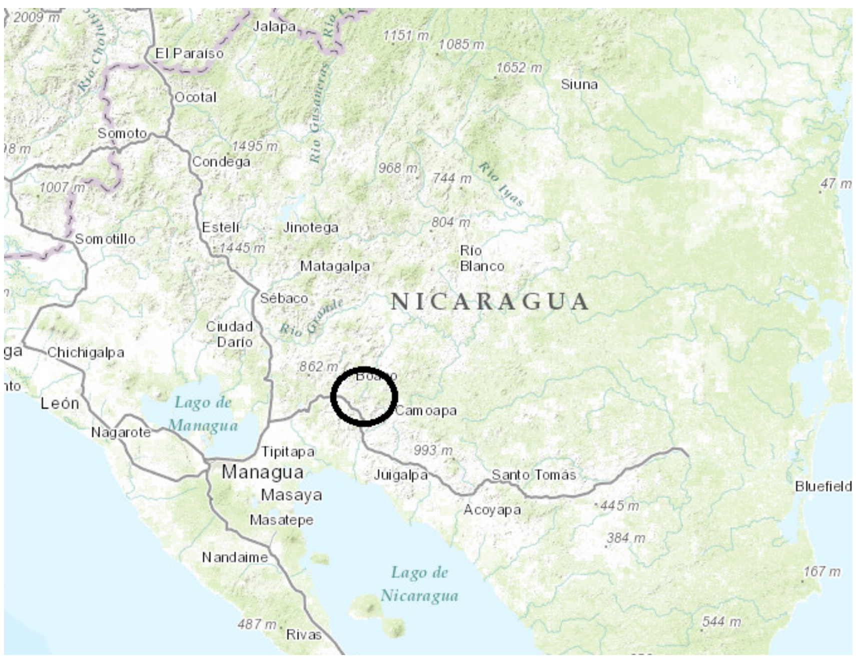


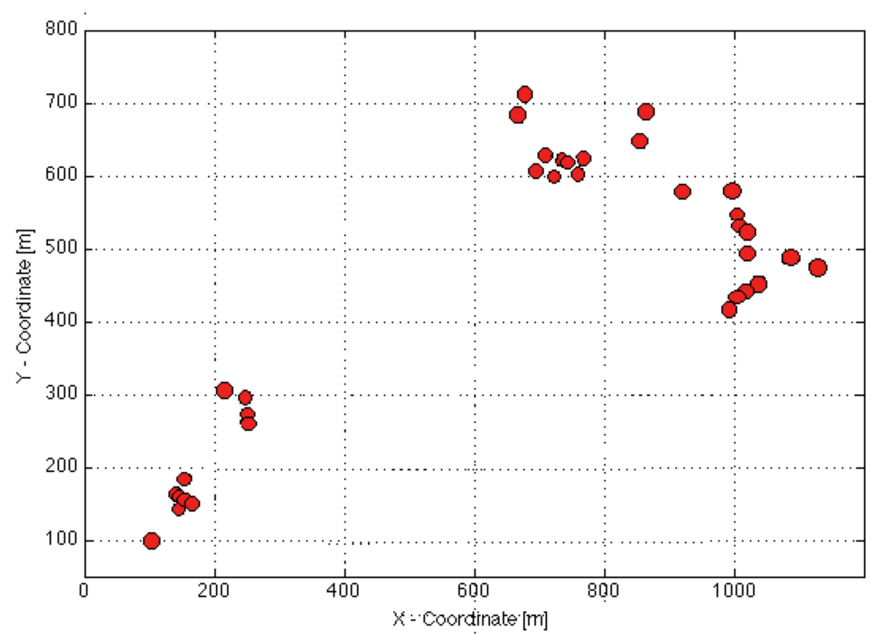
Improved power flow algorithm – Backwards/ Forward Sweep – to solve radial network with multiple generation points

Case Study – Sonzapote (Nicaragua)

- Sonzapote (Nicaragua),
- 345 inhabitants,
- Completely un-electrified,
- Demand assessment necessary
- Community composed by households, a school and a church

- 34 consumption points of the community selected





Case Study – Details of generation system design

Microgrid 1

DG Location	Devices	Type	Amount	Cost [USD]
1	PV Panel	3	8	8016
	Inverter	3	12	1110
	Batteries	1	23	7485
	Charge Controller	2	7	2800
18	PV Panel	3	8	8016
	Inverter	3	12	1110
	Batteries	1	22	7160
	Charge Controller	2	7	2800

Microgrid 2

DG Location	Devices	Type	Amount	Cost [USD]
31	PV Panel	3	4	4008
	Inverter	1	11	506
	Batteries	1	11	3580
	Charge Controller	3	2	1442
28	PV Panel	3	4	4008
	Inverter	1	11	506
	Batteries	1	11	3580
	Charge Controller	3	2	1442

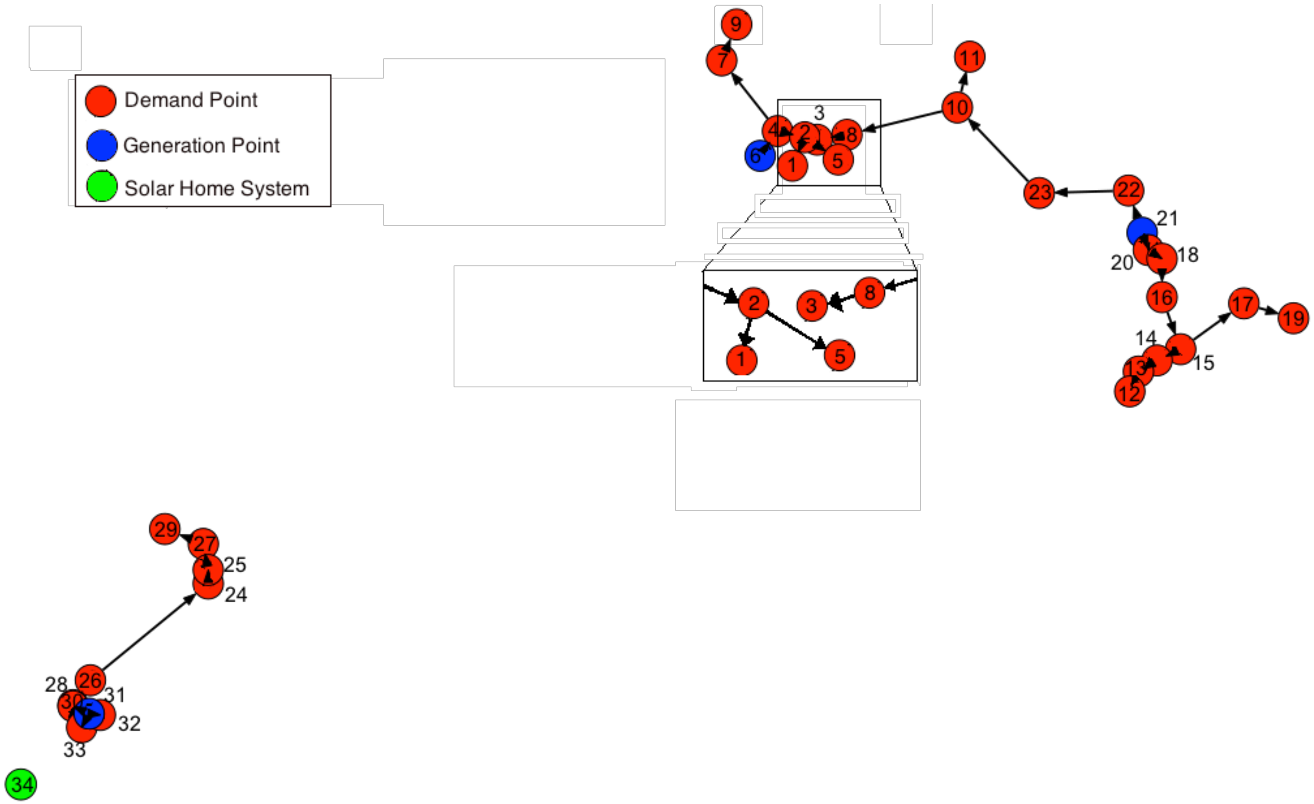
Proposed algorithm– Equipment considered

Inverters	Capacity [W]	Cost [USD]
Type 1	200	46
Type 2	300	70
Type 3	400	92.5
Type 4	1500	444
Batteries	**Capacity [Wh]**	**Cost [USD]**
Type 1	1290	325.47
Type 2	2520	693.21
PV Modules	**Capacity [Wp]**	**Cost [USD]**
Type 1	55	359
Type 2	150	800
Type 3	250	1002
Charge Controllers	**Capacity [W]**	**Cost [USD]**
Type 1	72	92.5
Type 2	300	400
Type 3	540	721
Cables	**Ampacity [A]**	**Cost [USD/m]**
Type 1	70	3.4
Type 2	100	3.9
Type 3	150	4.5
Type 4	205	5.4

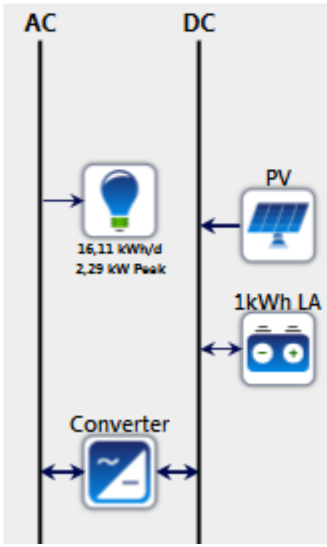
Reference Scenario – Centralized Generation

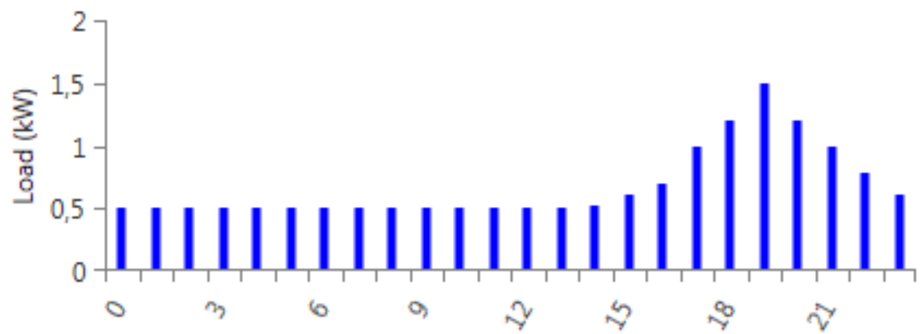
Scenario solved using the model presented in:

Ranaboldo, M., García-Villoria, A., Ferrer-Martí, L.,Pastor Moreno, R. (2014).A heuristic method to design autonomous village electrification projects with renewable energies.Energy 73, 96-109.



HOMER Pro - Modeling





	Capacity		Cost (HOMER)		Cost (Real HOMER)	
PV Array	7368	W	28084	USD	*30060*	*USD*
Batteries	44444	Wh	10080	USD	*11391*	*USD*
Inverter	2666	W	466	USD	*647,5*	*USD*
Cables	--	--	--	--	*7239*	*USD*
Charge Controller	--	--	--	--	*10094*	*USD*
		Total HOMER	38630 USD		***Total real HOMER***	***59431 USD***
					Total Algorithm	***61510 USD***