Smart grids: from traditional to modernized resilient systems

Víctor Escala García
Josep Fanals Batllori
Pol Heredia Julbe
Roger Izquierdo Toro
Palina Nicolas

Smart Grids

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Introduction

- Smart grids are becoming a necessity in order to integrate renewables, accommodate new actors, improve the observability and efficiency.
- The transition from conventional systems towards smart grids is challenging:
  - Incorporate distributed sources of energy.
  - Integrate storage systems.
  - Rely less on large traditional centralized power plants.

Thus, we have divided the progressive adaptations:

Chapter	Activities
Phase 1	Initial solution of the system
Phase 2	Addition of lines
Phase 3	Integration of wind and solar
Phase 4	Rehabilitated power plant and storage
SGAM	HLUC related to contingencies

Table 1: Phases of the project to move towards smart grids

Plan

System overview

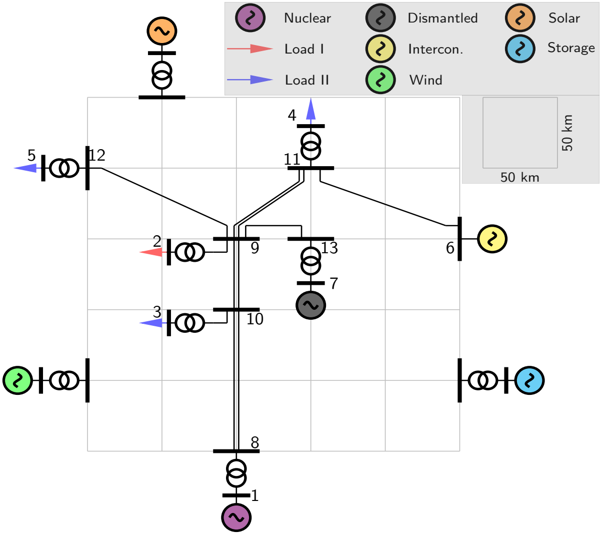


Figure 1: Overview of the network

Initial bus voltages

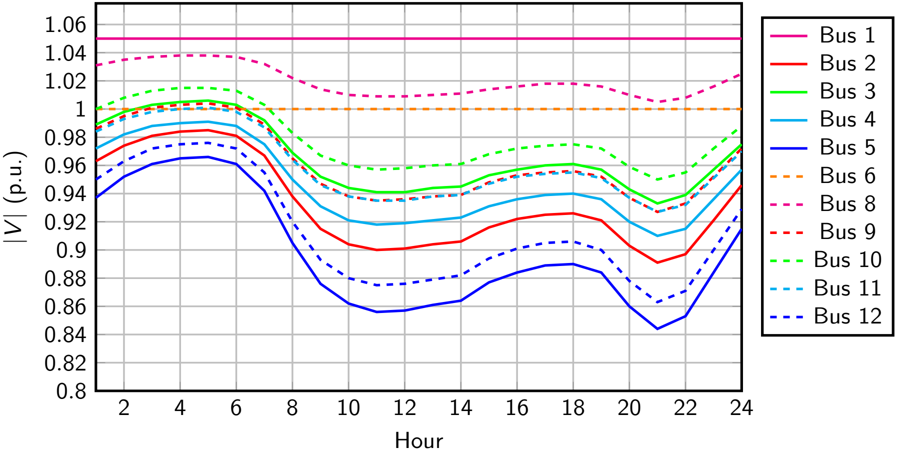


Figure 2: Voltage profile during 24 hours for the initial grid. The low-voltage buses are plotted in solid lines; the high-voltage ones are in dashed lines.

Initial lines loading

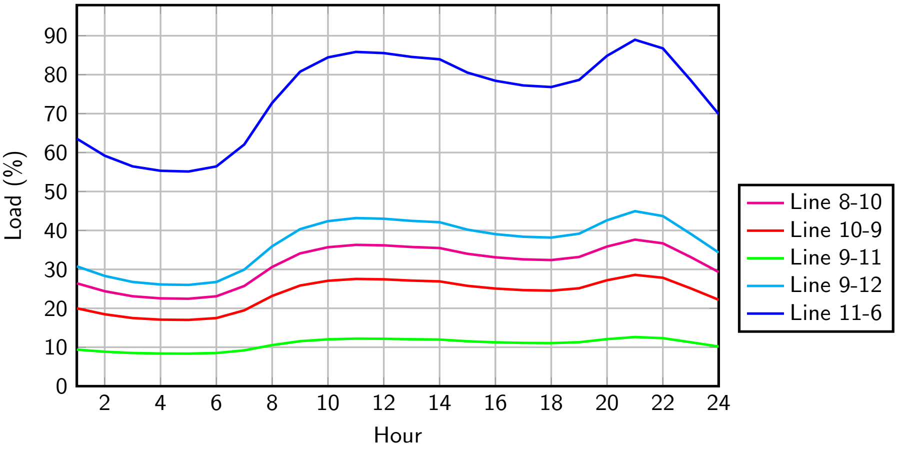


Figure 3: Representation of the percentual loading of the lines during 24 hours

Technical issues

The main observed issues are:

- Some load buses are below 0.9 p.u. during peak hours.
- While no lines surpass 100% of load, the interconnection line is close to 90%.
- In addition, the $N-1$ criteria is not met:

Element	Disconnection time (h)	Consequences
Line 8-10	12.50	No load served - divergence
Line 9-10	6.25	No load served - divergence
Line 9-11	8.85	Loads at buses 2, 3 and 5 unserved
Line 9-12	13.98	Load at bus 5 unserved
Line 11-6	13.98	No load served
Trafo 1-8	1.20	No load served - divergence
Trafo 2-9	1.20	Load at bus 2 unserved
Trafo 3-10	1.20	Load at bus 3 unserved
Trafo 4-11	1.20	Load at bus 4 unserved
Trafo 5-12	1.20	Load at bus 5 unserved

Table 2: Disconnection time and consequences of losing each element

Plan

Potential addition of lines

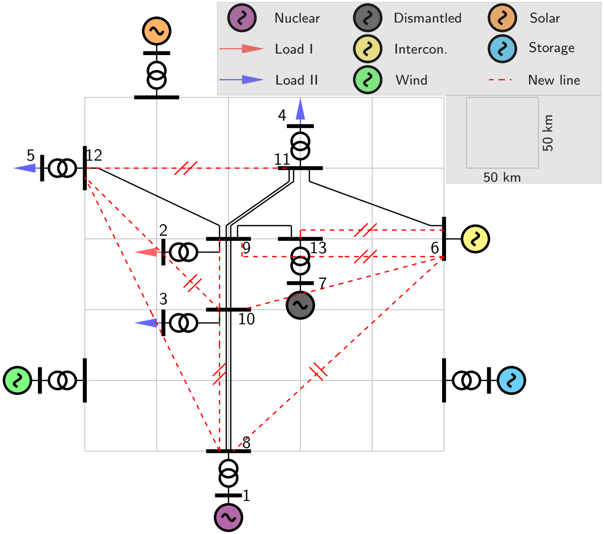


Figure 4: Overview of the new network. Double line indicates double circuit.

Algorithm to compute contingencies

Input: `net` initialized class, j, n
Output: stored results
Generate permutations $\forall \boldsymbol{\sigma}_g$ where $g = [1, 2, ..., 2^{(n-j)}]$
for $i = [1, 2, ..., j]$ **do**
    $\sigma_i \leftarrow$`false`
    $\sigma_r \leftarrow$`true`, where $r \neq i$ and $r \leq j$
    $\mathcal{A} \leftarrow \{\mathbf{1}_{\sigma_1}, \mathbf{1}_{\sigma_2}, ..., \mathbf{1}_{\sigma_j}\}$
    for $g = [1, 2, ..., 2^{(n-j)}]$ **do**
        $[\sigma_{j+1}, \sigma_{j+2}, ..., \sigma_n] \leftarrow \boldsymbol{\sigma}_g$
        $\mathcal{B} \leftarrow \{\mathbf{1}_{\sigma_{j+1}}, \mathbf{1}_{\sigma_{j+2}}, ..., \mathbf{1}_{\sigma_n}\}$
        $\mathcal{N} \leftarrow \mathcal{A} \cup \mathcal{B}$
        `pandapower.timeseries.run_timeseries(`$\mathcal{N}$`,net)`
        Store results
    end
end

Algorithm 1: Pseudocode to solve the contingencies

Contingency analysis for additional lines

Top 10 optimal configurations. Requirements are met and cost is minimized.

Identifier	**New lines**	**Infraestructure cost (M€)**
19	[6-13, 6-10, 8-9, 10-12]	359.50
214	[6-13, 6-10, 11-12, 8-9]	362.99
77	[6-13, 8-9, 10-12, 9-6]	375.04
49	[6-13, 11-12, 8-9, 9-6]	378.54
80	[6-13, 6-10, 11-12, 8-9, 10-12]	420.63
189	[6-13, 6-10, 8-9, 10-12, 9-6]	420.63
45	[6-13, 6-10, 8-9, 10-12, 8-12]	423.96
70	[6-13, 8-9, 10-12, 9-6]	424.12
157	[6-13, 6-10, 11-12, 8-9, 8-12]	427.46
250	[6-13, 11-12, 8-9, 10-12, 9-6]	436.17

Table 3: Best configurations with the additional lines

Serious need to install more lines connected to the interconnection bus.

Contingency analysis for a voltage level of 400 kV

Same for a rise in the voltage.

Identifier	New lines	Lines (M€)	Transformers (M€)	Total (M€)
163	[6-13, 8-9, 10-12]	313.92	64.79	378.71
133	[6-13, 11-12, 8-9]	317.41	64.79	382.20
235	[6-13, 8-9, 8-12]	320.75	64.79	385.54
30	[6-13, 8-12, 6-8]	346.07	64.79	410.86
19	[6-13, 6-10, 8-9, 10-12]	359.50	64.79	424.29
214	[6-13, 6-10, 11-12, 8-9]	362.99	64.79	427.78
58	[6-13, 6-10, 8-9, 8-12]	366.33	64.79	431.12
77	[6-13, 8-9, 10-12, 9-6]	375.04	64.79	439.83
169	[6-13, 8-9, 10-12, 8-12]	378.38	64.79	443.17
49	[6-13, 11-12, 8-9, 9-6]	378.54	64.79	443.33

Table 4: Economic results of replacing the substations

Three additional lines instead of four are required. However, the cost becomes a bit larger. It becomes a sub-optimal choice.

Plan

Connection of renewables to the system

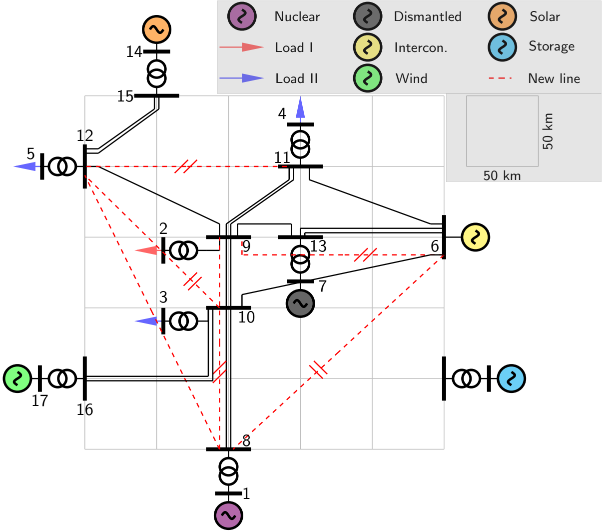


Figure 5: Overview of the network with renewables and the potential addition of lines

Profile extracted from PVGIS:

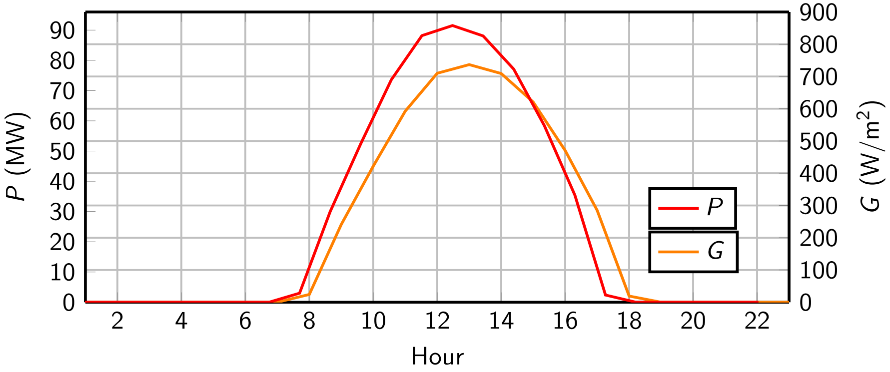


Figure 6: Irradiance and power from the PV plant along a representative day

Wind resources

Profile extracted from NASA database:

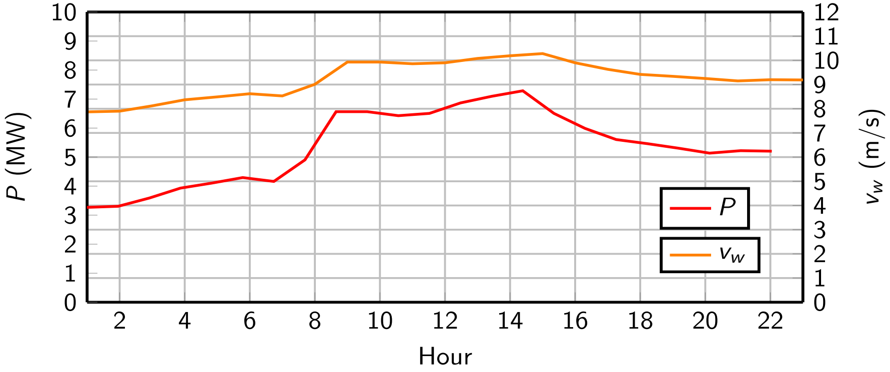


Figure 7: Wind speed and output power from the wind farm

Improvement due to renewables

It is worth it to compare the variation of the magnitudes due to renewables in normal operation.

Attributes	Without renewables	With renewables
V_{min} (p.u.)	0.962	0.968
V_{max} (p.u.)	1.050	1.050
Max. load (%)	41.65	40.76
Max. losses (MW)	14.54	14.43
Correct operation?	Yes	Yes

Table 5: Main results to compare between the grid with and without renewables

Results improve a bit. Unfortunately, the installed renewable power is not significant to cause a large impact.

Contingency analysis

Still four lines have to be added (interconnection lines have been set as static). The cost increases slightly because renewable power plants require extra lines.

Identifier	New lines	Infraestructure cost (M€)
24	[8-9, 10-12]	402.71
12	[8-9, 9-6]	406.21
46	[11-12, 8-9]	406.21
8	[8-9, 8-12]	409.54
0	[11-12, 8-9, 10-12]	463.84
4	[8-9, 10-12, 9-6]	463.84
37	[11-12, 10-12, 9-6]	463.84
63	[8-9, 10-12, 8-12]	467.18
20	[11-12, 8-9, 9-6]	467.34
38	[11-12, 8-9, 8-12]	470.67

Table 6: Best configurations with the additional lines

Plan

Connection of a storage unit and a dismantled plant

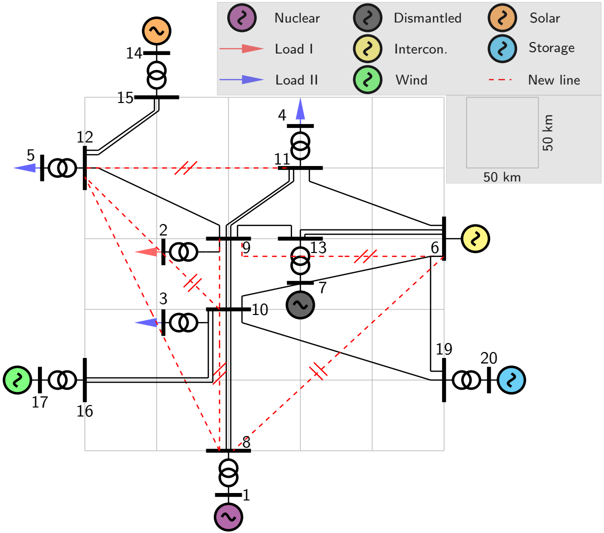


Figure 8: Overview of the network with storage and the dismantled plant

Daily profile of storage

The battery is based on lithium-ion technology.

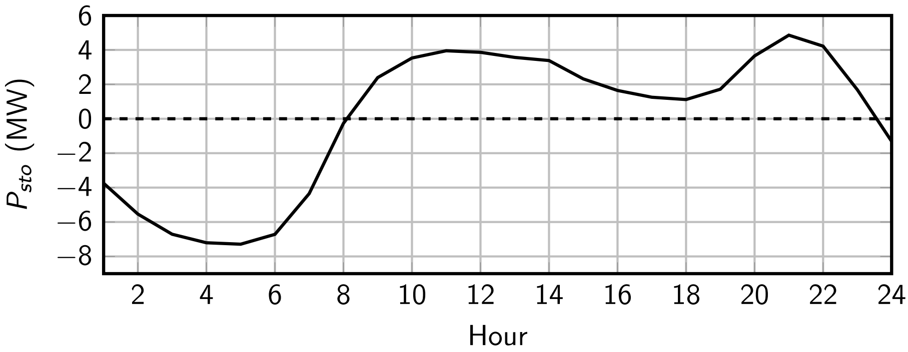


Figure 9: Daily charge and discharge profile for the battery system

Daily profile of the dismantled plant

Four fossil fuels were considered: coal, diesel, natural gas, and biomass.

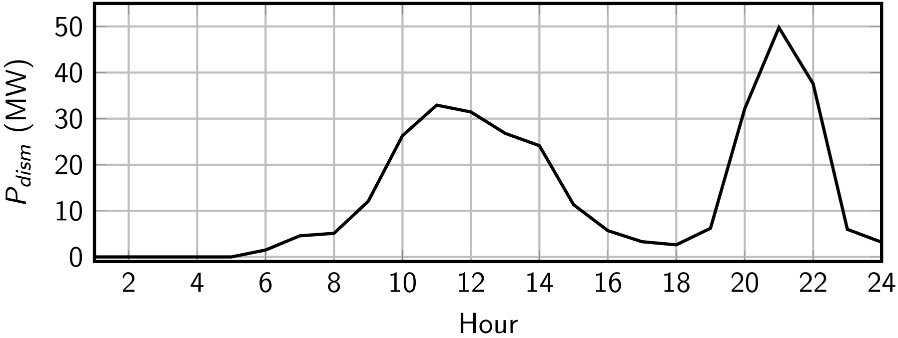


Figure 10: Daily generation profile of the rehabilitated plant

Base case results

Improvement of all grid attributes.

Attributes	Phase 2	Phase 3	Phase 4
V_{min} (p.u.)	0.962	0.968	0.971
V_{max} (p.u.)	1.050	1.050	1.050
Max. load (%)	41.65	40.76	39.63
Max. losses (MW)	14.54	14.43	13.89
Correct operation?	Yes	Yes	Yes

Table 7: Main results to compare between phases

Whole emission factor of 63 kg CO_2/MWh. Biomass is the cheapest option.

Fuel	Dismantled (tCO_2-eq)	Interconnection (tCO_2-eq)	Total (tCO_2-eq)
Coal	108.56	890.34	998.90
Diesel	89.64	890.34	979.98
Gas	59.76	890.34	950.10
Biomass	0.00	890.34	890.34

Table 8: Total daily emissions depending on the scenario

Contingency analysis

The combination of storage and the dismantled plant help at having to install one less additional line.

Identifier	New lines	Infraestructure cost (M€)
33	[8-9]	419.49
24	[8-9, 10-12]	477.12
12	[8-9, 9-6]	480.62
46	[11-12, 8-9]	480.62
8	[8-9, 8-12]	483.96
57	[8-9, 6-8]	505.94
0	[8-9, 10-12]	538.25
4	[8-9, 10-12, 9-6]	538.25
37	[11-12, 10-12, 8-12]	538.25
63	[8-9, 10-12, 8-12]	541.59

Table 9: Best configurations with storage and a rehabilitated plant

The total cost rises a bit due to the connections of storage.

Plan

HLUC: contigency analysis

HLUC layers:

- Component
- Business
- Function

Involved PUC layers:

- Information
- Communication

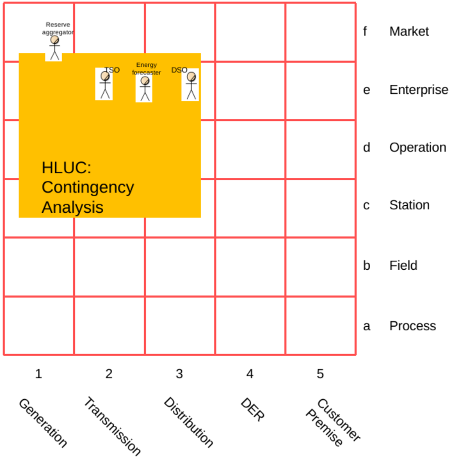
- **Scope:** evaluate the effects of a fault and calculate any overloads based on a computer application that simulates the power system to be prepared for any possible fault.
- **Objective:** protection of the impact of faults.
- **Grid issues:** short-circuits, overloads, undervoltages.
- **Relation to other use cases:** PUC 01: demand and generation forecasting; PUC 02: grid operation scheduling; PUC 03: grid observability and monitoring; PUC 04: fault detection and localization. Extracted from RESOLVD.
- **Viewpoint:** Technical.
- **Type:** HLUC.

Table 10: General description of the HLUC

HLUC actors

- Geographical Information System (GIS)
- Grid Operation Scheduler (GOS)
- Weather Forecast (WF)
- Reserve Aggregator (RA)
- Energy Forecaster (EF)
- Transmission System Operator (TSO)
- Distribution System Operator (DSO)
- Transmission Management System (TMS)
- Distribution Management System (DMS)

Business and function layer



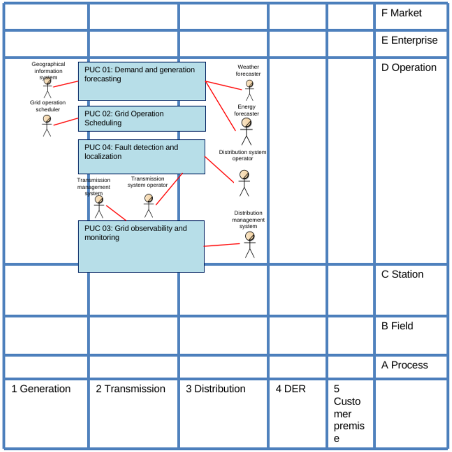


Figure 11: Business and function layer mapping

Plan

Conclusions

- The initial grid needs improvements to reduce voltage drops and lines loadings.
- A methodology to include new lines is critical. An algorithm to compute the contingencies has been presented.
- More lines connecting with the bus of interconnection are required.
- Installing renewables has a minor impact on the final results (although they improve).
- The storage unit and the dismantled power plant reduce the needs of additional lines.
- The high level use case regarding contingencies has been described following the SGAM methodology.

Plan

Tools

- Full writing in LaTeX.
- Learning of Python and packages such as `pandapower` and `pandas`.
- Collaborative work with Git:

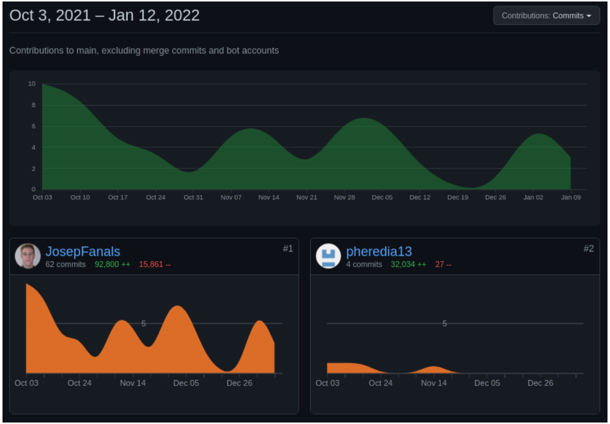


Figure 12: GitHub commits history

Workload distribution

- Víctor: Phase 1 results identification, SGAM
- Josep: full Python code, results extraction for all phases, report writing, presentation
- Pol: initial Python code, renewables sizing, SGAM
- Roger: Phase 1 results identification, Phase 4, SGAM, writing corrections
- Palina: Phase 1 results identification, introduction, writing corrections, supervision

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