A Framework for Flexible Loads Aggregation

Cesar Diaz Londono

Supervisors: Prof. Gianfranco Chicco, Dr. Andrea Mazza (Polito)

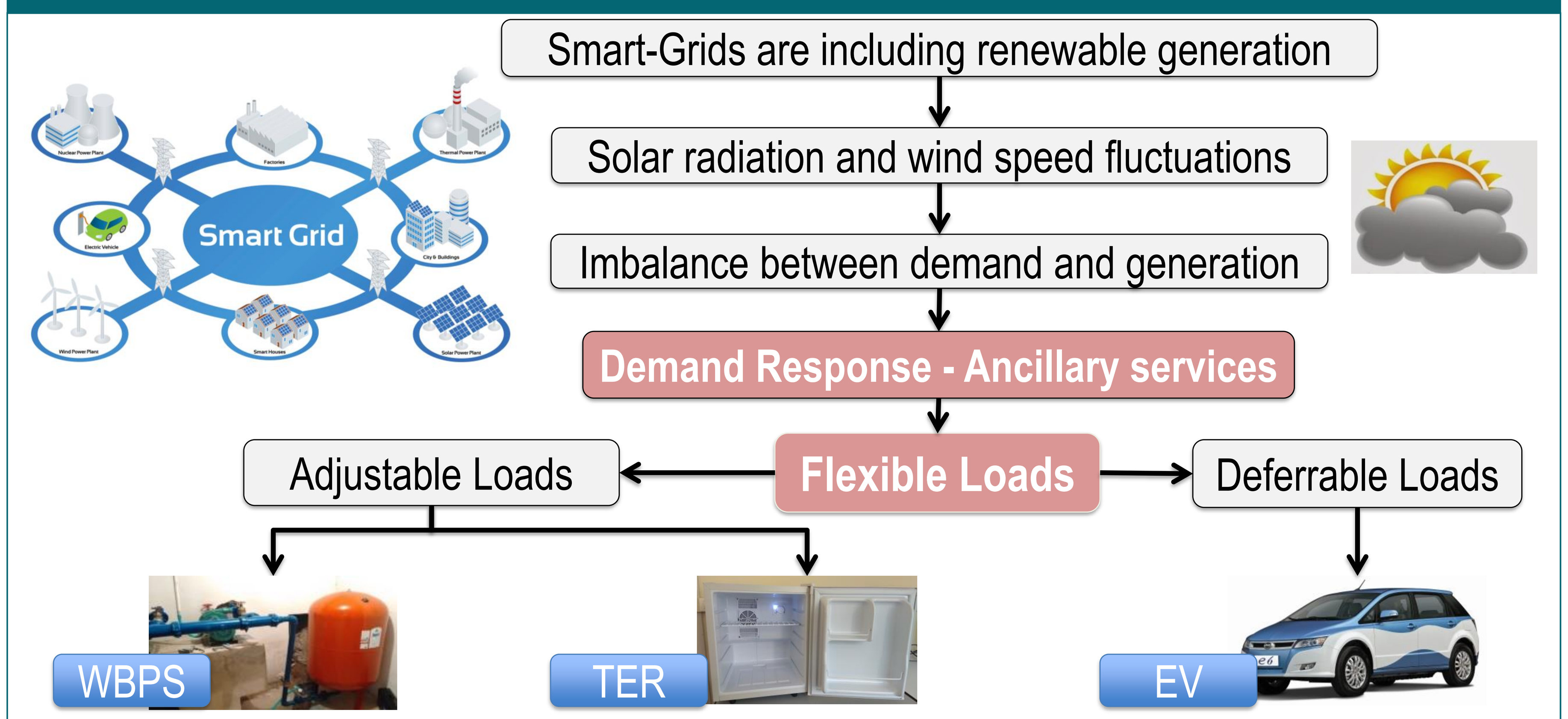
Supervisors: Prof. Fredy Ruiz, Prof. Diego Patino

(Pontificia Universidad Javeriana, Bogotá, Colombia)

ScuDo
Scuola di Dottorato ~ Doctoral School
WHAT YOU ARE, TAKES YOU FAR

XXXIII Cycle

Research context and question



The massive integration of renewable systems (fluctuating and non-controllable) in the power grid leads to difficulties in the system operation. These cause issues to the optimal energy management. Then, an energy unbalance in the grid can occur.

- *Considering a Smart Grid with renewable sources and flexible loads, the question is:*

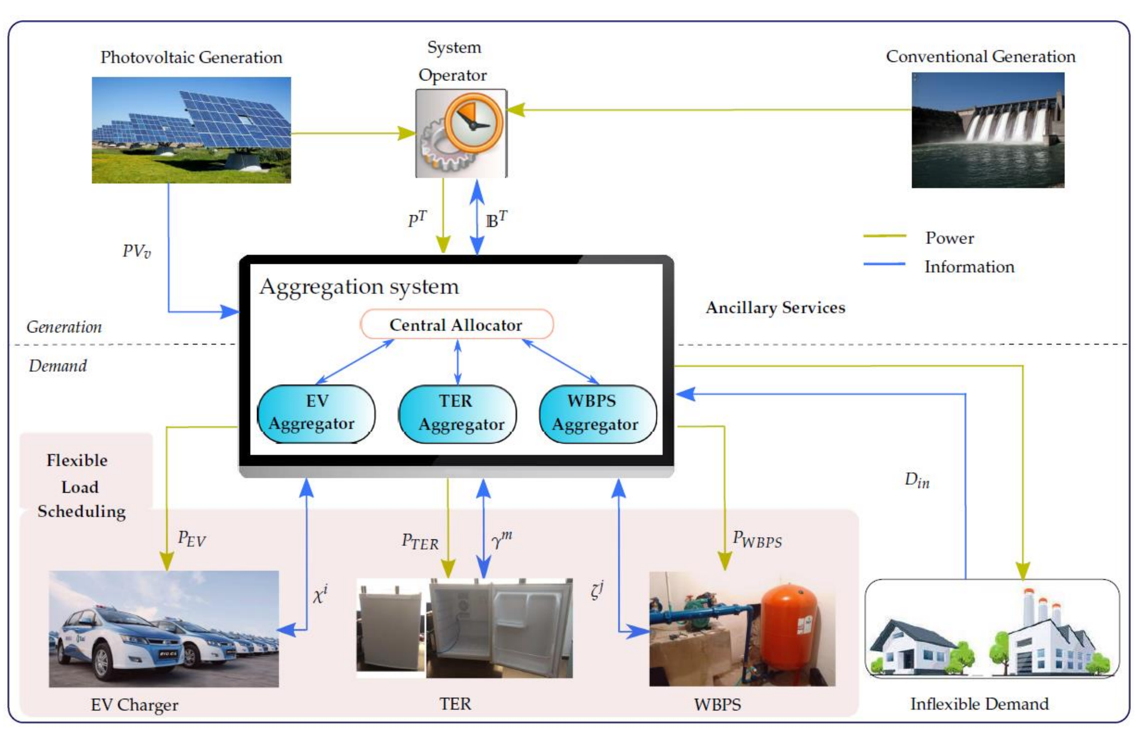
How to integrate different flexible loads by managing their power consumption, with the purpose of offering ancillary services to the smart grid and maintaining the grid energy balance?

Novel contributions

- A methodology for loads aggregation is proposed, for providing ancillary services.
- Dynamic models are developed and tuned with experimental data.
- Definition of the ancillary services that each load can offer to the grid.
- The design of aggregators (optimal and classic controllers) able to provide the services.
- A specific flexibility definition for EV chargers.
- A day-ahead and real-time strategies for EV stations, considering photovoltaic forecast.

Load aggregation methodology

1. **Flexible load modeling**. *Identification of a manipulable variable* and setup of the modification limits.
2. **Flexibility analysis**. For defining the ancillary services: i) the *load response time*; ii) *time the load can keep* a power modification; and, iii) *power capacity* and *periods of time* the load can modify its consumption.



3. **Flexible load aggregator design**. The process considers: i) Signal to be controlled; ii) *Ancillary service* to be provided; iii) Bilateral communication with the System Operator (SO); and iv) Bilateral communication with the flexible load.
4. **Evaluation of the proposed aggregator by simulation**. Simulations of each flexible loads' controllers are developed in MATLAB software and Simulink tool *for assessing and validating* the systems.

Submitted and published works

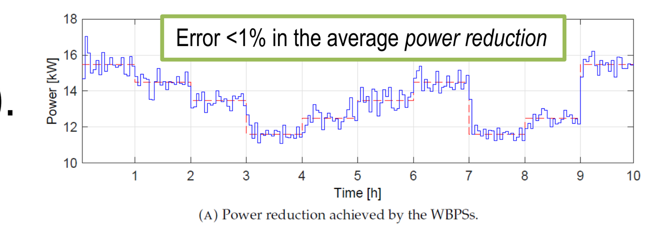
- C. Diaz, F. Ruiz and D. Patino., "*Modeling and control of water booster pressure systems as flexible loads for demand response*", Applied Energy, vol. 204, 2017, pp. 106-116.
- C. Diaz-Londono, L Colangelo, F. Ruiz, D. Patino, C. Novara, and G. Chicco., "*Optimal Strategy to Exploit the Flexibility of an Electric Vehicle Charging Station*", Energies, under review.
- C. Diaz-Londono, D. Enescu, A. Mazza, and F. Ruiz., "*Characterization and Flexibility of a ThermoElectric Refrigeration Unit*", 54th International Universities Power Engineering Conference (UPEC 2019), Bucharest, Romania, 2019, pp. 1-6.
- C. Diaz, A. Mazza, F. Ruiz, D. Patino, and G. Chicco., "*Understanding Model Predictive Control for Electric Vehicle Charging Dispatch*", 53rd International Universities Power Engineering Conference (UPEC 2018), Glasgow, Scotland, 2018, pp. 1-6.
- D. Enescu, C. Diaz, A. Ciocia, A. Mazza, and A. Russo., "*Experimental assessment of the temperature control system for a thermoelectric refrigeration unit*", 53rd International Universities Power Engineering Conference (UPEC 2018), Glasgow, Scotland, 2018, pp. 1-6.
- C. Diaz, F. Ruiz, and D. Patino., "*Smart Charge of an Electric Vehicles Station: A Model Predictive Control Approach*", 2nd IEEE Conference on Control Technology and Applications (CCTA 2018), Copenhagen, Denmark, 2018, pp. 54-59.
- C. Diaz, F. Ruiz, and D. Patino, "*Analysis of Water Booster Pressure Systems as Dispatchable Loads in Smart-Grids*", 7th IEEE International Conference on Innovative Smart Grid Technologies (ISGT Europe 2017), Turin, Italy, 2017, pp. 1-6.

Flexible load models and aggregators

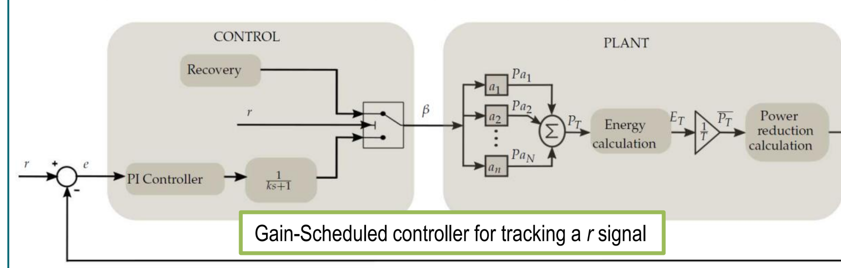
The load aggregation methodology is assessed regarding **three flexible loads**:

➢ Water Booster Presure Systems (WBPS)

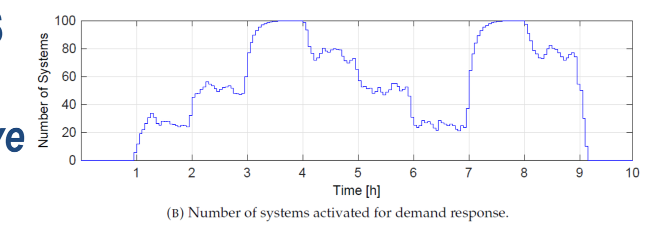
- The dynamic model, tuned with *real data* (1.11% of error).
- System flexibility by changing the *pressure set-point*.



(a) Power reduction achieved by the WBPS.



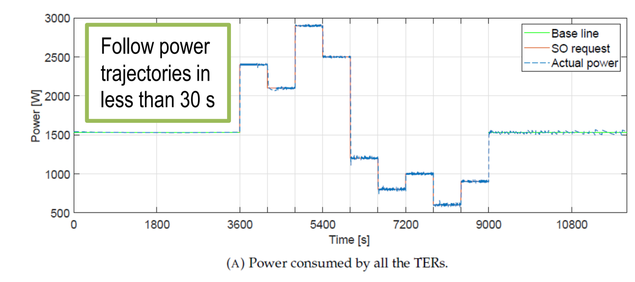
A set of WBPS can provide spinning reserve services.



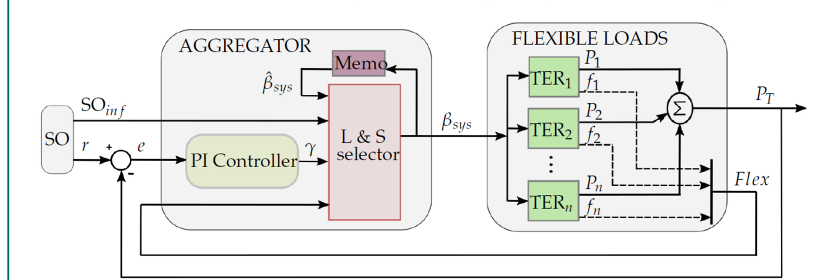
(b) Number of systems activated for demand response.

➢ ThermoElectric Refrigeration (TER) Units

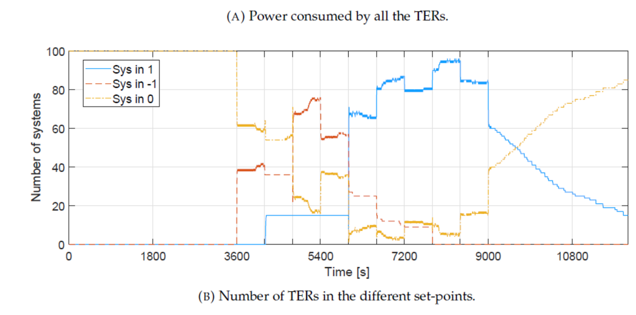
- A dynamic model of a TER unit is estimated from *experimental data* (error < 1°C).
- Flexible load by changing the *temperature set-point*.



(a) Power consumed by all the TERs.



A set of TERs is capable to offer regulation service (reducing or increasing power).

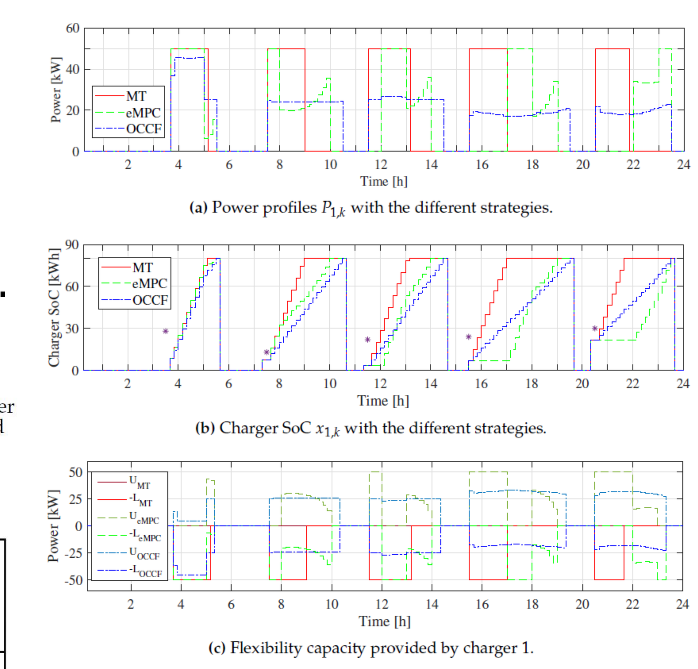


(b) Number of TERs in the different set-points.

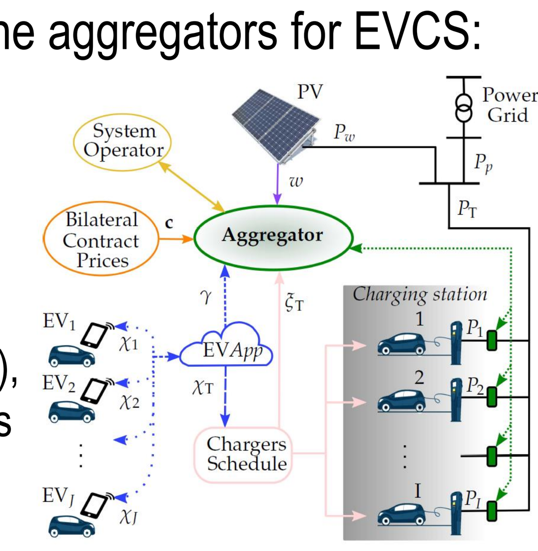
- Aggregator decides the set-point of each TER, based on a three-state signal (0,1, or-1).

➢ Electric Vehicles (EV) Chargers

- A dynamic model of an EV charger is developed.
  - ✓ Uncertainty on arrival time and arrival SoC are considered.
- EV charger *flexibility capacity is defined* as power deviations attainable with respect to a nominal profile.
- Novel strategies used by the aggregators for EVCS:
  - ✓ economic Model Predictive Control (eMPC), *minimize operation costs.*
  - ✓ Optimal Control with minimum Cost and maximum Flexibility (OCCF), reducing the operating costs and *maximize the power flexibility capacity.*



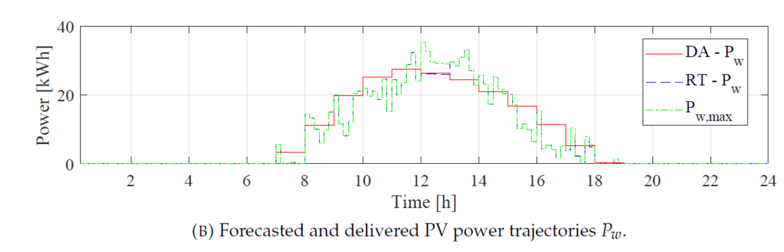
(a) Power profiles with the different strategies.
(b) Charger SoC with the different strategies.
(c) Flexibility capacity provided by charger 1.



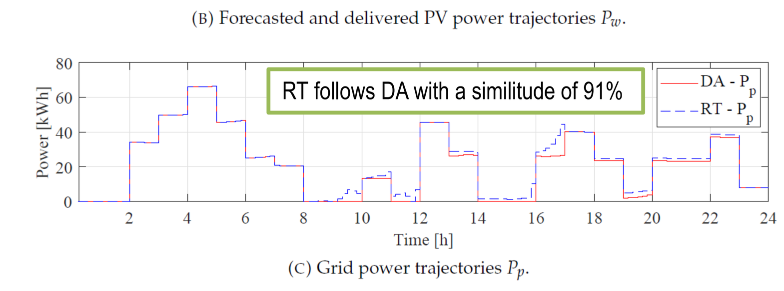
It offers the possibility to provide spinning reserve service.

❑ **Strategy for EVCS participation in Day-Ahead (DA) and Real-Time (RT) Markets.**

- Two novel strategies were proposed:
  - ✓ A DA schedule, aiming to minimize the operation cost.
  - ✓ A RT dispatch, looking for minimizing the error on following the DA schedule.
- The EVCS considers a Photo-Voltaic (PV) plant.
  - ✓ A PV model is proposed based on Bogotá data.



(b) Forecasted and delivered PV power trajectories P_w.



(c) Grid power trajectories P_r.

Conclusions

- This research has provided aggregation strategies for improving smart grids management when a high penetration of renewable energy sources is considered, helping to reduce carbon emissions.
- Economic benefits can be obtained by the stakeholders, reducing operating costs and obtaining profits from the ancillary service provision.
- Detailed technical solutions have been developed for the implementation of demand response services through direct load control.

List of attended classes

- 01LGSRV – Characterization and planning of small-scale multigeneration systems (13/9/2019, 5 credits)
- 01SWJRV – Control and optimization in Smart Grids (31/05/2018, 4)
- 01LYXRV – Electrical load management, forecasting and control (21/9/2018, 5)
- 02ITTRV – Generators and photovoltaic systems (20/4/2018, 5)
- PUJ (Colombia) – Optimal control (2016, 4)
- UNIANDES (Colombia) – Energy policy and markets (2015, 4)
- PUJ (Colombia) – Optimization techniques (2015, 4)
- PUJ (Colombia) – Hybrid and nonlinear systems (2015, 4)
- PUJ (Colombia) – Industrial automation (2015, 4)

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering