Assessing battery management for energy communities: economic evaluation of a AI led system

Angelo Facchini[1,2], Alfonso Damiano[2], Saman Korjani[2],Mario Mureddu[1], Alessandro Rubino[3]

[1] IMT Scuola Alti Studi Lucca

[2] Dipartimento di Ingegneria Elettrica ed Elettronica – Università di Cagliari

[3] Dipartimento Jonico in "Sistemi Giuridici ed Economici del Mediterraneo: società, ambiente, culture " – Università di Bari

Overview of the talk

- *The role and economics of Storage in the energy systems*
- *Planning and management tools for ESS usage*
  - *Historical profiles vs real-time optimal management*
- *Addressing multiperiod optimisation and aging costs*
  - *Balancing Responsive Artificial Intelligence Storage (BRAInS) module*
- *Real time application*
- *Initial results and discussion*

Potential services provided by energy storage to the system

Most of the studies that can be found in the literature analyze storage from a user's point of view (the kind of service storage provides).

From a market design point of view, it is important to analyze the question in terms of who offers storage services. There are two relevant "potential markets" for storage services:

- **TIME SHIFT**. Buy and sell energy in different periods
- **LOCATIONAL SHIFT**. Avoid the need to transport energy from one point to another

	Generation	Transmission	Distribution	Retail
Conventional	Black Start Arbitrage Support to generation	Participation to the I, II, III frequency control Improvement of the frequency stability of weak grids Investment deferral Participation to angular stability	Capacity support Dynamic, local voltage control Contingency grid support Intentional islanding Reactive power compensation Limitation of Upstream disturbances	End- user peak shaving ToU Energy Cost management Particular requirements in power quality Community and energy supply Limitation of Upstream disturbances Compensation of the reactive power
Renewable	Distributed Generation Flexibility Capacity Firming Limitation of upstream disturbances Curtailment minimization			

State of the art

Unlike typical generating resources that have long and guaranteed lifetimes, electrochemical energy storage (EES) suffers from a range of degradation issues that vary as a function of EES type and application

Several studies explored ways to account for the degradation cost in investment and operational decisions for specific applications

A comprehensive approach that optimally valuates and manages EES degradation over different decision horizons is still undocumented

1

Electric vehicle charging/vehicle to grid

Hoke, A., et al. ; IEEE J. Emerg. Sel. Top. Power Electron. **2**, 691–700 (2014).
Farzin, H., et al. IEEE Trans. Sustain. Energy **7**, 1730–1738 (2016).

2

Microgrid management

Zhang, Z., et al. *Energy Convers. Manag.* **105**, 675–684 (2015).
Bordin, C. et al. *Renew. Energy* **101**, 417–430 (2017)

3

energy arbitrage/peak shaving

Shi, Y., *IEEE Trans. Power Syst.* (in the press);
Xu, B., *IEEE Trans. Power Syst.* **33**, 2248–2259 (2018).
Tant, J., *IEEE Trans. Sustain. Energy* **4**, 182–191 (2013).
He, G., *IEEE Trans. Smart Grid* **7**, 2359–2367 (2016).
Kazemi, M. & Zareipour, H. *IEEE Trans. Smart Grid* (in the press);

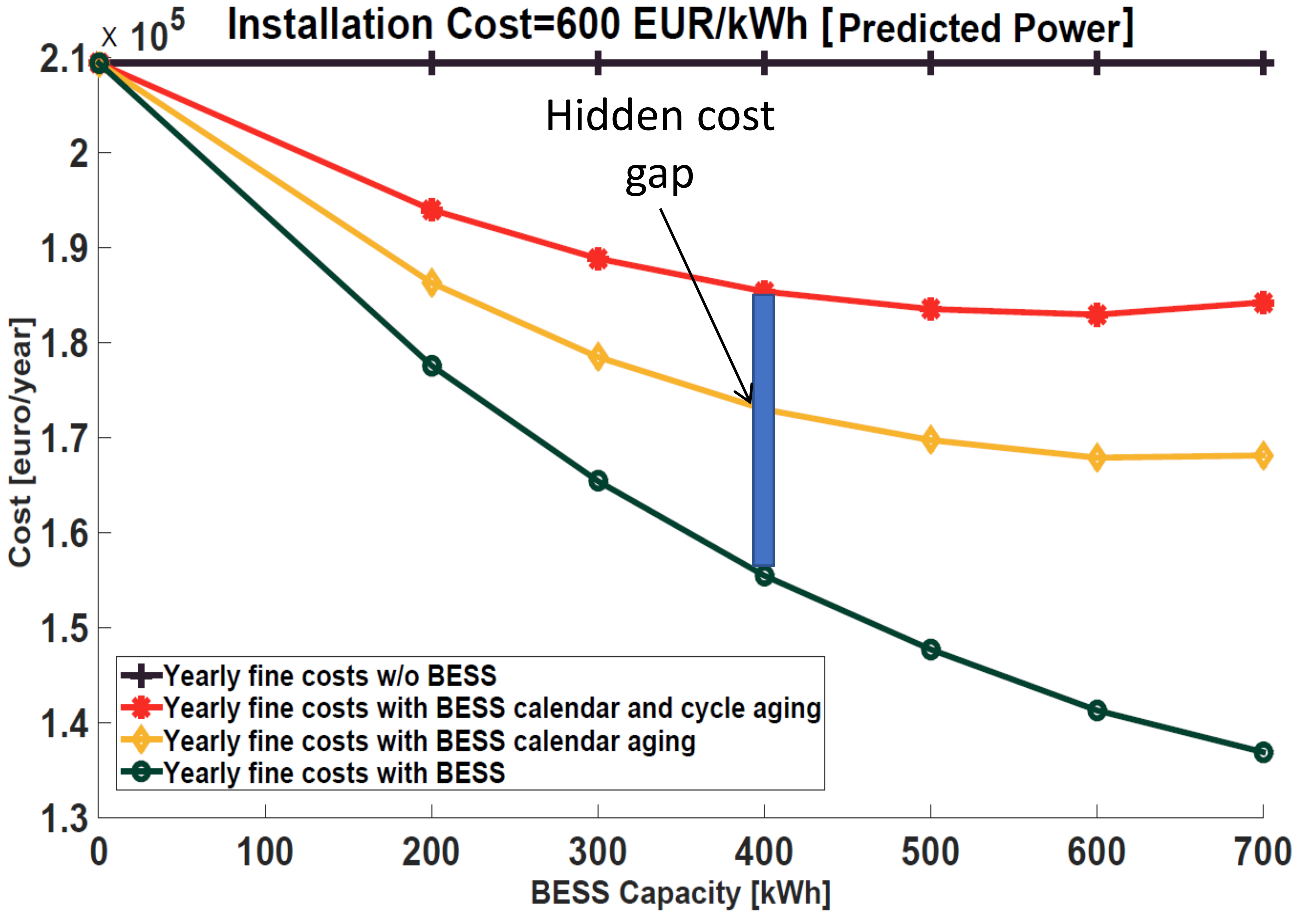
4

Frequency regulation
He, G., *IEEE Trans. Smart Grid* **7**, 2359–2367 (2016).
Kazemi, M. & Zareipour, H. *IEEE Trans. Smart Grid* (in the press); Swierczynski, M., *IEEE Trans. Sustain. Energy* **5**, 90–101 (2014).

5

Multiservices
Perez, A., *IEEE Trans. Sustain. Energy* **7**, 1718–1729 (2016)

Introduce cycle and calendar aging



We consider a storage installed in a standard IEEE test network composed of domestic users and DER deployed, and installation cost of 600 Euro/kW

- **Red lines:** both calendar and cycle aging included
- **Yellow Lines:** only Calendar aging included
- **Green lines:** No aging included

- Results show that including both aging and calendar **hidden costs are relevant** as the battery size increasing.

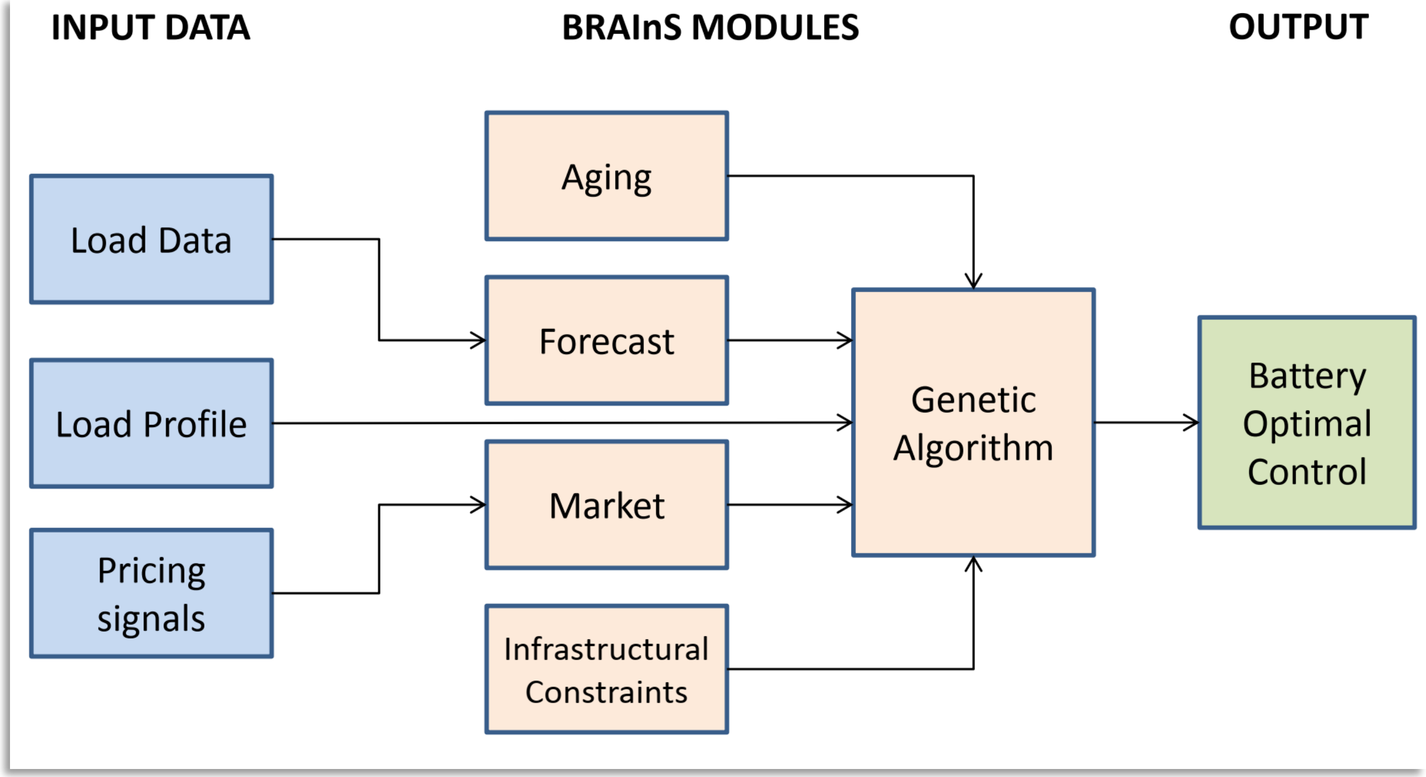
Inaccurate management and planning of storage systems produces inefficiency reduces the profitability of ESS in the long term

What is the BRAInS tool

Balancing Responsive Artificial Intelligence Storage (BRAInS) *is a multi period real time management method based on Genetic Algorithm for storage systems operating in energy systems based on 4 modules:*

- **Load Data**: 1hr granularity and span for 1 year
- **Load Profile**: Load baseline of the VPP as defined in Korjani et al. (2017)
- **Pricing Signals**: set at 150€/MWh

- **Aging:** nonlinear effects for calendar and cycling aging
- **Infrastructural coinstraints:** standard 69 bus IEEE PG&E grid (Baran, M. E. & Wu, F. F; 1989)
- **Forecast Module:** two step parametric identification (H and L frequency separation)
- **Market**: simplified market and regulatory set up where VPP is penalised for fluctuations to the reference load profile
- **Genetic Algorithm:** optimise energy flows also taking into account BESS constraints

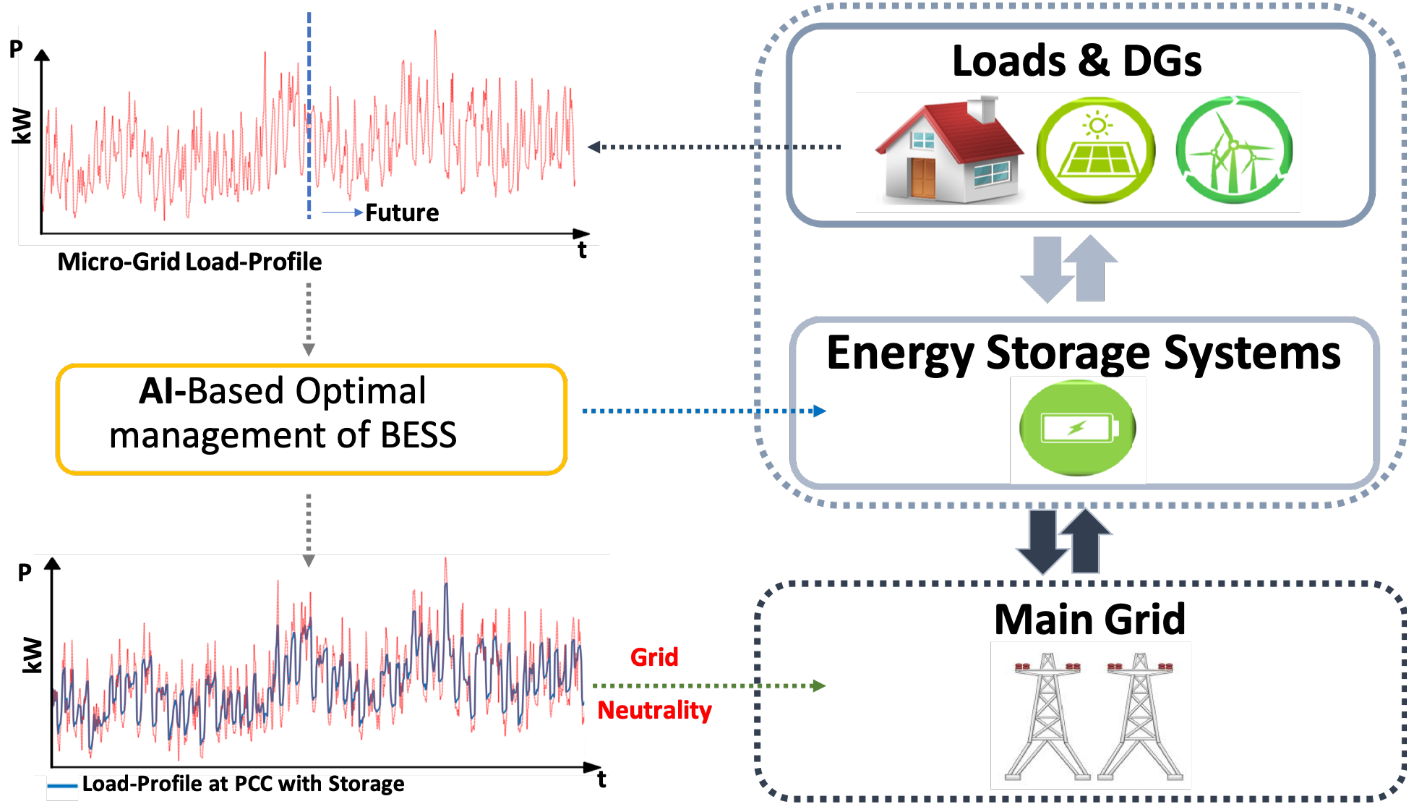


Conceptual model of BRAInS

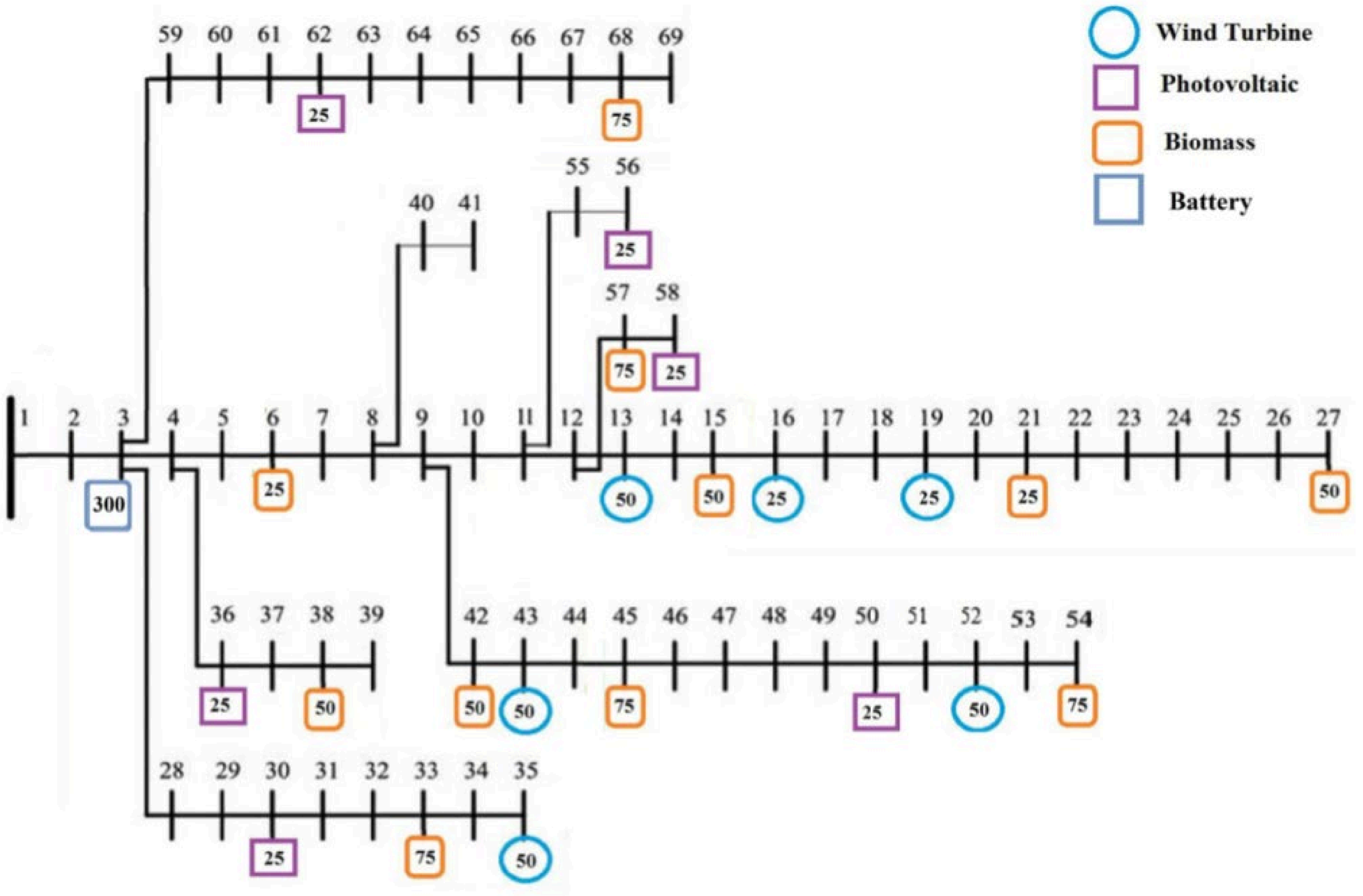
BRAInS *goal:*

- *Optimises the use of storage systems in order to maximise the lifetime of the battery while **increasing the return of investment**.*
- *Ensures the **microgrid neutrality** with respect to main grid, actively contributing to a full integration of distributed energy sources.*

- **Battery degradation** is due to two factors:
  - Age
  - **Specific use** (i.e. the charge/discharge cycles in time)
- While age is not changeable, the degradation due to the use can be reduced by means of an optimal management strategy
- According to the cost of power fluctuations the optimiser computes in **real time** the amount of power to be stored (or released) considering:
  - **Past and predicted future consumption**
  - **Cost of the stored/released power** in terms of aging
  - **Expected cost of fees** due to power fluctuation (depending on the regulatory framework)



Experimental setup and data source



- VPP based on standard IEEE 69 bus
- Presence of intermittent sources from wind and PV
- Actual data for both generation and Household/service consumers
- One storage system with different size (range 100-700kW)

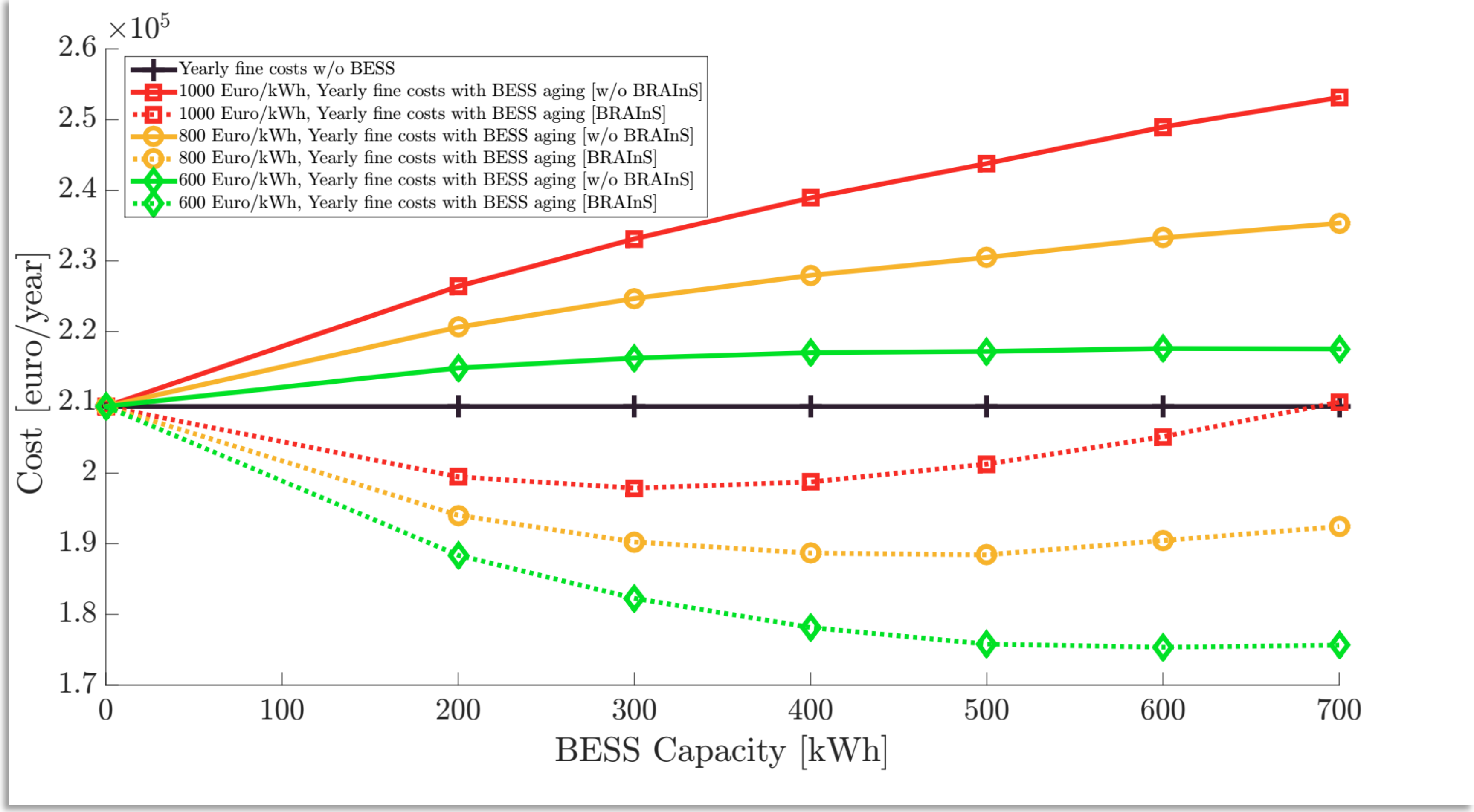
Korjani, S., Mureddu, M., Facchini, A., & Damiano, A. (2017). Aging cost optimization for planning and management of energy storage systems. *Energies*. https://doi.org/10.3390/en10111916

How BRAInS works – Different Battery size

Offline operation: BRAInS is used as planning tool to find the best battery size

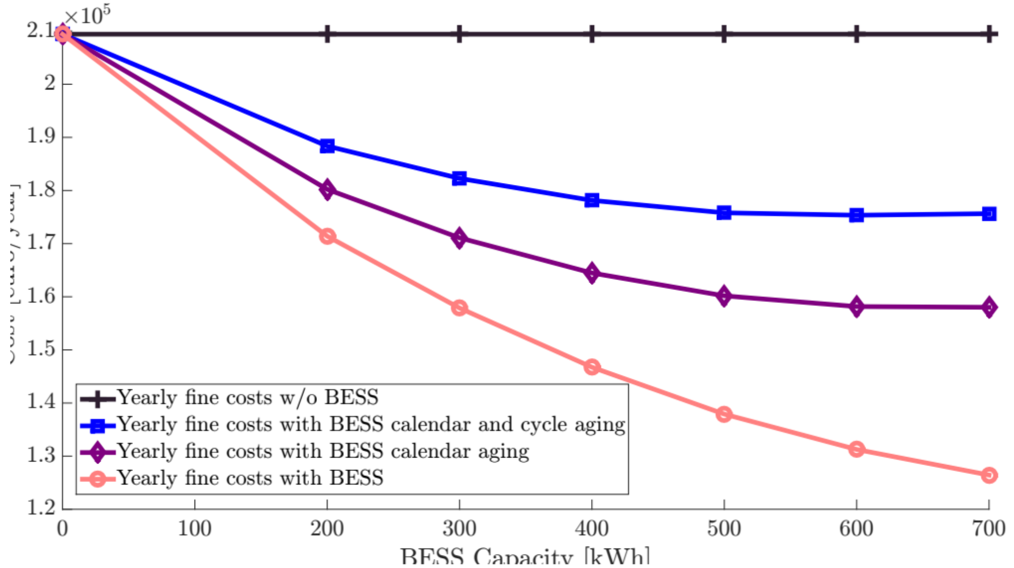
3 possible set ups:

- No BESS installed: VPP load is free to fluctuate and pays the full amount of fines
- Use of BRAInS for managing the charge/discharge of the battery
- Unmanaged battery used for its full capacity both in charge and in discharge

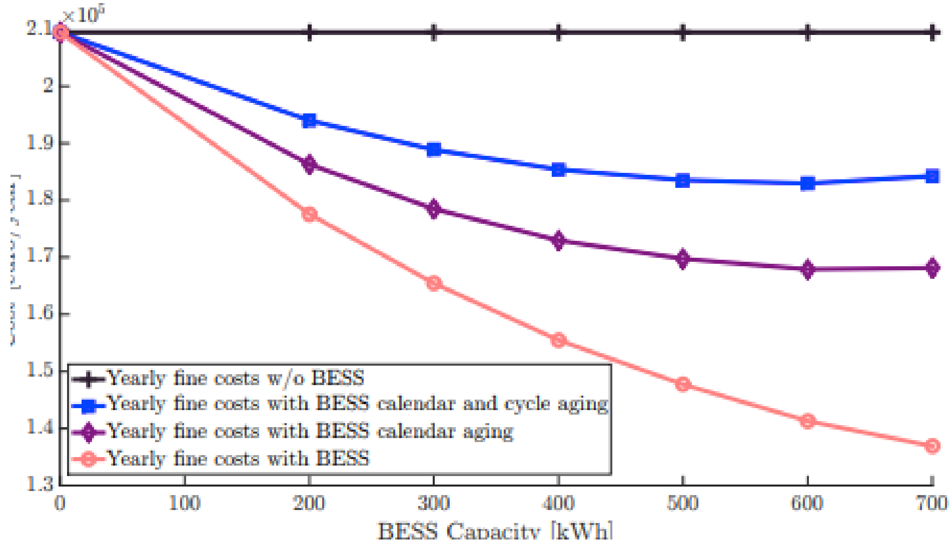


Real time operation

- BRAInS is used as management tool for the operation of a battery installed in a microgrid acting as a VPP
- A forecast algorithm is used to predict future fluctuations, perfect forecast is used to provide an upper bound for the management performance



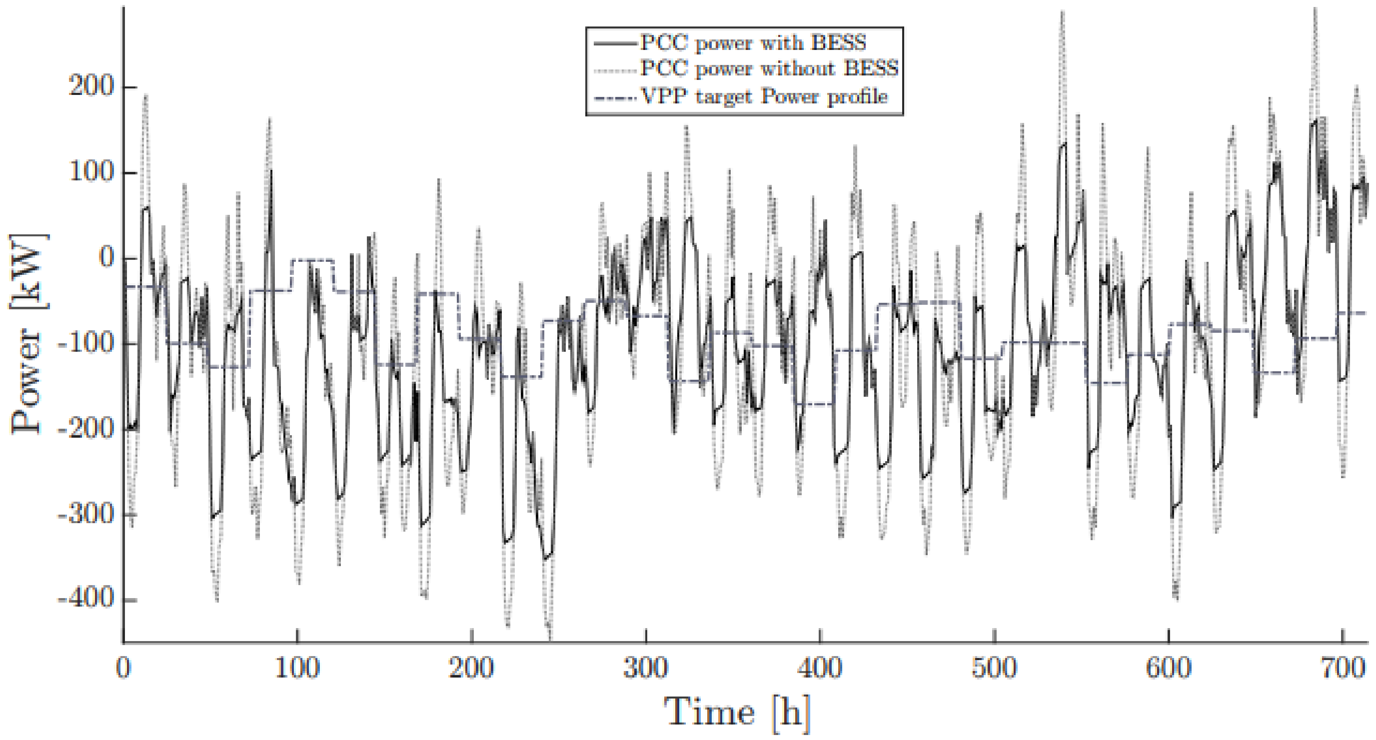
(a) Perfect forecast, BRAInS

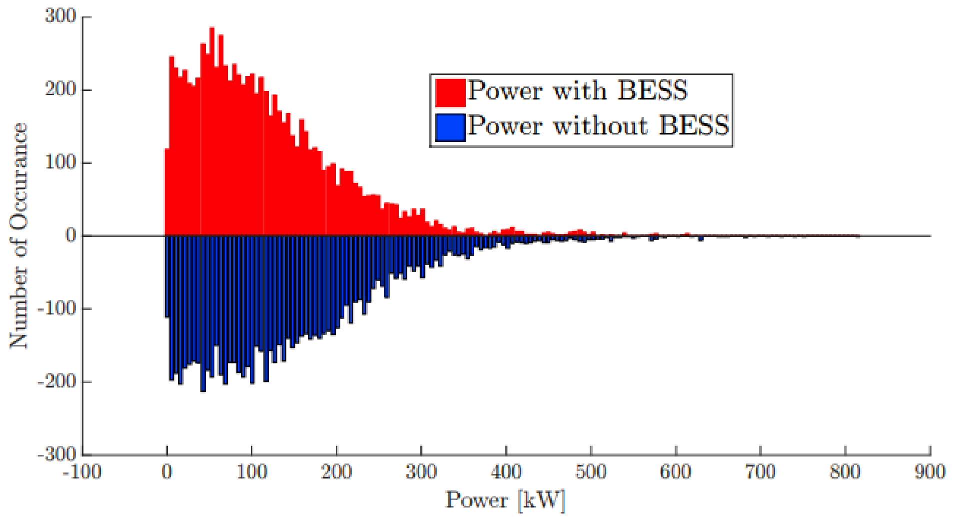


(b) Real-time operation, BRAInS

Peak shaving

- Large peaks are effectively shaved, while small fluctuations are not reduced because of their impact on the battery aging
- Peaks histograms shows a reduction of large peaks



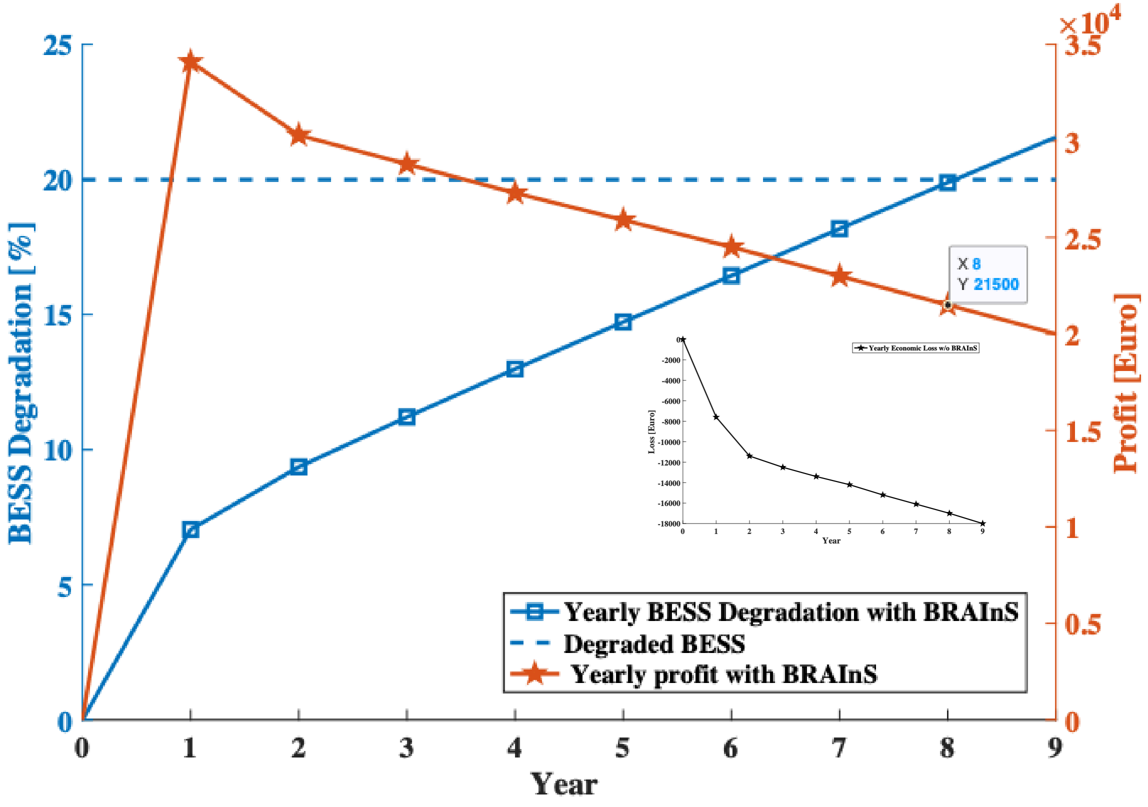


Economic performance

- The battery can be in operation up to its 80% of the initial charge. After this threshold is non longer effective on the grid
- Expected revenues are always positive for the life-span of the battery (degradation after 8 years in this specific setup)

Table 2: Profit with 800 €/kWh Installation Cost of BESS

800 €/kWh Installation Cost of BESS			
BESS Size [kWh]	Yearly Profit BRAInS - Perfect Forecast	Yearly Profit w/o BRAInS - Perfect Forecast	Yearly Profit BRAInS - Real-time
700	€17004.904 [8.12%]	€-25927.824 [-12.38%]	€7937.018 [3.79%]
600	€18973.452 [9.06%]	€-23859.38 [-11.39%]	€11559.984 [5.52%]
500	€20983.884 [10.02%]	€-21079.48 [-10.07%]	€13151.576 [6.28%]
400	€20753.522 [9.91%]	€-18547.38 [-8.86%]	€14219.618 [6.79%]
300	€19182.872 [9.16%]	€-15280.069 [-7.29%]	€12942.156 [6.18%]
200	€15392.37 [7.35%]	€-11215.71 [-5.35%]	€10114.986 [4.83%]



Main Features

- Planning tool that can be specifically **tailored to different users** (household, services, industrial, mixed)
- **Suggest the best storage size** by analysing 1 year of operation
- **Sheds light on hidden costs** impacting on storage systems related to the consumption patterns of the specific user
- **Fully configurable** with respect to:
  - Regulatory framework
  - Storage system technology and installation cost
  - Size and type of grid/microgrid
  - Cycle and calendar aging models

Cutting-edge aspects

- **Real time** analysis and management
- Goes beyond age degradation models, as referring only to calendar age leads to a **significative underestimation** of the management costs, yielding a **loss in the long-period perspective**.

Conclusions and policy implications

- BRAInS introduces a planning and management method that is fully configurable and flexible
- BESS degradation are considered including both **aging and cycling costs**
- BESS sizing becomes crucial and strongly dependent on consumer's behaviours
- Installation costs become the main component of the overall costs
  - With BRAInS even installation cost of 1000€/kWh might be viable
- Self consumption might not suffice to provide positive ROI (a portfolio of market should be available to VPPs)
  - EC directive 2019/944
- DSO should be incentivised to identify flexibility as a value

Monica Giulietti
Professor of Microeconomics,
Loughborough School of Business and Economics,
Loughborough University

Alessandro Rubino,
Assistant Professor in Economics and Environment,
Ionian Department of Law, Economics and Environment,
University of Bari Aldo Moro

Angelo Facchini,
Assistant Professor,
IMT Alti Studi Lucca

Michael Fell
Research Associate,
Bartlett School Env, Energy & Resources,
Faculty of the Built Environment,
University College London

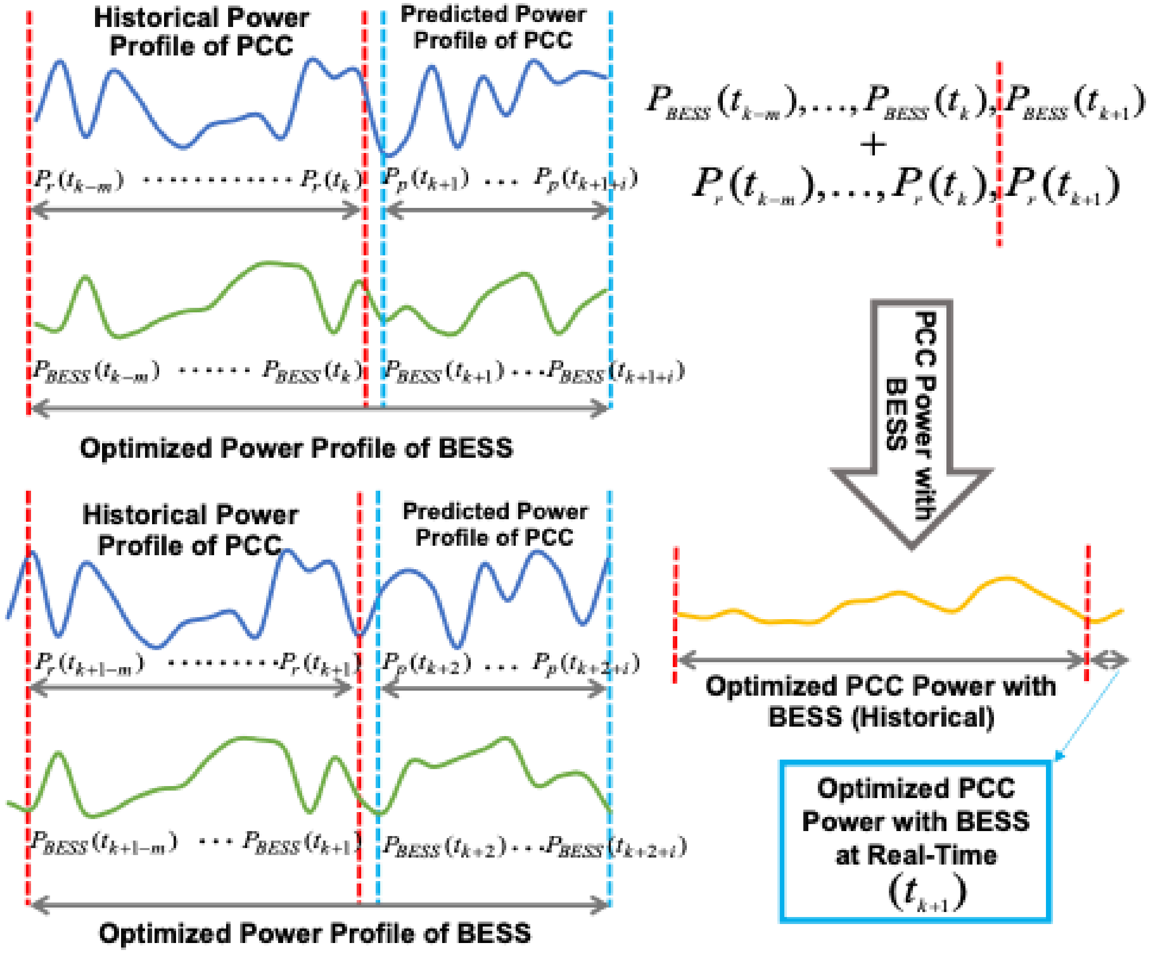
Andrea Morone
Professor of Economics,
Department of Economics, Management and Business Law,
University of Bari Aldo Moro

Thank you for your attention

- Consider submitting your next paper to our Special Issue
- **New Energy Downstream**

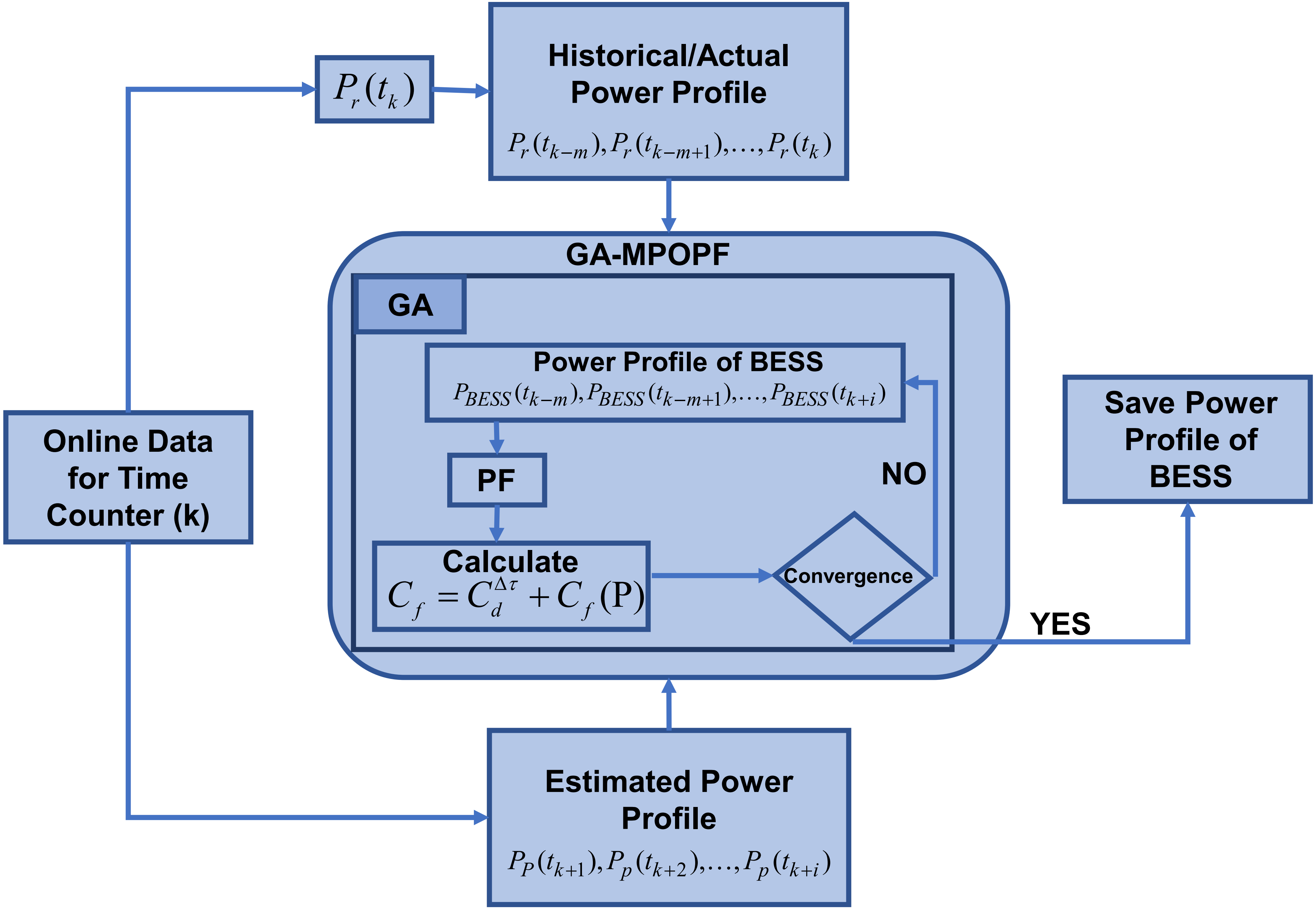
- Deadline : April 30th 2020
- Journal :Energy Sources PartB: Economics, Planning and Policy

Analysis of temporal profiles and forecast



- Forecast is computed by means of a combination of time series methods and parametric system identification
- exponential smoothing and box-Jenkins model
- Exponential smoothing extracts the low-frequency fluctuations
- Box-Jenkins predicts the high-frequency fluctuations

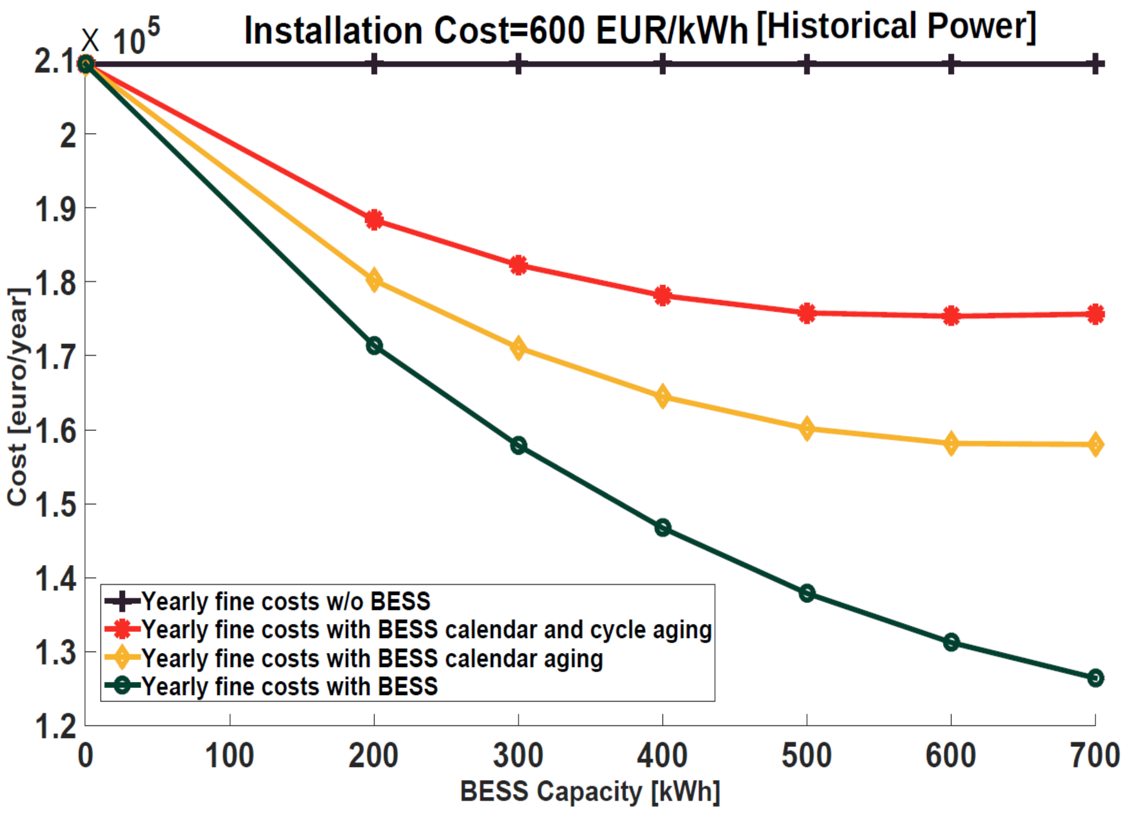
Paoletti, S., Casini, M., Giannitrapani, A., Facchini, A., Garulli, A., & Vicino, A. (2011). Load forecasting for active distribution networks. *IEEE PES Innovative Smart Grid Technologies Conference Europe*. https://doi.org/10.1109/ISGTEurope.2011.6162780



$P_r(t_k)$
Historical/Actual Power Profile
$P_r(t_{k-m}), P_r(t_{k-m+1}), \ldots, P_r(t_k)$
GA-MPOPF
GA
Power Profile of BESS
$P_{BESS}(t_{k-m}), P_{BESS}(t_{k-m+1}), \ldots, P_{BESS}(t_{k+i})$
PF
Calculate
$C_f = C_d^{\Delta\tau} + C_f(\mathrm{P})$
Convergence
NO
YES
Save Power Profile of BESS
Online Data for Time Counter (k)
Estimated Power Profile
$P_P(t_{k+1}), P_p(t_{k+2}), \ldots, P_p(t_{k+i})$

Performance of the prediction method

Results with Best Knowledge of Future



Results with Prediction of Future