Distributed battery energy storage coordination for fast frequency response

Tianqiao Zhao
Alessandra Parisio
Jovica V. Milanovic

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Outline

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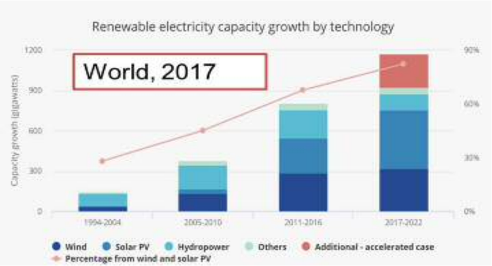
Challenges in Future Power Systems

- Renewable energy sources (RES) are gradually starting to dominate the energy generation mix
- Frequency stability is of significant concern due to lack of inertial response from RES
- Role of energy storage to support integration of RES is well recognised [1]



Renewable electricity capacity growth [2]

[1] *Power Responsive Steering group, Demand Side Flexibility, Annual Report 2017, National Grid, 2017* and *Strategic Energy Technology Plan, European Commission*

Opportunities for storage systems

∗ Increasing power system flexibility

1. Improve frequency response of reduced inertial power systems
2. Deliver the response in either direction (export/import)
3. Reduce the need to curtail wind and/or PV generation

∗ Providing multiple services

1. Energy arbitrage
2. **Ancillary services**

Some facts

- Cost reduction expected in the range of 50% to 70% depending on technology by 2030
- Battery cost dropped by 70% from 2007 to 2014 [3]
- New services to take advantage of the energy storage systems, e.g., Enhanced Frequency response [4]

Power Potential project [5]

- Trial in South East England begun in January 2019
- Battery storage, wind farms, solar PV and synchronous generation involved to generate up to an extra 4GW
- If this works and extended to further 59 sites, savings could total £12m by 2050

[3] European Commission, Commission staff working document, *Energy storage - the role of electricity*, 2017

[4] Enhanced Frequency Response 2016, National Grid 2016

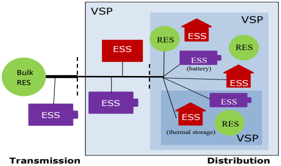
[5] National Grid, Network Innovation Allowance Annual Summary 2017/2018

MOTIVATION

- Explore the potential contribution from distributed storage technologies to grid operation
- Develop optimisation and control strategies for coordinating thousands of distributed storage technologies for balancing and ancillary services

∗ Potential solution: Virtual Storage Plant (VSP)

Aggregation of storage units with same/different technologies at various locations to provide grid support while maximizing their performance and reducing costs.



VSP (MY-STORE)

Current projects

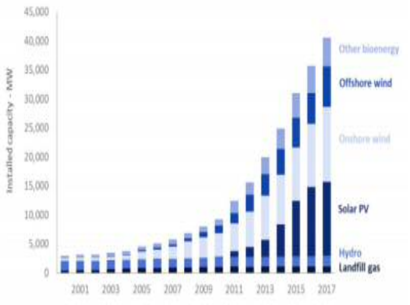
- Multi-energY storage-Social, TechnO-economic, Regulatory and Environmental assessment under uncertainty (MY-STORE)
- CROSS Border management of variable renewable energies and storage units enabling a translational Wholesale market (Crossbow)

Outline

Frequency response and storage systems

Frequency stability in UK

80% emission reduction by 2050 require large scale integration of renewables and additional efforts to maintain system frequency stability



UK electrical generating capacity of renewable energy plant[5]

* Storage systems for fast frequency response:
  - Emerging fast response capabilities (0.1-0.2s) of battery energy storage systems (BESS)
  - Very large number of BESS potentially available

[5] Digest of UK Energy Statistics, 2018, Department for Business, Energy Industrial Strategy UK

Fast frequency response

* Challenges:
  - Dynamic and fast response requirements (within 1s or 2s)
  - RES uncertainties and dynamic service provision
  - Difficult to control a large number of storage devices using centralized control strategy

Contribution

- Optimal management of a large number of coordinated BESS
- Improved frequency response following enhanced frequency response introduced by UK
- Flexible and scalable operation

"Distributed Control of Battery Energy Storage Systems for Improved Frequency Regulation", submitted to IEEE Transactions on Power Systems

New balancing services for frequency

- Australian Energy Market Operator (AEMO) is exploring the potential of fast frequency response for managing high rate of change of frequency
- Eirgrid in Ireland has introduced the DS3 Program to evaluate and assess fast frequency response
- National Grid in UK has introduced a balancing service named Enhanced Frequency Response

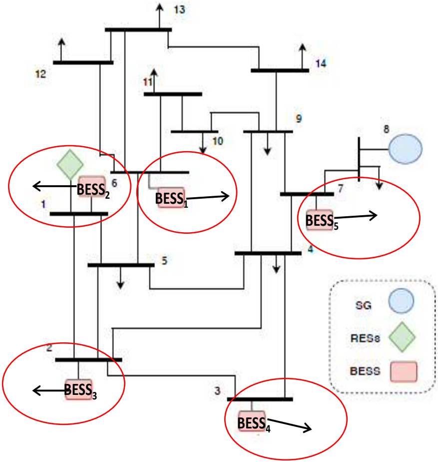
Enhanced Frequency Response

1). Maintain system frequency within 1% of 50Hz under normal operation
2). Response within 1s to frequency deviation
3). Minimum response of 1 MW (from single or aggregated units)

BESS OPTIMAL MANAGEMENT

Main features

1) BESS setpoints calculated in less than 1s
2) Multi-agent system framework where each BESS is an agent
3) Plug-and-play functionality
4) Minimise BESS costs and maximise reward

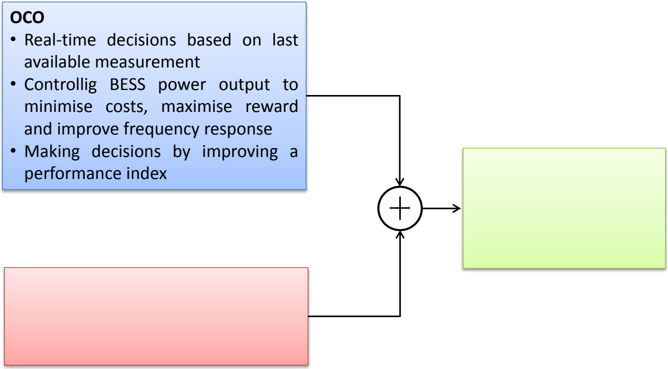


T. Zhao, A. Parisio, J. V. Milanovic, *Distributed Control of Battery Energy Storage Systems for Improved Frequency Regulation*, submitted to IEEE Transactions on Power Systems

BESS OPTIMAL MANAGEMENT PROBLEM

Solving the problem

Online convex optimisation (OCO) using multi-agent system (MAS) framework



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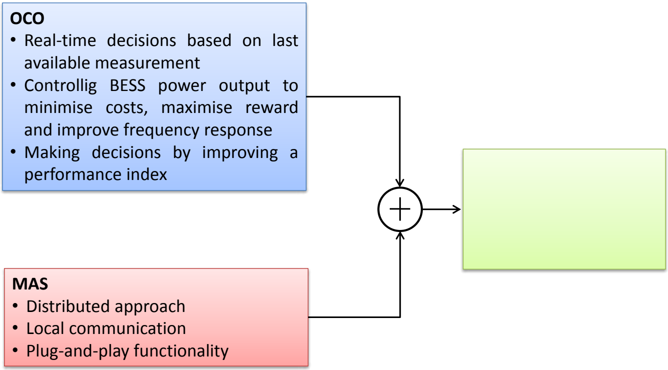

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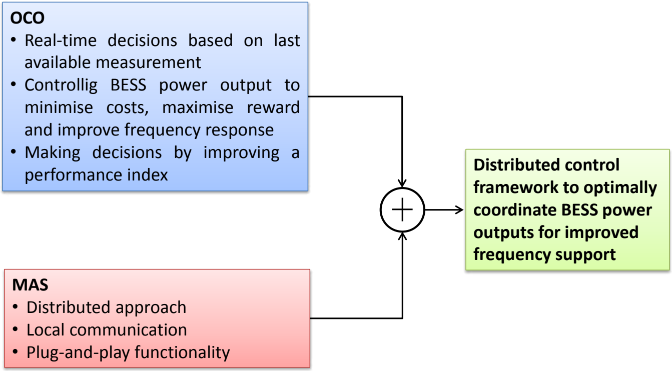
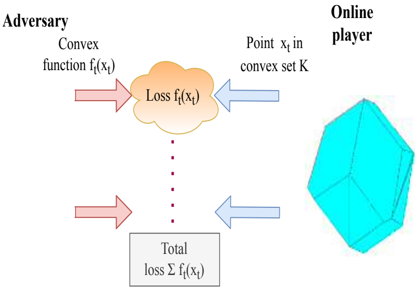


ONLINE CONVEX OPTIMISATION

Introduced by GJ. Gordon (1999) [6]
One of the leading online learning frameworks in several domains (e.g., online routing, selection for search engines).

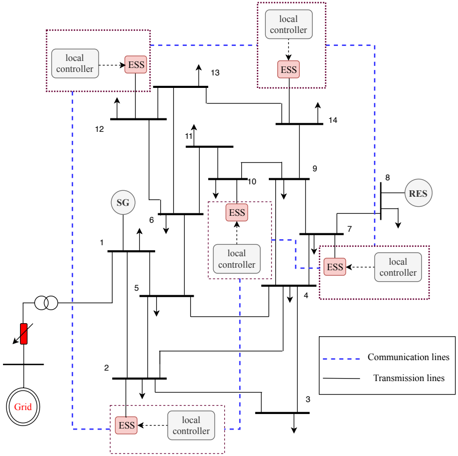
- At time t, the player chooses a strategy without the knowledge of the current cost
- The player observes the revealed cost function and incurs cost
- **Regret**: the difference between the cost incurred and the best fixed point chosen offline
- **Goal**: sub-linear regret function (on average the algorithm performs as the best strategy in hindsight)



Benchmark: $$\text{regret}_T = \sum_{t=1}^{T} f_t(\mathbf{x}_t) - \min_{\mathbf{x}^* \in \mathcal{K}} \sum_{t=1}^{T} f_t(\mathbf{x}^*)$$

[6] Gordon GJ. Regret bounds for prediction problems. InCOLT 1999
http://www.cs.princeton.edu/ ehazan/tutorial/OCO-tutorial-part1.pdf

Online convex optimisation for BESS optimal management



The communication and physical networks

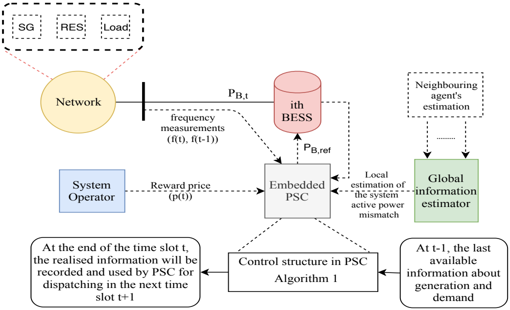
$$\min_{P_B^i \in \mathcal{F}_{B,i}} \quad \sum_{t=1}^{T} C_t(P_{B,t})$$

s.t.

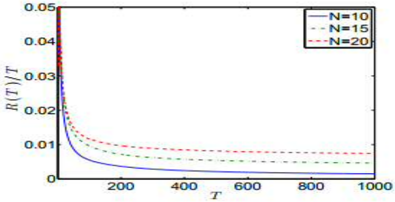
$h_t(P_{B,t}) = 0$ supply-demand balance

Lagrangian function:
$\mathcal{L}_t(P_{B,t}, \lambda_t) := C_t(P_{B,t}) + \lambda_t^T h_t(P_{B,t})$,
where $P_{B,t} \in \mathcal{F}_B$

BESS LOCAL CONTROLLER



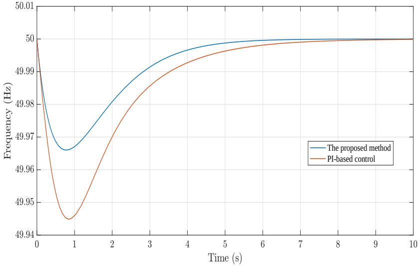
Regret function is sub-linear
Average $R(T)/T \to 0$
N is the number of agents



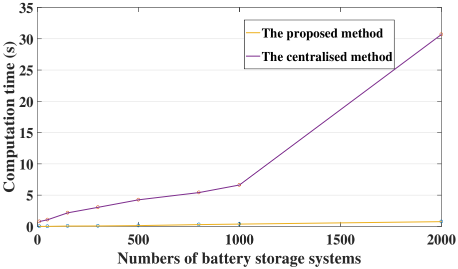
Lee S, Zavlanos MM. On the sublinear regret of distributed primal-dual algorithms for online constrained optimization. arXiv preprint arXiv:1705.11128. 2017 May 31.

Simulation study: comparisons

IEEE 14-bus system with 10 BESS of 2.5 MWh and SoC [20, 80] %
At t = 0 a supply-demand mismatch occurs (24 MW)



Comparison with a traditional PI-based method



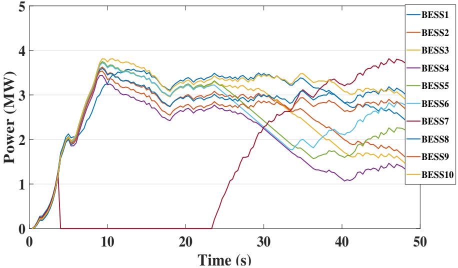
Computation times of centralised and distributed algorithms

The distributed OCO yields an improved frequency response with respect to a traditional PI-based control.

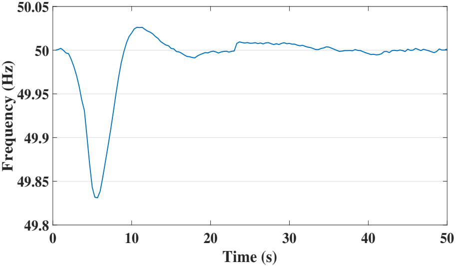
I. Serban and C. Marinescu, Battery energy storage system for frequency support in microgrids and with enhanced control features for uninterruptible supply of local loads, IJEPES, 2014.

SIMULATION STUDY: PLUG AND PLAY

IEEE 33-bus system with 10 BESS of 13 MWh and SoC [20, 80]%.
At t = 0 a supply-demand mismatch occurs (random variable with U(22:5; 27:5) MW).
BESS7 is plugged out unexpectedly at 4s and reconnected to the grid at 23s.



The output power update of storage systems



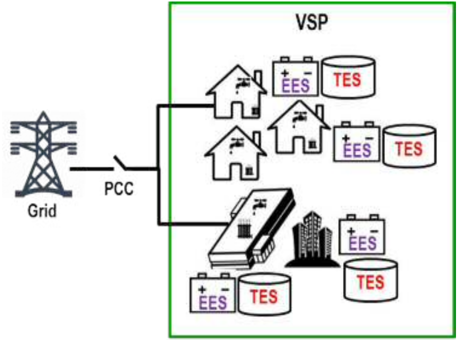
System frequency response

The system frequency is regulated to the nominal value and the service provision is sustained under unexpected plug-and-play operation

Outline

Multi-energy VSP and Short Term Operating Reserve

Thermal storage (TES) and electricity storage (EES) for reserve services in microgrids



Multi-energy Virtual Storage Plant

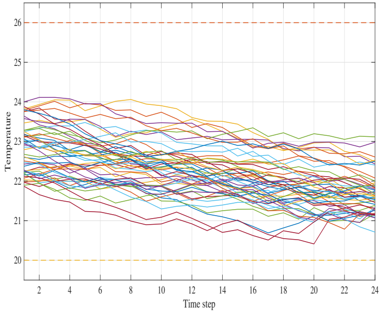
Short Term Operating Reserve (STOR)

- Pre-agreed contracted reserve
- Minimum contracted capability of 3MW
- Reserve service sustained for at least 2 hours
- Response time between 20 and 240 minutes

Methodology: Distributed MPC with Affine Disturbance Feedback

A CASE STUDY

The VSP is to provide STOR at 14:00 for 2 hours



Building temperatures within the comfort range (50 buildings)

VSP with 50 buildings

- Dynamical models of thermal zones, heating system, EES, TES

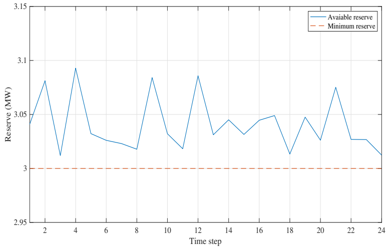
- Each building is equipped with one EES and one TES

- TES is fed by a heat pump and an electric boiler

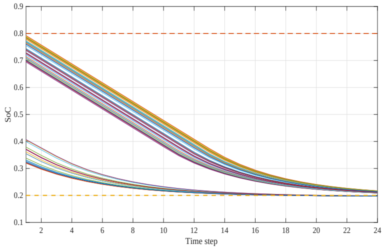
T. Zhao, A. Parisio, J. V. Milanovic, *Distributed Control of Virtual Storage Plants in Microgrids for Short Term Operating Reserve in UK*, submitted to IEEE CDC 2019

RESERVE PROVISION

- After the service provision, BESS can recharge for 20 hours



Provided STOR by 50 600kWh BESS



BESS SoC profiles

- The total revenue obtained by STOR is $\pounds 630.25$
- The computational time for each MPC iteration is 0.0343s (0.34 with 500 buildings)

Outline

Conclusions and future work

Distributed energy storage systems have the potential to support flexible and efficient grid operation

Ongoing and future work

- Develop a simulation environment for dynamic studies
- Investigate the control performance with a large number of energy storage units in transmission and distribution networks
- Explore the locational aspects and consider different technologies
- Include multiple services and voltage support

Thank you!