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Optimization of large-scale virtual power plants integrating wind farms

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Abstract

This study explores various optimization-based control architectures, built respectively on centralized, decentralized, hierarchical and distributed optimization, to tackle the problem of Virtual Power Plants (VPPs) scheduling on the day-ahead market (DAM). First, we formulate the optimal scheduling of a generic large-scale multi-technology VPP on the DAM as centralized and decentralized mixed-integer programming problems. Second, due to the issues that a centralized architecture may create in terms of privacy, resilience and scalability, we explore three augmented Lagrangian relaxation (ALR)-based decomposition coordination algorithms: *Alternating Direction Method of Multipliers (ADMM)*, *Auxiliary Problem Principle (APP)* and *Analytical Target Cascading (ATC)*. These control strategies are compared using data from a real-world case study provided by the French aggregator Compagnie Nationale du Rhône. Results show the economic advantage of aggregating Distributed Energy Resources (DERs), instead of operating them independently on the DAM. Moreover, we show the benefits that decomposition provides in terms of scalability, protection of DER users' privacy and robustness to communication failures. Finally, hierarchical (ATC and ADMM) and distributed (APP) approaches are compared in terms of convergence properties and complexity of their implementation (e.g., parameters tuning) in the industrial environment.

Objectives

COORDINATED VS UNCOORDINATED

We show the potential economic advantages of aggregating DERs into a large-scale VPP, compared to a sparse and uncoordinated management of the VPP portfolio of resources.

DECOMPOSITION OF THE PROBLEM

We show a simple decomposition strategy to reformulate the original VPP scheduling problem in a form which is suitable to the application of hierarchical and distributed optimization.

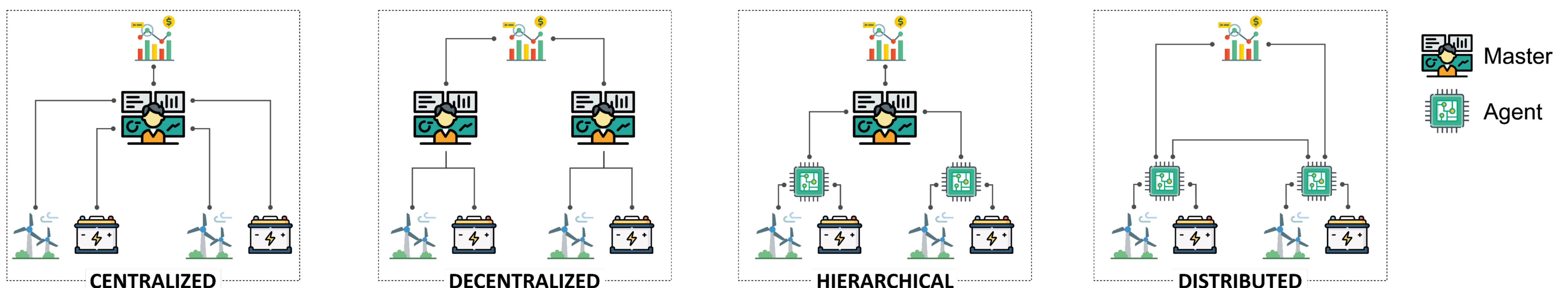
DECOMPOSITION COORDINATION

We explore hierarchical and distributed optimization algorithms to tackle the VPP scheduling problem. Then, we evaluate them in terms of convergence rate, scalability, privacy and resilience.

Methods

At present, most VPPs are operated with fully centralized architectures. Is this the best approach? If we consider the system as a multi-agent system, alternatives to centralized optimization (CO) become available.

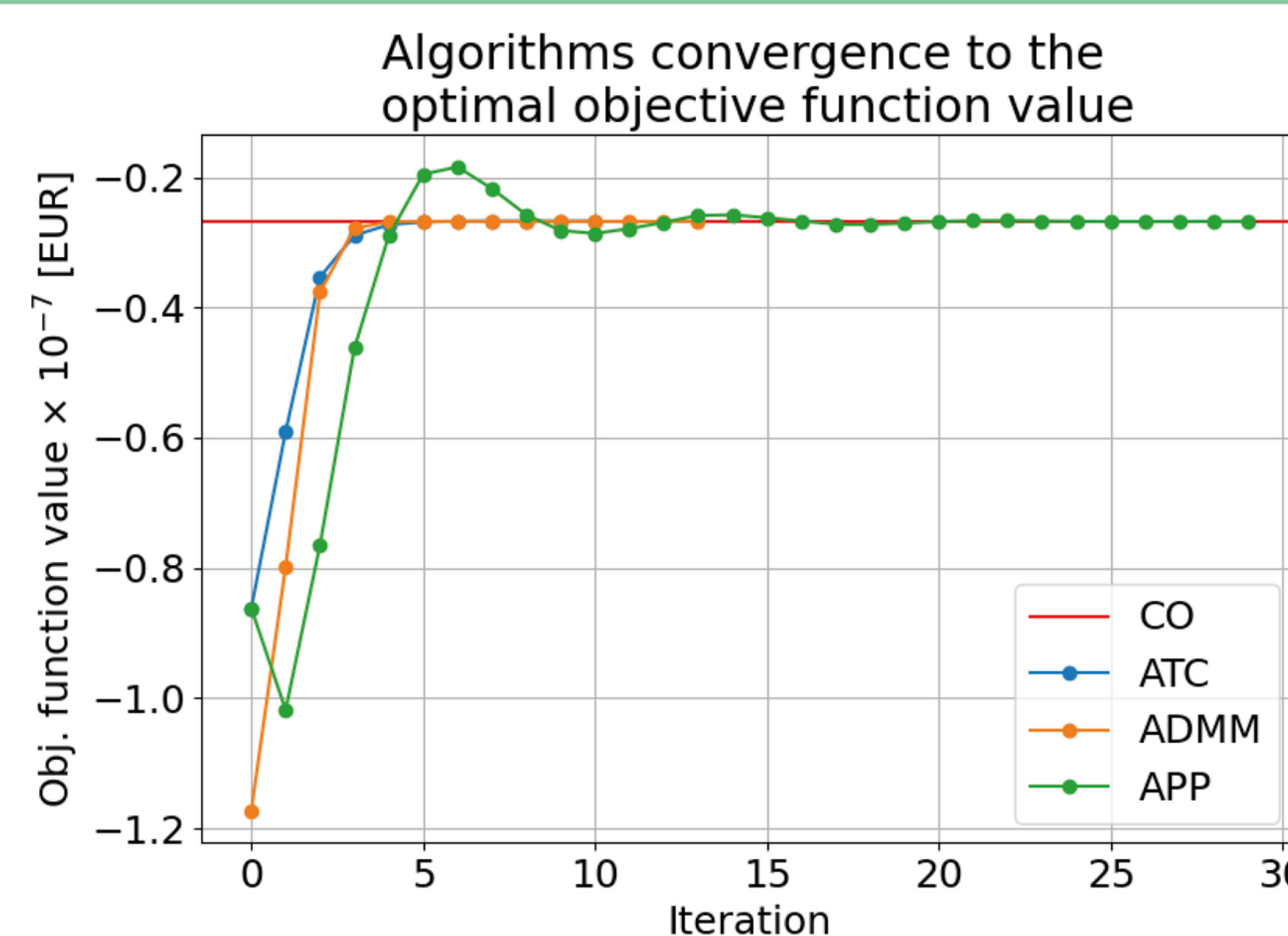
We can distinguish between centralized (single controller), decentralized (purely local algorithms), hierarchical (agents communicate with a master at higher level) and distributed (agents communicate only with neighbors, no master controller) architectures.



Results

CO enables a better coordination of the VPP portfolio compared to decentralized optimization (DO). Thus, CO increases by 28% the market revenue compared to DO.

Scores	DO	CO
Market revenue [EUR/MWh/h]	29	37.12
BESS 1 degradation [EUR/h]	0.44	0.47
BESS 2 degradation [EUR/h]	0.5	0.54



All algorithms converge to the CO optimal objective function value with less than 1% error. Parallelization reduces the computational effort, however CO is still faster for small-scale problems.

	CO	ATC	ADMM	APP
Obj. relative error [%]	-	0.24	0.18	0.84
No. of iterations	-	11	6	25
Time (sequential) [s]	-	67	25	489
Time (parallel) [s]	3	38	21	425

Conclusions

A coordinated management of the VPP significantly enhances the market value of the portfolio. Hierarchical and distributed algorithms reach less than 1% error and enhance scalability, privacy and resilience. However, problem decomposition and parameters tuning require additional effort.

ADMM shows the smallest convergence error, but it is highly sensitive to parameters tuning. With parallelization, APP is expected to be the fastest approach to tackle large-scale problems (high scalability). ATC results to be the less sensitive algorithm to variations in the parameter values.