Guest Editorial

Introduction to IEEE Control Systems Letters Special Section on Multi-Agent Coordination for Energy Systems: From Model Based to Data-Driven Methods

Glielmo, Luigi; Grammatico, Sergio; Kebriaei, Hamed; Smith, Roy S.

DOI
10.1109/LCSYS.2023.3331928

Publication date
2023

Document Version
Final published version

Published in
IEEE Control Systems Letters

Guest Editorial: Introduction to IEEE Control Systems Letters Special Section on Multi-Agent Coordination for Energy Systems: From Model Based to Data-Driven Methods

DISTRIBUTED control architectures are paving the way for the next generation of energy system infrastructures, primarily due to the combination of smart grid technologies and energy market deregulation. The new framework offers increased privacy and decision autonomy for the end-users, but it poses challenges due to the lack of direct control of the aggregate behavior of a large number of energy end-users. To compensate for the resulting uncertainty, the end-users should coordinate at different levels in the power system hierarchy, so that their aggregate behavior can help achieve global objectives, without hindering their privacy and local autonomy.

The coordination can be achieved either by the agents themselves (assuming that the agents can share information with each other) or be facilitated by an external entity (if the agents communicate with some external entity but not with each other). Furthermore, the coordination can be categorized as cooperative, competitive or even mixed, based on the individual objectives.

As expected, the papers collected in this special section utilize different approaches to reach such a coordination, as the goals differ from case to case. In [A1], [A3], and [A4], the goal is to reach a Nash equilibrium solution: through pairwise imitation rules between agents at random-time in [A1], where the goal is shaving the demand in a demand-response scheme; through stochastic games with chance constraints in [A3], where the agents share a storage resource; through two-layer (coordinators and agents) iterations in a stochastic game in [A4], to exploit the flexibility of electric vehicle charging.

In [A2], an optimal allocation problem (among power generators and storage units) is solved in a distributed fashion guaranteeing that at all time, and at every iteration of the algorithm, the power balance is maintained.

In [A5], a distributed MPC is designed to reach asymptotic stability via passivity of a microgrid characterized by synchronous generator dynamics.

Digital Object Identifier 10.1109/LCSYS.2023.3331928

In [A6], a data-driven approach is employed to reach consensus in a reinforcement learning framework among agents with individual photovoltaic generation that have to share storage resources.

Appendix: Related Articles

[A1] J. Martinez-Piazuelo, W. Ananduta, C. Ocampo-Martinez, S. Grammatico, and N. Quijano, "Population games with replicator dynamics under event-triggered payoff provider and a demand response application," *IEEE Control Syst. Lett.*, vol. 7, no. 1, pp. 3417–3422, 2023, doi: 1109/LCSYS.2023.3285532. The authors consider a large population of decision makers that choose their evolutionary strategies based on simple pairwise imitation rules, setting up a dynamic process by replicator dynamics. A realistic scenario is analyzed where pay-off signals are updated occasionally, still yielding, through two event-triggered communication schemes, asymptotic convergence guarantees to a Nash equilibrium. The proposed approach is applicable as an efficient distributed demand response mechanism.

[A2] M. Doostmohammadian, "Distributed energy resource management: All-time resource-demand feasibility, delay-tolerance, nonlinearity, and beyond," *IEEE Control Syst. Lett.*, vol. 7, no. 1, pp. 3423–3428, 2023, doi: 10.1109/LCSYS.2023.3303219. Here the mathematical problem considered is the optimal allocation of the generated powers and the reserved, stored, powers on the basis of nodes' local cost gradient information while meeting the power demand. The challenges are to maintain the power balance at all times during the distributed iterations of the scheduling algorithm; to tolerate communication time-delays and changes in the network; to incorporate possible model nonlinearity in the algorithm; and to benefit from distributed (or networked) features. The author shows both the all-time feasibility of the proposed scheme and its convergence under certain bounds on the step-rate using Lyapunov-type proofs.

[A3] S. Yadollahi, H. Kebriaei, and S. Soudjani, "Generalized stochastic dynamic aggregative game for demand-side management in microgrids with shared battery," *IEEE Control Syst. Lett.*, vol. 7, no. 1, pp. 3429–3434, 2023, doi: 10.1109/LCSYS.2023.3325707. This paper starts from demand-side management in a microgrid where agents utilize grid energy and a shared battery charged by renewable energy sources. The problem is cast as a generalized stochastic dynamic aggregative game with chance constraints to include uncertainties in the renewable generation and agents' demands. The authors investigate the Nash equilibrium of this game considering both the uniqueness of the solution and the effect of uncertainty on the solution. Simulation results demonstrate that the presented stochastic method is superior to deterministic methods.

[A4] M. Ghavami, B. G. Bakhshayesh, M. Haeri, G. Como, and H. Kebriaei, "A consensus-based generalized multi-population aggregative game with application to charging coordination of electric vehicles," *IEEE Control Syst. Lett.*, vol. 7, no. 1, pp. 3435–3440, 2023, doi: 10.1109/LCSYS.2023.3326993. This paper introduces a consensus-based generalized multi-population aggregative game coordination approach with application to electric vehicles charging under transmission line constraints. The algorithm enables agents to seek an equilibrium solution while considering the limited infrastructure capacities that impose coupling constraints among the users. The Nash-seeking algorithm consists of two interrelated iterations. In the upper layer, population coordinators collaborate for a distributed estimation of the coupling aggregate term in the agents' cost function and the associated Lagrange multiplier of the coupling constraint, transmitting the latest updated values to their population's agents. In the lower layer, each agent updates its best response based on the most recent information received and communicates it back to its population coordinator. For the case when the agents' best response mappings are non-expansive, the algorithm's convergence to the generalized Nash equilibrium point of the game is proven. Simulation results demonstrate the algorithm's effectiveness.

[A5] T. de Jong and M. Lazar, "Energy based cooperative distributed MPC for frequency control in microgrids," *IEEE Control Syst. Lett.*, vol. 7, no. 1, pp. 3441–3446, 2023, doi: 10.1109/LCSYS.2023.3327901. This paper develops an energy based cooperative distributed model predictive control (DMPC) scheme for frequency (or voltage) stabilization in microgrids. Firstly, a novel integral supply constraint based on Bregman energy functions, ensuring equilibrium-independent asymptotic stability of nonlinear microgrid models, is presented. Secondly, the authors design DMPC controllers with integral supply constraints that cooperate towards achieving global microgrid stability via supply sharing. This cooperative DMPC scheme is compared to a non-cooperative DMPC scheme that uses passivity-type constraints and becomes infeasible during a load change scenario. The DMPC scheme yields shorter settling times and much smaller overshoots when compared with distributed averaging proportional integral controllers.

[A6] A. Joshi, M. Tipaldi, and L. Glielmo, "A consensus Q-learning approach for decentralized control of shared energy storage," *IEEE Control Syst. Lett.*, vol. 7, no. 1, pp. 3447–3452, 2023, doi: 10.1109/LCSYS.2023.3329072. The decentralized scheduling of an energy storage system shared among residential households is analyzed here by considering the households as learning agents and modeling their interaction as a Markov Game. To address the challenges associated with the non-stationary nature of multi-agent learning, the authors propose a consensus-based tabular Q-learning method. Additionally, they provide simulation studies utilizing a real-world household dataset and demonstrate the effectiveness of the approach.

LUIGI GLIELMO
DIETI, Department of EE and IT
University of Napoli Federico II
80125 Naples, Italy

SERGIO GRAMMATICO
Delft Center for Systems and Control
TU Delft
2628 CD Delft, The Netherlands

HAMED KEBRIAEI
School of Electrical and Computer Engineering, College of Engineering
University of Tehran
Tehran 1439957131, Iran

ROY S. SMITH
Department of Information Technology and Electrical Engineering
ETH Zurich
8092 Zürich, Switzerland