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Recent progress on the study of distributed economic dispatch in smart grid: an overview

Key words: Distributed economic dispatch; Distributed optimization; Smart grid; Continuous-time optimization algorithm; Discrete-time optimization algorithm

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Background

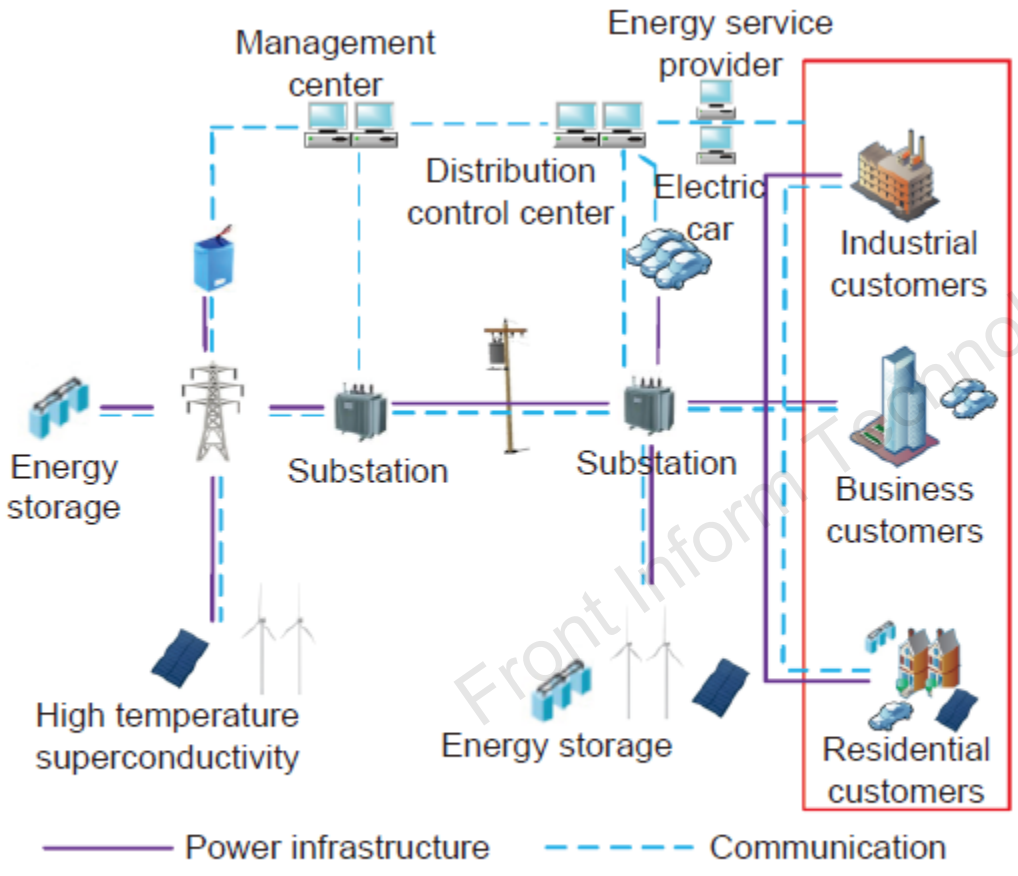
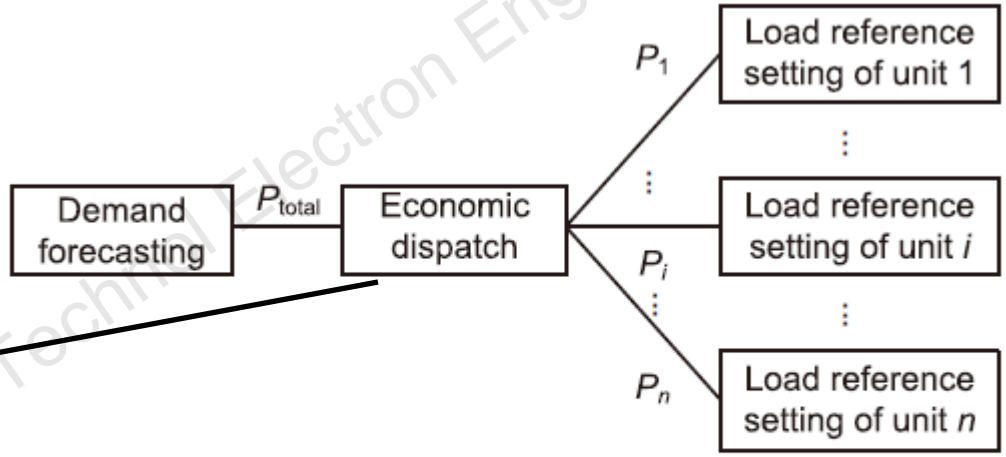


Fig. 1 A simplified framework of smart grid

- The smart grid (SG) incorporates a large number of distributed energy resources (including various gas turbines and wind-power resources), energy storage devices, and flexible loads, leading to a great complexity in the energy management of SG.
- It incorporates advanced management, control, and communication technologies to improve the operational efficiency of power generation units and electricity transmission facilities as well as furnish flexible choices for various consumers.

Economic dispatch

Consider a traditional economic dispatch with the supply-demand balance and generator constraints in the smart grid.



$$\min \sum_{i=1}^{N} C_i(P_i)$$

$$\text{s.t.} \sum_{i=1}^{N} P_i = P_{\text{total}},\ P_i^{\min} \le P_i \le P_i^{\max},$$

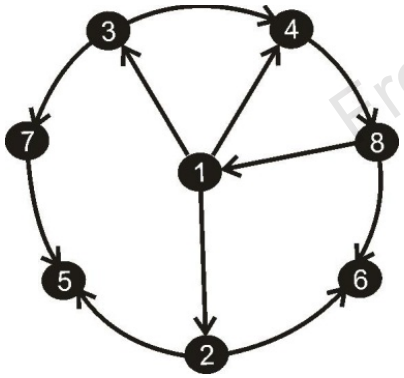
Fig. 2 Execution process of economic dispatch

P_{total} represents the total power demand predicted by demand forecasting

The main objective of economic dispatch in the smart grid is to make the power system run under the most economical condition while meeting the power demand and generator capacity constraints.

Distributed economic dispatch

- **Motivation:** Several benefits, such as easy implementation, low maintenance cost, high energy efficiency, and strong robustness against uncertainties, can be gained using the distributed optimization and computational methods.
- **Objective:** The distributed economic dispatch aims at designing a distributed algorithm for each generator to dispatch the active power based on the locally available information to meet electricity demand cooperatively at a minimized cost.
- **The distributed economic dispatch is designed based on the consensus protocol.**



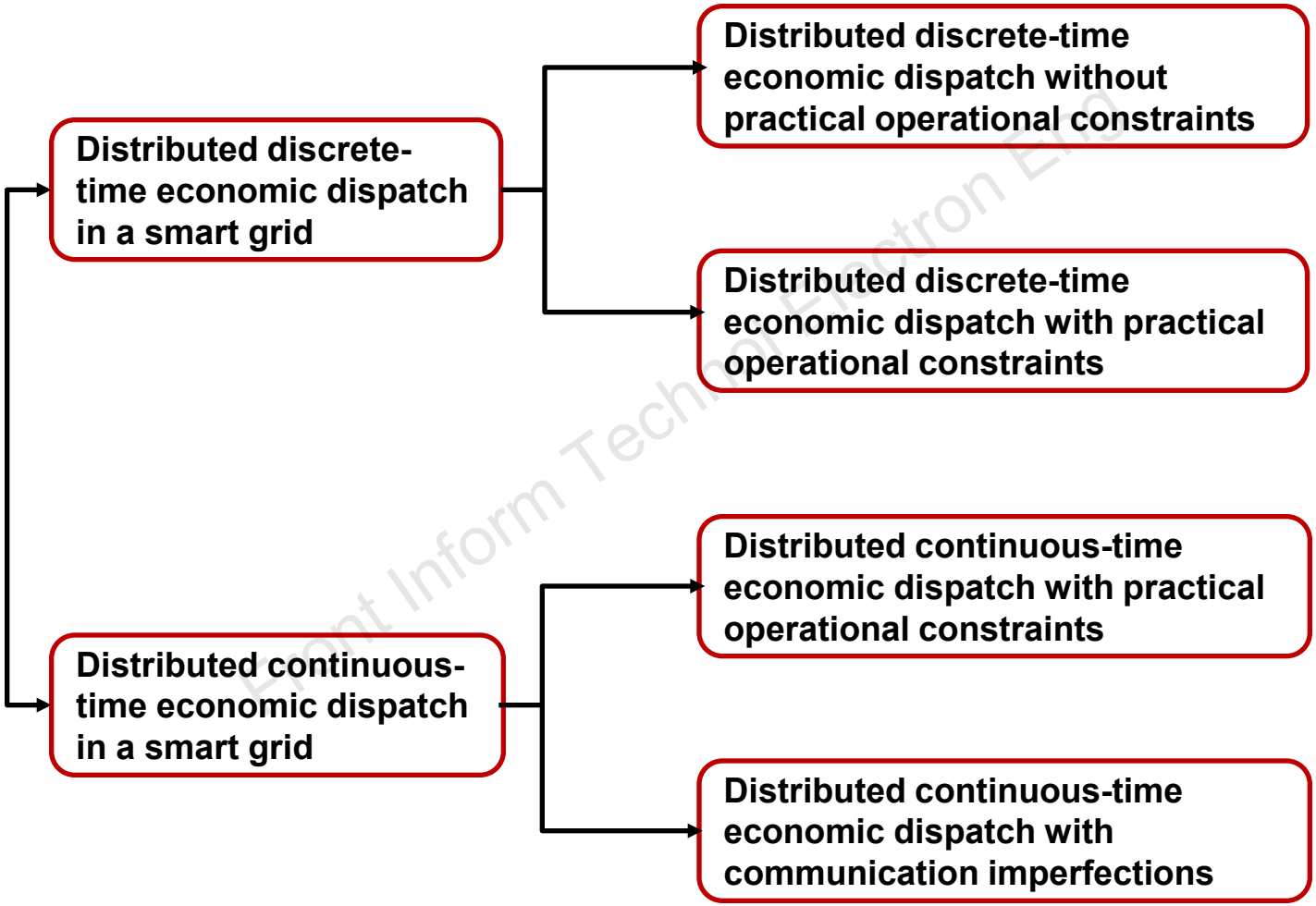
Distributed continuous-time consensus protocol

$$\dot{\boldsymbol{x}}_i(t) = c\sum_{j=1}^{N} a_{ij}[\boldsymbol{x}_j(t) - \boldsymbol{x}_i(t)]$$

Distributed discrete-time consensus protocol

$$\boldsymbol{x}_i[k+1] = \sum_{j=1}^{N} a_{ij}\boldsymbol{x}_j[k]$$

Main contents



Distributed discrete-time economic dispatch without practical operational constraint

Zhang Z, Chow MY, 2011. Incremental cost consensus algorithm in a smart grid environment. IEEE Power and Energy Society General Meeting Power and Energy Society General Meeting, Detroit, MI, USA, USA, p.1-6.
Zhang Z, Chow MY, 2012. Convergence analysis of the incremental cost consensus algorithm under different communication network topologies in a smart grid. *IEEE Trans Power Syst*, 27(4):1761-1768.

$$\lambda_i[k+1] = \sum_{j=1}^{N} d_{ij}\lambda_j[k],$$

$$\lambda_{\text{leader}}[k+1] = \sum_{j=1}^{N} d_{ij}\lambda_j[k] + \varepsilon\Delta P,$$

Wang R, Li Q, Zhang B, et al., 2019b. Distributed consensus based algorithm for economic dispatch in a microgrid. *IEEE Trans Smart Grid*, 10(4):3630-3640.

$$\Delta P_i[k+1] = \sum_{j\in\mathcal{N}_i} d_{ij}\Delta P_j[k] - (P_i[k+1] - P_i[k]),$$

Distributed discrete-time ED without practical operational constraint

Binetti G, Davoudi A, Lewis F, et al., 2014a. Distributed consensus based economic dispatch with transmission losses. *IEEE Trans Power Syst*, 29(4):1711-1720.

$$\sum_{i=1}^{N} P_i = P_{\text{Total}} + P_{Loss}$$

Transmission loss

Binetti G, Davoudi A, Naso D, et al., 2014b. A distributed auction based algorithm for the nonconvex economic dispatch problem. *IEEE Trans Ind Inform*, 10(2):1124-1132.

Ramp rate limit:

$$-P_i^{ramp1} \le P_i[k] - P_i[k-1] \le P_i^{ramp2}$$

Distributed continuous-time economic dispatch with practical operational constraints

He X, Ho DW, Huang T, et al., 2018. Second-order continuous-time algorithms for economic power dispatch in smart grids. *IEEE Trans Syst Man Cybern Syst,* 48(9):1482-1492.

$$\begin{cases} \dot{P}_i(t) = -\sum\limits_{j=1, j\neq i}^{N} a_{ij}(Q_j(t) - Q_i(t)), \\ \dot{Q}_i(t) \in -\varepsilon Q_i(t) - \partial f_i^{\theta}(P_i(t)), \ i = 1, 2, \ldots, N. \end{cases}$$

Nonsmooth
exact penalty function

Cherukuri A, Cortés J, 2016. Initialization-free distributed coordination for economic dispatch under varying loads and generator commitment. *Automatica*, 74:183-193.

This paper considered initialization-free economic dispatch algorithms over a strongly connected, weight-balanced digraph.

Distributed continuous-time economic dispatch with communication imperfections

Communication delay:

A modified distributed algorithm for the evolution of incremental cost :

$$\dot{y}_i(t) = -2c\gamma_i \sum_{j=1}^{N} l_{ij} y_j(t - \tau_{ij}),$$

Zhu Y, Yu W, Wen G, 2016. Distributed consensus strategy for economic power dispatch in a smart grid with communication time delays. IEEE Int Conf on Industrial Technology, p.1384-1389.

Communication uncertainties:

Distributed continuous-time ED algorithm with the adaptive weight-adjustment technique:

$$\dot{\zeta}_i(t) = 2c\gamma_i \sum_{j \in \mathcal{N}_i} [a_{ij}(t) + \omega_{ij}(t)][\zeta_j(t) - \zeta_i(t)],$$

$$\dot{a}_{ij}(t) = h_{ij}[\zeta_j(t) - \zeta_i(t)]^2, \ j \in \mathcal{N}_i,$$

Wen G, Yu X, Liu Z, et al., 2018. Adaptive consensus-based robust strategy for economic dispatch of smart grids subject to communication uncertainties. *IEEE Trans Ind Inform*, 14(6):2484-2496.

Future research topics

- Distributed security economic dispatch of the smart grid:
  - ✓ Design resilient economic dispatch algorithms for the smart grid subject to cyber-attacks on generators and/or on the underlying communication networks
  - ✓ Design distributed privacy-preserving economic dispatch strategies
- Distributed fast economic dispatch in the smart grid with practical constraints:
  - ✓ Develop distributed fast economic dispatch algorithms such that the dispatch objectives can be achieved in finite or fixed time while satisfying the practical constraints
- Efficient initialization-free distributed economic dispatch in the economic dispatch:
  - ✓ Construct more efficient initialization-free distributed economic dispatch algorithms for the smart grid
- Distributed economic dispatch in the smart grid in the presence of smart energy storage batteries and flexible loads:
  - ✓ Design a distributed algorithm taking full advantages of flexible loads and smart energy storage batteries in solving economic dispatch
- Distributed economic dispatch in the smart grids with artificial intelligence (AI) technologies