Optimal Power Dispatch of Power Networks with Potential Games

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Backgrounds

Smart Grid : electricity network using digital technology

- Real time management of supply and demand
- Energy efficiency
- Increasing reliability
- Use of Renewable energy (solar, wind, etc)

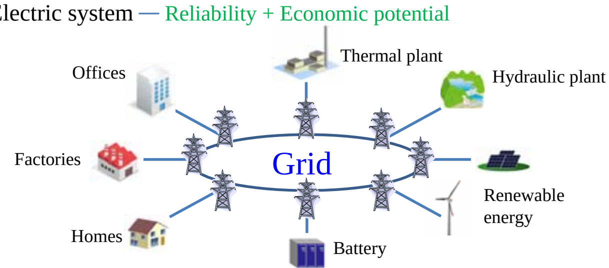
{ reduction greenhouse gases
{ their output fluctuate widely and randomly
instability!

⇩

Conventional power plants and renewable energy need to generate electricity in a coordinated way

Objective (Optimal Power Dispatch)

Electric system — Reliability + Economic potential



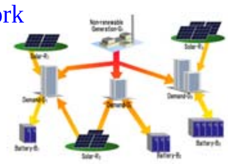
{ property of generators(thermal, solar, etc)
{ network structure

⇨ Optimal power dispatch for customers

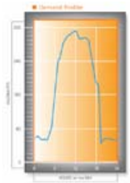
determine each generator's supply such that minimizes fuel cost and satisfies supply-demand balance

Objective (Related Work)

Related work : Analysis of power network



- Optimal power flow with battery[1, 2]
  - introduction of battery
  - static ⟶ dynamic optimization
  - analysis optimal generation schedule
- Demand response[3]
  - manage customer consumption in response to supply condition
  - non-cooperative game (customers and utility)
  - decision-making process of price and power dispatch



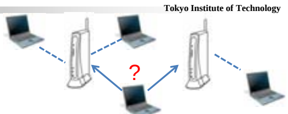
DoE, Smart Grid Intro, 2008

No design policy of optimal power dispatch

⇨ Game theoretic approach

Objective (Game-theoretic Control)

Game-theoretic approach



- Agents are self-interested

⇨ Non-cooperative game

- The solution to the problem = the equilibrium of the game

Applications : resource allocation, sensor coverage

Advantages

- robustness to failures and environmental disturbances
- guarantee global convergence
- improved scalability

⇨ Potential game has { Design policies of objective function / Learning algorithms }

Objective of this work

To apply potential game to optimal power dispatch problem of power network

Definition of Game

- Player set $N = \{1, \cdots, n\}$
- Collection of action sets $A = A_1 \times \ldots \times A_n$
  - Agent i's action set : A_i
  - Agent i's action : $a_i \in A_i$
- Collection of objective function $U = \{U_1, \cdots, U_n\}$
  - Agent i's objective function $U_i : A \to \mathbb{R}$

Every agent chooses a_i to maximize U_i

⇨ Game $G = < N, A, U >$

Nash equilibrium

A pure Nash equilibrium is an action $a^* \in A$ such that $\forall i \in N$

$$U_i(a_i^*, a_{-i}^*) = \max_{a_i \in A_i} U_i(a_i, a_{-i}^*)$$

$$(a_{-i} = (a_1, a_2, \cdots, a_{i-1}, a_{i+1}, \cdots, a_n))$$

(Ex.) Payoff Matrix

Player 2

Player 1	A	B
A	(2,2) NE	(1,0)
B	(0,1)	(4,4) NE

Potential Game

- Potential function (global objective function) $\phi : \mathcal{A} \rightarrow \mathbb{R}$

ϕ : max ⇨ Objective of a group is achieved

Potential game

A game $G = < N, \mathcal{A}, U >$ is a potential game if there is a potential function ϕ such that $\forall i \in N$, $\forall a_{-i} \in \mathcal{A}_{-i}$ and $\forall a_i', a_i'' \in \mathcal{A}_i$,

$$U_i(a_i', a_{-i}) - U_i(a_i'', a_{-i}) = \phi(a_i', a_{-i}) - \phi(a_i'', a_{-i})$$

Key property

- the guaranteed existence of a Nash equilibrium
- Local maxima of ϕ are Nash equlibra

(Ex.) Payoff

	A	B
A	(2,2)	(1,0)
B	(0,1)	(4,4)

Potential

	A	B
A	2	0
B	0	3

Global objective

⇨ Application of appropriate learning algorithms

Optimal Distributed Inhomogeneous Synchronous Learning(ODISL)[6]

- Convergence to optimal Nash equilibrium with probability 1

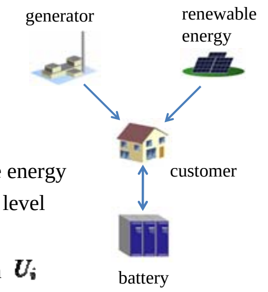
Scenarios

Problem setting

➢ Design of potential game

- Agent : generator, renewable energy, battery, customer
- Potential function ϕ
  - minimize supply from generator
  - maximize supply from renewable energy
  - remaining battery level = desired level
  - demand = supply

⇨ Each agent's objective function U_i



Numerical simulation

➢ Learning algorithm : ODISL[6]

➢ Compared with results of [2]

Reference

[1] K. M. Candy, S. H. Low, U. Topcu and H. Xu, "A Simple Optimal Power Flow Model with Energy Storage," Proc. of *the 49th IEEE Conference on Decision and Control*, pp.1051-1057, 2010

[2]星, "分散協調予測制御を用いたバッテリーを含むパワーネットワークの動的最適潮流計算," 東京工業大学修士論文, 2011

[3] L. Chen, N. Li, S. H. Low, and J. C. Doyle, "On Two Market Model for Demand Response in Power Networks," Proc. of *the first IEEE International Conference on Smart Grid Communications*, pp.1708-1713, 2010

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[5] R. Gopolakrishnan, "An Architectural View of Game Theoretic Control," *California Institute of Technology Master's Thesis*, 2010

[6]後藤, "ポテンシャルゲーム理論的協調制御における学習アルゴリズムの提案," 東京工業大学修士論文, 2011