Renewable Energy Popularization Based on Evolutionary Game Theory

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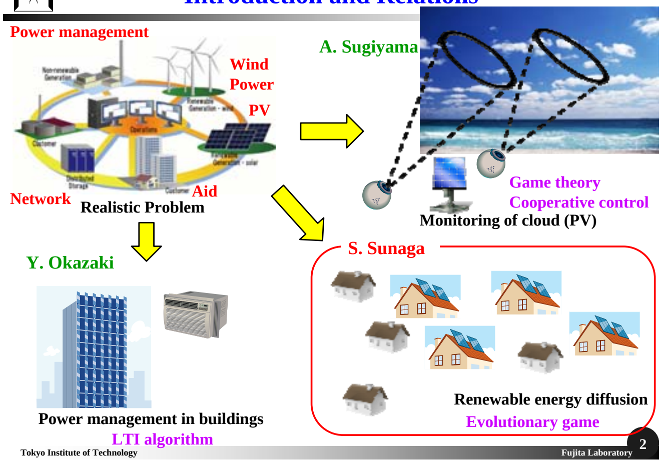
Introduction and Relations



Background

- **Energy Problem**

Environmental Problem

・Carbon dioxide **Global warming**

・Nuclear power **Pollution problem**

Thermal plant Nuclear accident

Stable Supply of Energy

Robust to disturbance

・Disasters

・Balance between supplier and customer

Especially America and developing countries

Blackout

- **Renewable Energy**

Wind, solar , solar heat, … and so on

Clean energy

Low load to environment

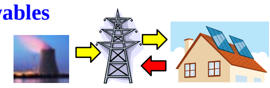
Wind

Solar

Background

- **Photo Voltaic(PV) : Renewables**

A kind of renewable energy



Reverse power flow

Weather

Problem : Characteristic

・Instability of power generation[1]

・Reverse power flow[1]

- **Previous Work : Renewables**

・Distributed optimal control [2]
Supplier side

・Optimal control [3]
Consumer side

・Optimal predictive control [4]
Networks

Approach : Optimization and Game Theory

Objective

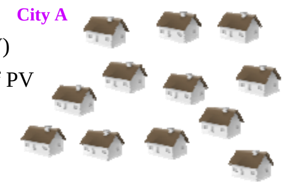
- **Objective of Research**

Regulation of renewable energy(PV)

・Robustness against imbalance of PV

・Optimization of PV rate

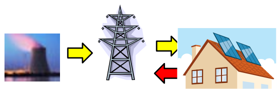
City A



Problems

・Many agents in a community
Many connections of agents

・Instabilityof power generation



Reverse power flow

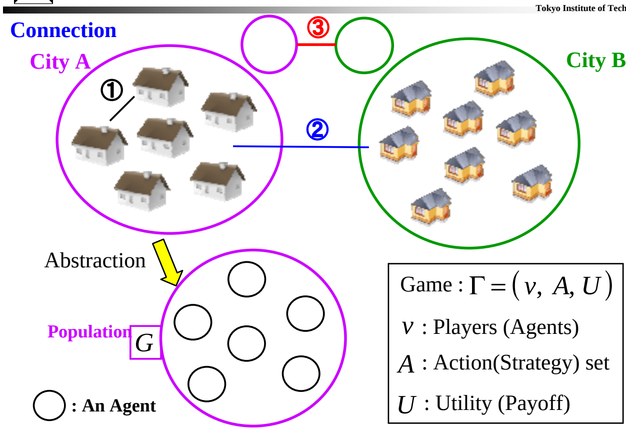
Evolutionary Game Theory[8][9]

・Management of many agents **From biology**

・Strategy average of agents **Homogenization of strategy**

・Application of payoff-based game theory

Image



Game : $\Gamma = (v,\ A,\ U)$

v : Players (Agents)

A : Action(Strategy) set

U : Utility (Payoff)

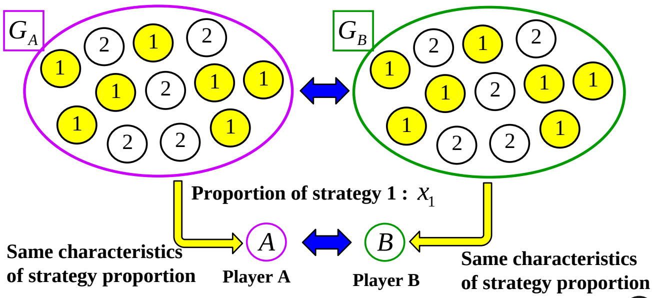
Population and Player

(1) : An individual which takes strategy 1 — Use PV

(2) : An individual which takes strategy 2 — Not use PV

Payoff of players A : Ψ_A

Payoff of players B : Ψ_B



Evolutionary Games

■ **Strategy : Action** A

An action which agents have

$x_i,\ i=1,2$: Strategy frequency

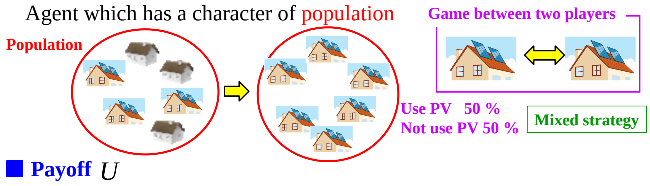
Use PV — x_1 : Strategy 1

Not use PV — x_2 : Strategy 2

Note : $x_2 = 1 - x_1$

■ **Player** v

Agent which has a character of population



■ **Payoff** U

Rewards to select a strategy Ψ

Average expected payoff

$$U(x_1) = (\text{Payoff using PV}) \times x_1 + (\text{Payoff not using PV}) \times (1 - x_1)$$

Appendix : Game Theory

Payoff tabular (Player A and B)

A \ B	Strategy 1	Strategy 2
Strategy 1	a	c
Strategy 2	b	d

An example

a : Payoff which both player A and B take strategy 1

2 Player Games : Each player can take either of strategies 1 and 2

Utility Matrix (Payoff) : $\Psi = \begin{bmatrix} a & c \\ b & d \end{bmatrix}$

Mixed Strategy : Player A takes strategy 1 w.p. p_1 (strategy 2 w.p. $1-p_1$)

Player B takes strategy 1 w.p. q_1 (strategy 2 w.p. $1-q_1$)

Expected Payoff :

Both Player A and B

$$a \times p_1 q_1 + c \times p_1 (1-q_1) + b \times (1-p_1) q_1 + d \times (1-p_1)(1-q_1) = p^T \Psi q$$

Evolutionary Games

■ **Replicator Dynamics**

Selection in population related to strategy frequency

Getting more advantage strategy

Replicator Dynamics (2 Strategies)

$$\dot{x}_1 = \left(U_1(x_1) - \bar{U}(x_1)\right) x_1$$

$$\dot{x}_2 = \left(U_2(x_1) - \bar{U}(x_1)\right) x_2$$

$\bar{U}(x_1)$: Average expected payoff of population

$U_1(x_1)$: Expected payoff of strategy 1

$U_2(x_1)$: Expected payoff of strategy 2

$$\Gamma' = (\Gamma,\ D) \qquad (\ \Gamma = (v,\ A,\ U)\ ) \quad D : \text{Replicator dynamics}$$

■ **This Research**

Payoffs are regarded as cost — Negative payoff

Agents select high payoff strategy ⇨ Agents select low cost strategy

Survey: Electric Fee and PV Power

Electric power consumed by family : About 300kWh／month

⇨ About 0.42kWh／hour

http://www.fepc.or.jp/present/jigyou/japan/index.html
http://www.fepc.or.jp/present/jigyou/japan/sw_index_04/index.html

PV power : 1000kWh／1kWh module

3kWh～4kWh module is standard for family

⇨ About 0.34～0.46kWh／hour

http://www.jpea.gr.jp/11basic05.html

Note : In this web page, electric power by family is 56500kWh／year

⇨ About 0.645kWh／hour

Electrical utility of PV : 42 yen/kWh

Electrical utility of megainfra : 16 yen/kWh

Average of 9 electrical company's fee

Modeling Based on Electrical Utility

$$\dot{x}_1 = \left(U_1(x_1) - \bar{U}(x_1)\right) x_1$$

$$\left(\bar{U}(x_1) = U_1(x_1) x_1 + U_2(x_1)(1 - x_1)\right)$$

$\bar{U}(x_1)$: Average expected payoff

$U_1(x_1)$: Expected payoff of strategy 1

Costs of selected strategy 1 (Using PV) : y

$$a = (\text{Electrical utility rate of using PV}) \times \text{Electricity of PV power} + (\text{Electrical utility rate of not using PV}) \times \text{Electricity of grid power}$$

$$y = (1 - R) \times a + R \times c$$

R : Risk of imbalance

c : Cost caused by imbalance

Costs of selected strategy 2 (Not using PV) : z

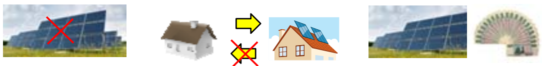
$$z = (\text{Electrical utility rate of not using PV}) \times \text{Electricity of grid power}$$

Feature Work

■ Modeling

Adding realistic parameters

PV panel failure rate, direction limitation, PV panel cost

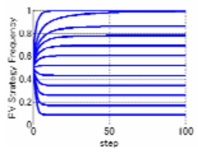


and so on …

■ Dynamics Analysis

・Bifurcation phenomenon **Relation to allocation of cost**

・Control theory **PID control**

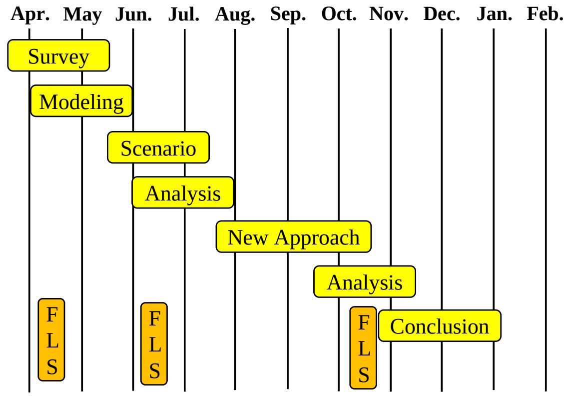


■ Scenario

・Adding learning algorithm **PIPIP**

・Variety of sceneries **Stability, Efficiency, …**

Research Plan



References

■Renewable Energy

[1] E. Y. Bitar, P. P. Khargonekar, K. Poolla, “Systems and Control Opportunities in the Integration of Renewable Energy into the Smart Grid,” IFAC World Congress, 201

[2] Z. Changhong, T. Ufuk, L. Steven, “Frequency-Based Load Control in Power Systems,” *Proc. of the IEEE Conf. on American Control Conference*, 2012.

[3] R. Rajagopal, E. Bitar, F. Wu, P. Varaiya, “Risk Limiting Dispatch of Wind Power,” *Proc. of the IEEE Conf. on American Control Conference*, 2012.

[4] S. A. E Maria, G. Dennice, T. Ufuk, “Risk-Mitigated Optimal Power Flow with High Wind Penetration,” *Proc. of the IEEE Conf. on American Control Conference*, 2012.

References

■Evolutionary Game

[5] T. Kanazawa, H. Goto, and T. Ushio, “Replicator Dynamics with Dynamic Payoff Reallocation Based on the Government’s Payoff,” *2007 International Symposium on Nonlinear Theory and its Applications*, 2007.

[6] D. Pais and N. E. Leonard, “Limit Cycles in Replicator-Mutator Network Dynamics,” *Proc. of the IEEE Conf. on Decision and Control*, 2011

[7] M. Saito, T. Hatanaka and M. Fujita, “Decision Dynamics in Cooperative Search Based on Evolutionary Game Theory,” *Communications in Information and Systems, Special Issue on Control of Complex and Nonlinear Systems*, Dedicated to John Baillieul on the Occasion of His 65th Birthday, Vol. 11, No. 1, pp. 57-70, 2011.

[8] 生天目, “ゲーム理論と進化ダイナミクス：人間関係に潜む複雑系,” 森北出版, 2004.

[9] Martin A. Nowak, “進化のダイナミクス：生命の謎を解き明かす方程式,” 共立出版, 2009.