Overview of Energy Systems and Relations with my Research Field

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Outline

Objective
1. Learn common knowledge many researchers have
2. Adjust my research field (Photovoltaics/Battery)

Theme: Think Big, **Do Small**

Part I Global Energy and Environment: National Strategy*

Part II Smart/Micro-grid and Renewables: Technical Strategy

What is a dynamics and performance/limitation which a photovoltaics and a battery have?

(i) Photovoltaics and Distributed Smartgrids Management System

(ii) Battery and its Management*

"Renewables" and ***"Distributed Energy System"***

[*] 4th Basic Program for Science and Technology, CREST Project etc.

Similarity of Physical/Chemical Approach

Physical/Chemical Dynamics

diffusion drift recombination creation

(Physical)
Equation of Minor Carrier

$$\begin{cases} \frac{\partial}{\partial t}n_p(x) = D_n\frac{\partial^2}{\partial x^2}n_p + \mu_n E(s)\frac{\partial}{\partial x}n_p - \frac{n_p - n_{p0}}{\tau_n} + G_n \\ \frac{\partial}{\partial t}p_n(x) = D_p\frac{\partial^2}{\partial x^2}p_n + \mu_p E(s)\frac{\partial}{\partial x}p_n - \frac{p_n - p_{n0}}{\tau_p} + G_p \end{cases}$$

(Chemical)
Diffusion flux of neutral particles (中性粒子の拡散流束)

Slope of Chemical Potential: $-C_i v_i \frac{d\mu_i}{dx} = -v_i RT\frac{dC_i}{dx}$

Fick's Law of diffusion: $-D_i\frac{dC_i}{dx} \quad (D_i = v_i RT)$

Electrochemical Potential: $\phi = \mu + zFV$ (Sum of Chemical/Electrostatic Potential)

Relation with our researches[1,2]

No relation?

Material/Performance

"Distributed Energy System"

[1] T. Hatanaka, YW and M. Fujita, "Game Theoretic Cooperative Energy Network Management for Distributed Microgrids: Variability Reduction of Photovoltaic Generation," *Proc. of 2013 ACC*, submitted, 2013
[2] YW, TH and MF, "Variability Reduction of Photovoltaics via Game Theoretic Receding Horizon Cooperative Network Formation for Distributed Microgrids," *JCMSI*, submitted, 2012

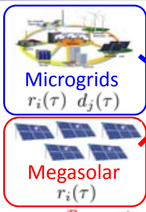
Research Result[1,2]: Outline

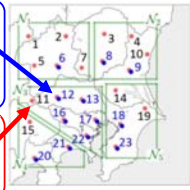
***Player*: PV Power Sources** $i \in \mathcal{V} = \{1, \cdots, 23\}$

power: $r_i(\tau)$ **at time** τ

***Resource*: Micrograds** $j \in \mathcal{R}$ $\{6, 8, 9, 12, 13, 16, 17, 18, 20, 21, 22, 23\}$

demand: $d_j(\tau)$ **at time** τ



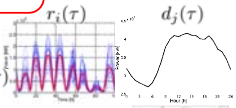


Action: Each player $i \in \mathcal{V}$ selects the collection of used resources $a_i \subseteq \mathcal{A}_i \in 2^{\mathcal{R}}$

Given Data: **EXAM SYSTEM[3]** ➡ Estimate $r_i(\tau)$

Publicly Available Demand Data ➡ Estimate $d_j(\tau)$

[Tune total generated power to 35% of demand]



Transmission Losses[1,2]

- Large as the distance from i to j increases
- Consider the conversion loss between the areas $\mathcal{N}_i, \mathcal{N}_j$

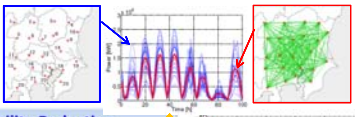
[3] H. Takenaka et al., "Estimation of Solar Radiation Using a Neural Network Based on Radiative Transfer," *J. Geophysical Research*, Vol. 116, D08215, 2011

Cost Functions: Variability Reduction

Temporal Variability Reduction:

Evolution of the average is far smoother than individual data

➡ "Smoothing Effect"



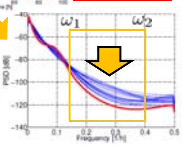
Cost Function 1: Temporal Variability Reduction

$$f_j(a) = \int_{\omega_1}^{\omega_2} \gamma(\omega) P_j(a;\omega) d\omega$$

$\gamma(\omega)$: **Weighting function**

$P_j(a;\omega)$: **PSD of Normalized Data**

$E_j^{\mathrm{nom}}(a) = (E_j(a,\tau)/\|E_j\|_1)_{\tau\in[t_0,t_f]}$



Smooth
- Total amount of renewable energy
- Individual power received at each grid

Spatial Variability Reduction:

Cost Function 2: Total gap of Demand and Supply (Spatial Variability Reduction)

$$g_j(a) = |[t_0, t_f] \setminus \mathcal{T}_m(a)|$$

$$\mathcal{T}_m(a) = \{\tau | d_j(\tau) - E_j(a,\tau) \geq c_j\}$$

c_j : product of the maximal capacity of grid $j \in \mathcal{R}$ and the allowable level on the operating rate

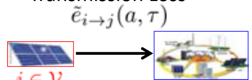
Cost Function and Game Structure

Transmission Loss Reduction:

Cost Function 3: Transmission Loss Reduction

$$h_j(a) = \sum_{\tau\in[t_0,t_f]} \sum_{i\in\mathcal{V}_j(a)} \tilde{e}_{i\to j}(a,\tau)$$

Transmission Loss $\tilde{e}_{i\to j}(a,\tau)$



To reduce the transmission losses h_j **(choosing neighbor grids)** ⇔ **To reduce the temporal variability** f_j **(choosing grids in wider area)**

Trade-off

Grid $j \in \mathcal{R}$ **: maximize**

$$W_j(a) = -w_j(w_f f_j(a) + w_g g_j(a) + w_h h_j(a))$$

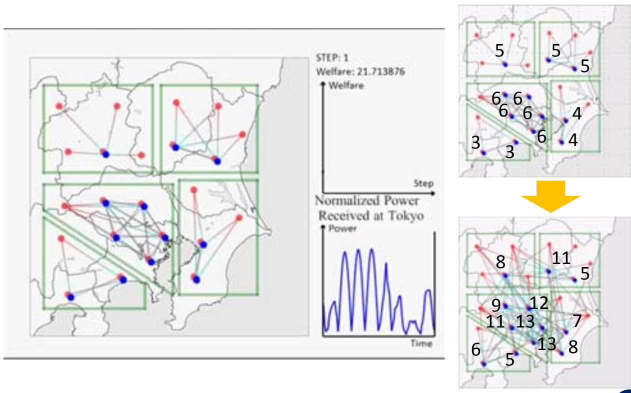
w_j, w_f, w_g, w_h **: positive scalar weighting coefficients**

Problem: Maximize the global objective function ?

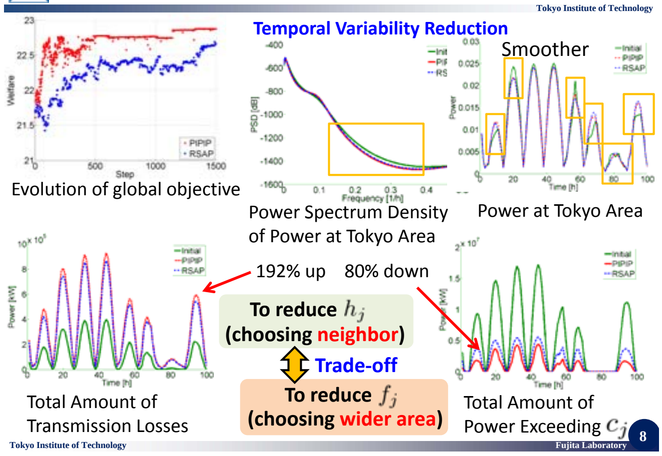
$$W(a) = \sum_{j\in\mathcal{R}} W_j(a)$$

➡ **Solution**: Potential Game with $\phi = W$ (marginal contribution)

Research Result[1,2]: Simulation Movie (PIPIP)

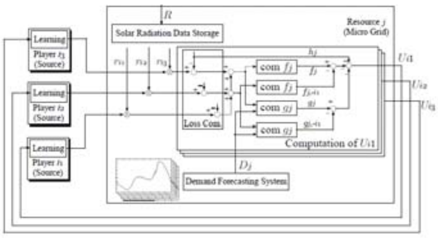


Research Result[1,2]: Simulation Analysis



Research Result [1,2]: Distributed Info. Processing

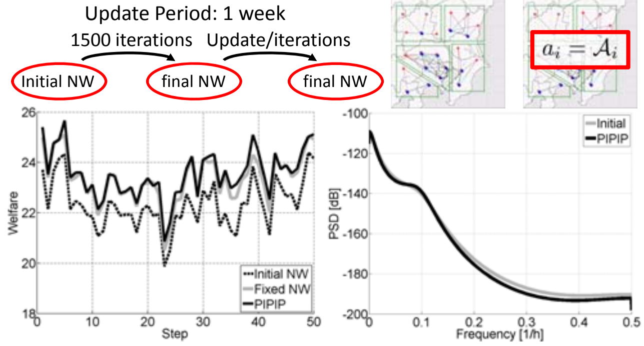
Radiation Forecasting
Technology



- Each $j \in \mathcal{R}$ does not need to know demand of other grids $(D_{j'})_{j' \neq j}$
- $i \in \mathcal{V}$ needs to communicate a scalar value only with $j \in a_i$
- $j \in \mathcal{R}$ needs to communicate a scalar value only with $i \in \mathcal{V}_j(a)$

Research Result [2]: Receding Horizon Control

Setting Data: 1 year-data from 2010/8
Update Period: 1 week

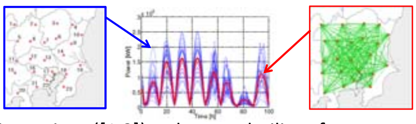


Evolution of global objective

Power Spectrum Density
of Power at Tokyo Area

Research for Photovoltaics: Future Works*

(I) Guarantees on PV Generator: Quality of Energy



This seminar ([1,2]) reduces volatility of photovoltaic generators via Network Formation

➡ But, need guarantee of more volatility reduction for isolated generator

(II) Collaboration with other primary generators

(III) EMS in a smart gird: Frequency/Voltage Control

➡ Kato's research project (cf. FL12-9-1)

What is my next research? ➡ Battery Management