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Optimal Pump and Inverter Control for Drinking Water and Wastewater Treatment Systems

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Outline

1. Introduction
2. Problem formulation
3. The concept of the optimization for searching optimal solutions
4. The previous method for searching decomposition points
5. The proposed method for searching decomposition points
6. A numerical example for inverter controlled pumps
7. Concluding remarks

1. Introduction

"Regulation relating to the energy savings" has been revised.
April/1/2003

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Treatment plants for drinking water and wastewater are designated as type1&2 designated energy management factory.

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Requirements for energy savings of pumps and blowers of plants.

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Solution: Realization of the energy savings using inverter controlled pumps.

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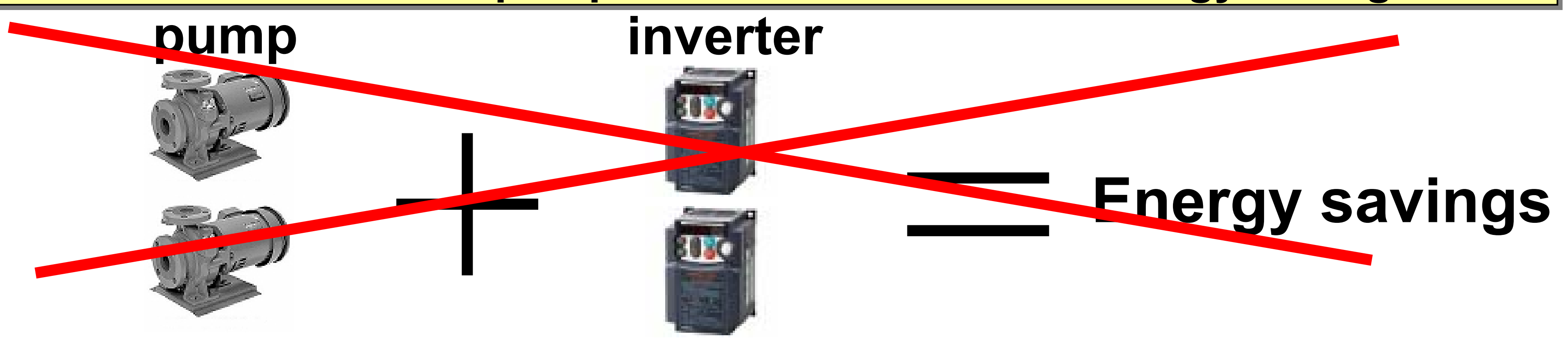
If a treatment plant has a inverter controlled pump, realization of the energy savings might be easy.
However, multiple inverter controlled pumps?

Are inverter controlled pumps best solution for the energy savings?

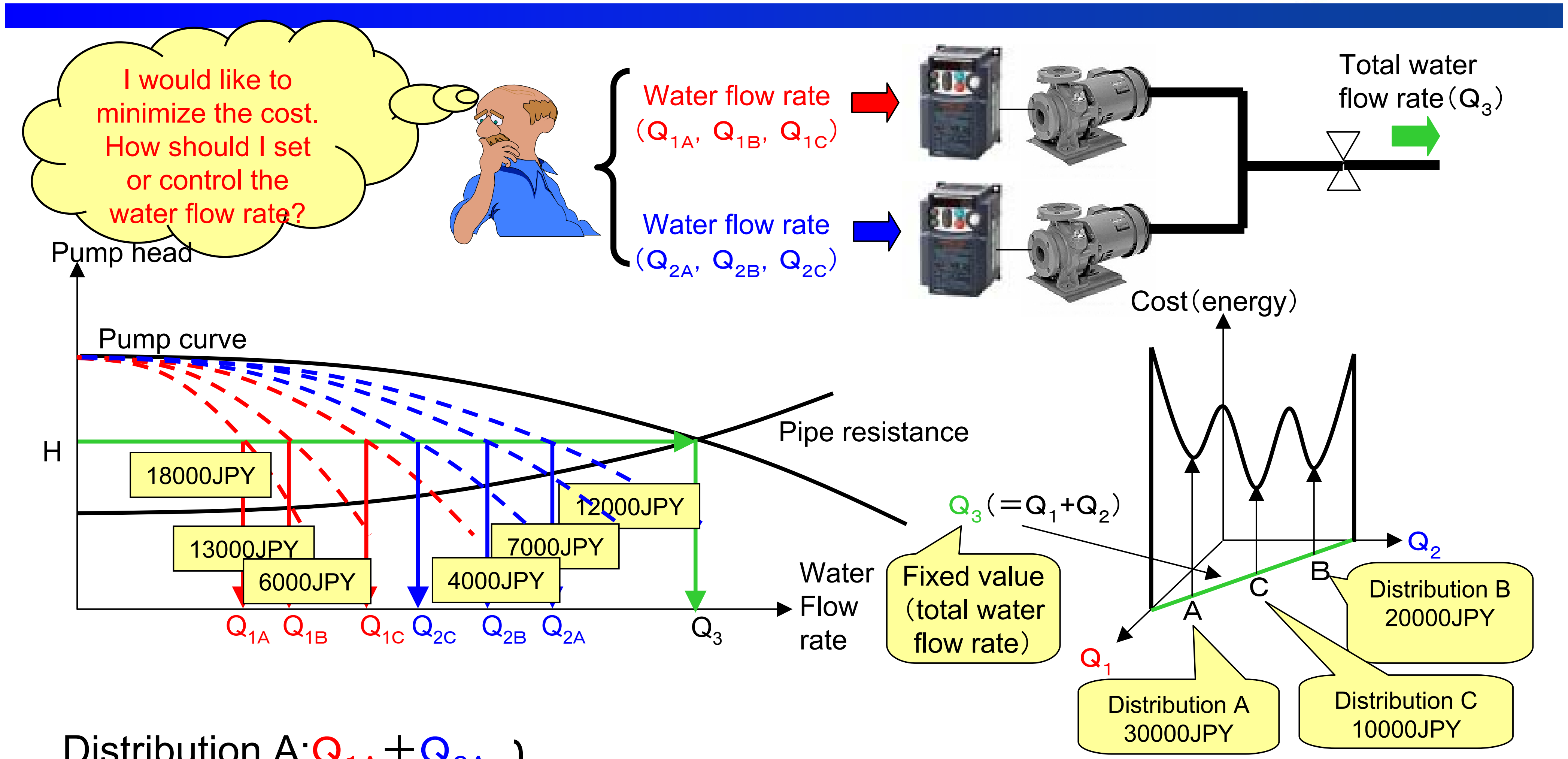


When the multiple pumps are controlled by the multiple inverters, the energy of the all pumps depends on the distribution of the water flow rate. If we set unfit water flow rate, we can not realize the energy savings.

We have to optimize the water flow rate to minimize the total energy of the pumps.

We propose a new optimization method to realize real energy savings.

Water flow rate control of the multiple inverter controlled pumps



$$\left.\begin{array}{l}\text{Distribution A:}\ Q_{1A}+Q_{2A}\\ \text{Distribution B:}\ Q_{1B}+Q_{2B}\\ \text{Distribution C:}\ Q_{1C}+Q_{2C}\end{array}\right\} = Q_3$$

Distribution C realizes the real energy savings.

2. Problem formulation

e-Front runners

Consider the following optimization problem.

$$\min\{c(x) : x \in \Re^n\}$$

- **C(x) is assumed to be a bounded smooth function**
- **Global minimal solution exists and the number of local minimal solutions are finite.**

Our approach for searching multiple local optimal solutions：
We transform the optimization problems into nonlinear dynamics and solve the problem.

Optimization Problems and Nonlinear Dynamics

Optimization Problems	⇔	Nonlinear Dynamics
Objective function	⇔	Vector field
Local optimal solution	⇔	Stable equilibrium point (SEP)
Global optimal solution	⇔	Stable equilibrium point
Saddle points on the ridge of the objective function	⇔	Decomposition point, Type I unstable equilibrium point (UEP)
Convergence region	⇔	Stability Region
Boundary of the convergence region	⇔	Stability Boundary

Find multiple stable equilibrium points
⇒Find multiple local optimal solutions

3. The concept of the optimization for searching optimal solutions

e-Front runners

The concept has been proposed by Prof. Chiang at Cornell in 1996.

Find multiple local optimal solutions.

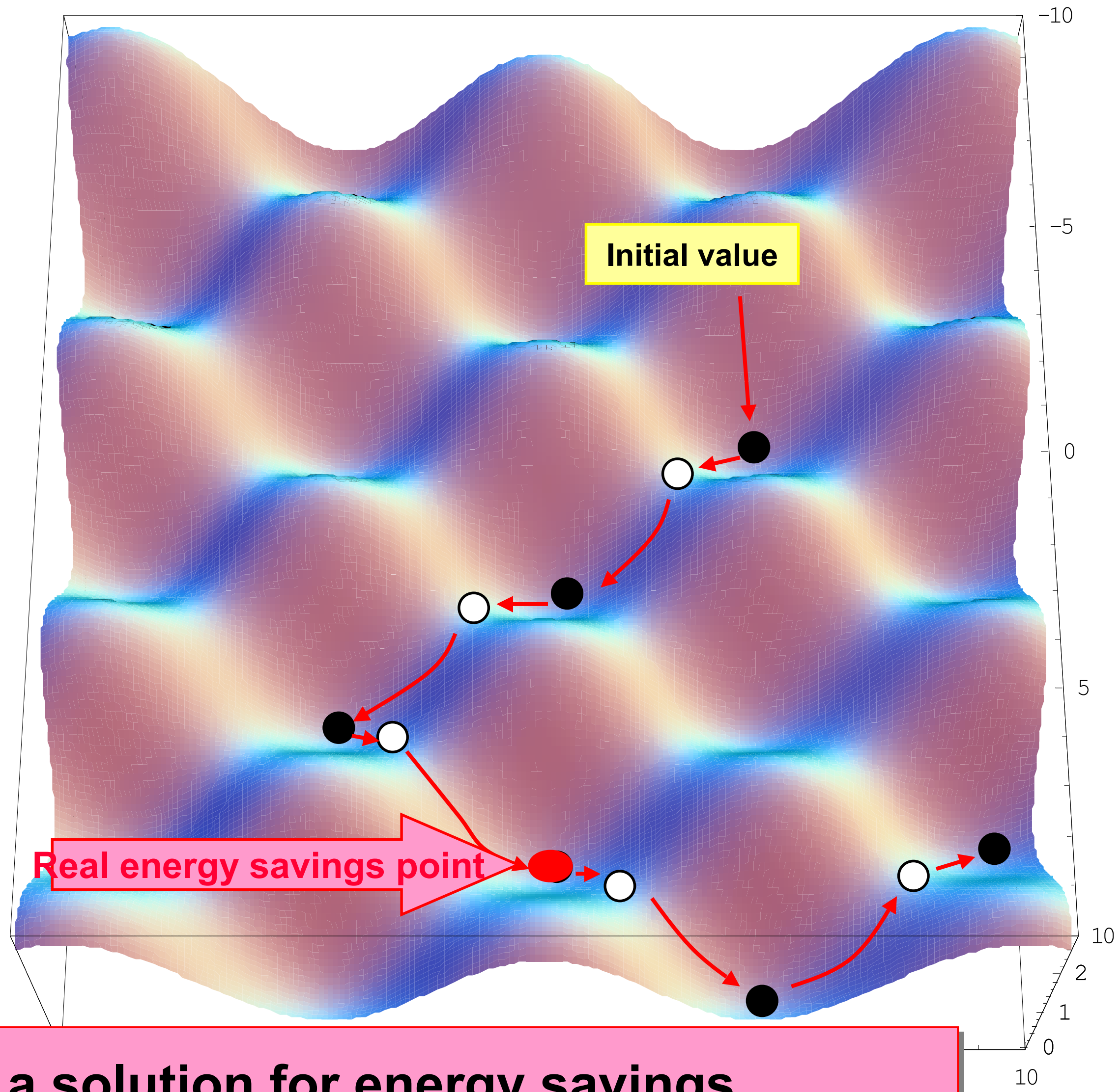
Significant two search steps:

STEP1:
A local search from a white point (or an initial point) to a black point.

○ ⇒ ●

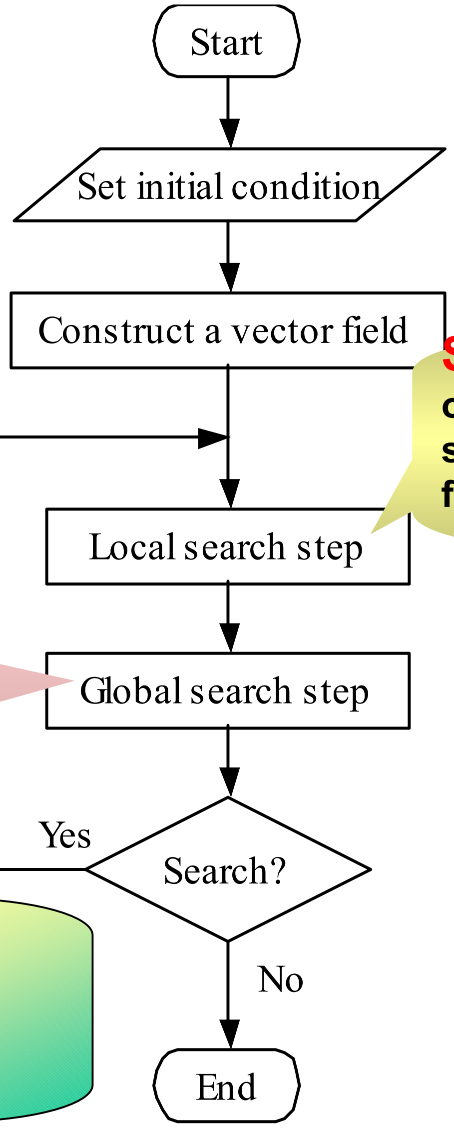
STEP2:
A global search from a black point to a white point.

● ⇒ ○



This method can search a solution for energy savings.

2-STEP for finding multiple local optimal solutions



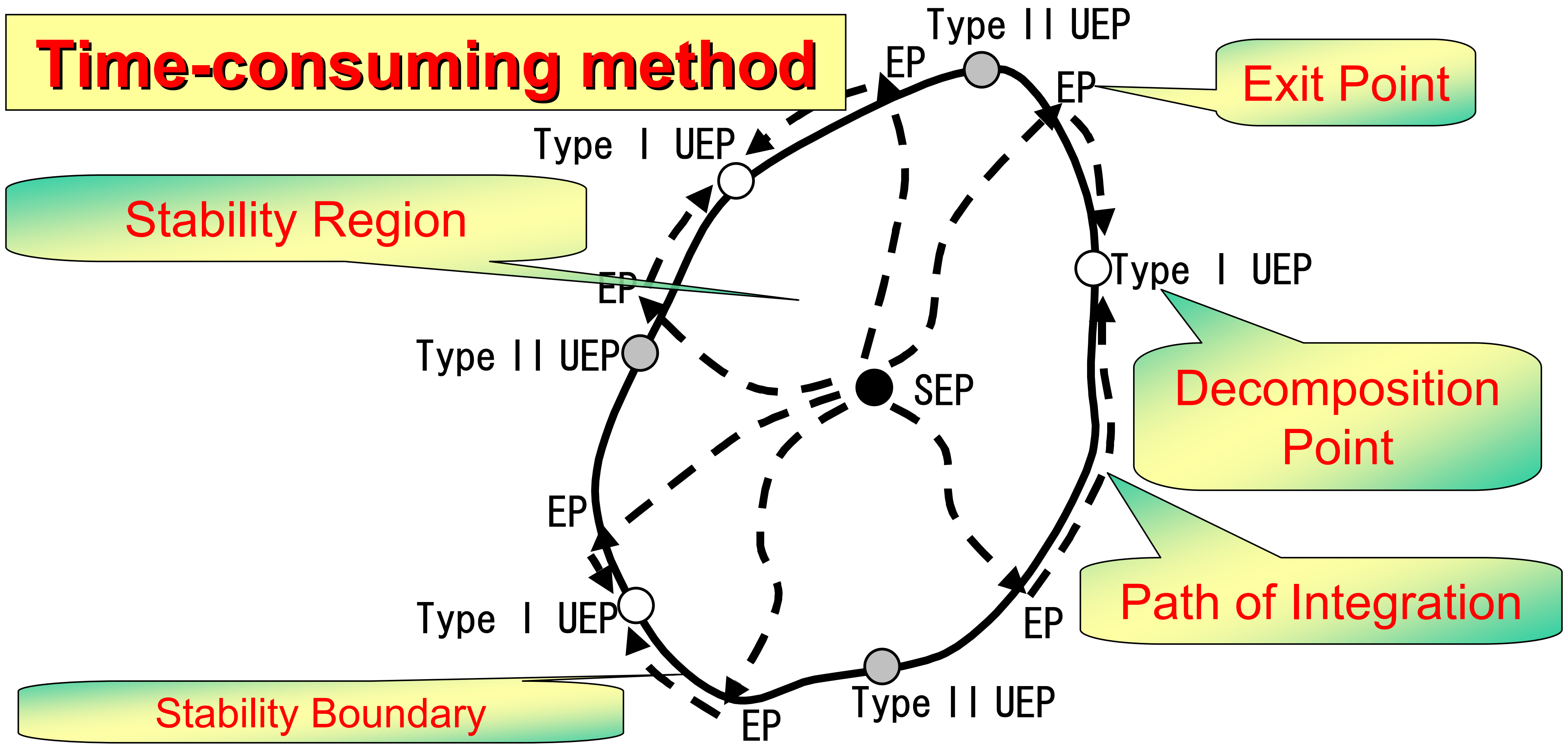
STEP 1: Approach one of the local optimal solutions by a certain local search method in the constructed vector filed.

STEP 2: Escape from a stability region of the obtained local optimal solution of the STEP 2 via a decomposition point and approach another local optimal solution by moving along the opposite direction of the unstable manifold of the decomposition point

Challenging Task

4. The previous method for searching decomposition points

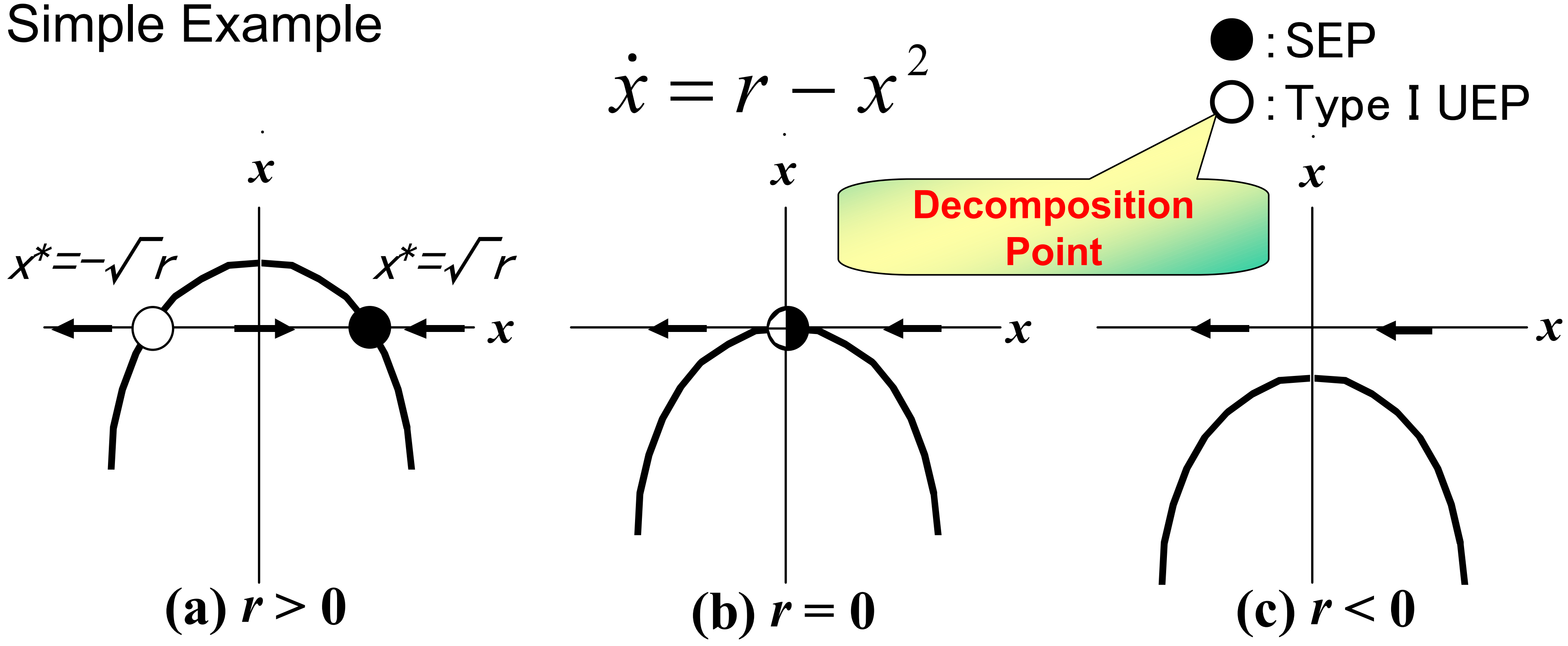
This method has been proposed by Chiang in 1996.



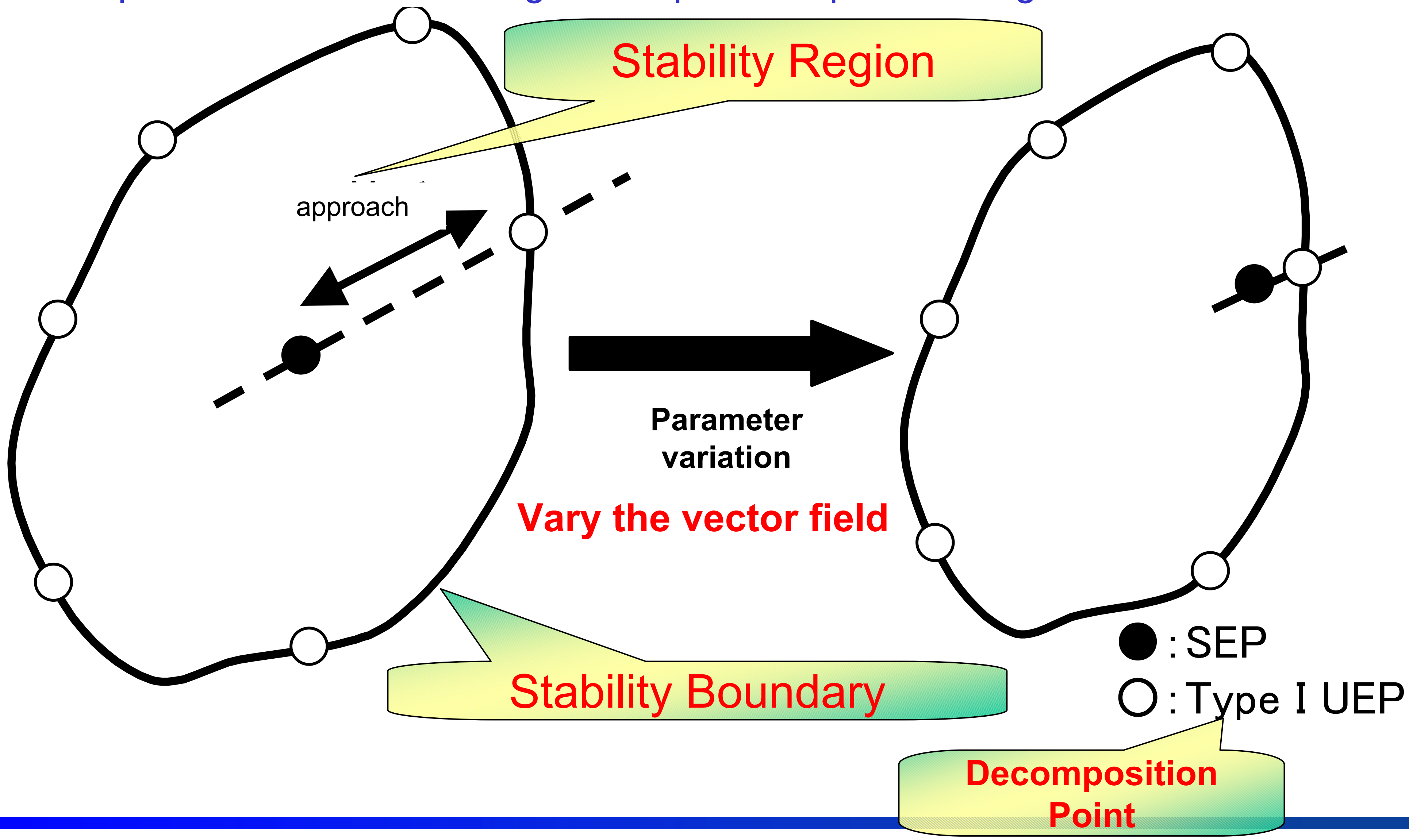
Parameter dependence of the vector field (Bifurcation)

Simple Example

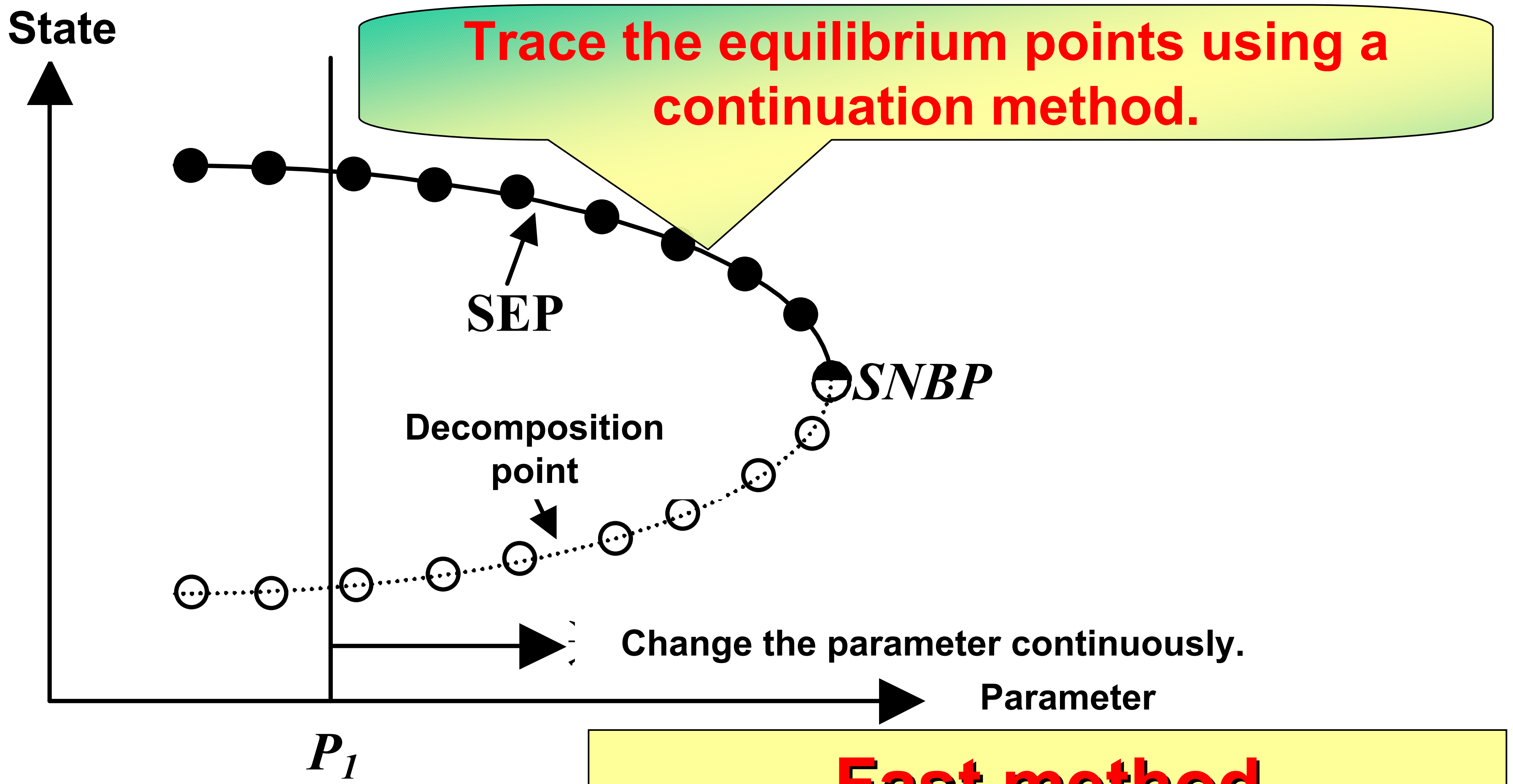
$$\dot{x} = r - x^2$$



The Proposed method for finding decomposition points using the bifurcation



Bifurcation Diagram



Fast method

6. A numerical example for inverter controlled pumps

Minimize:

$$P_v = \sum_{i=1}^{N} \frac{\gamma_{3i} x_i^3 + \gamma_{1i} x_i}{\alpha_{2i} x_i^2 + \alpha_{0i} + x_i \sqrt{\beta_{4i} x_i^2 + \beta_{2i}}}$$

Subject to:

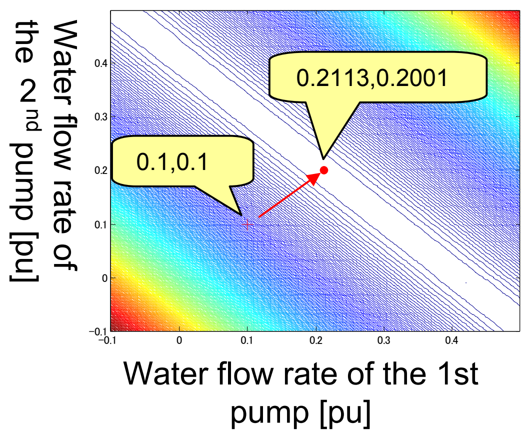
$$\begin{cases} Q_T = \sum_{i=1}^{N} x_i \\ x_i \geq 0 \end{cases}$$

P_v:pump energy
x_1:ith pump water flow rate
Q_T:total pump water flow rate
The others: pump constants

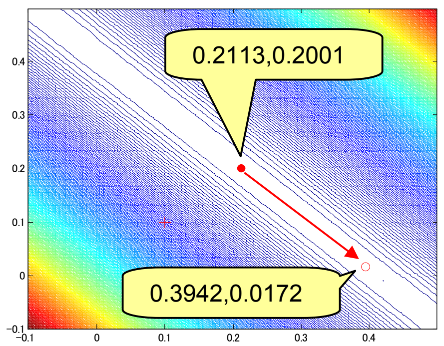
Constants (standard):

The number of the pumps: N=2
Rated pump water flow rate Q_{0_total}=11196[m^3/h]
Rated water head H_{0_total}=14[m]
Actual water head h_a=10.47[m]
Constant of the pipe resistance h_r=10.67[m]
Each pump water flow rate Q_{total}=4608[m^3/h]
($Q_{pu\_total\_total}$= 0.4116[pu])
Motor efficiency η_{m_i}=94[%]（i=1,2）
Inverter efficiency η_{i_i}=97[%]（i=1,2）

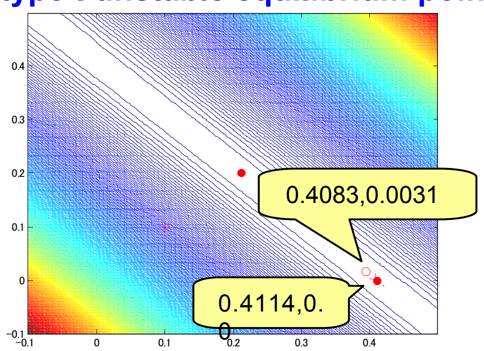
Search 1st optimal solution from the initial condition.



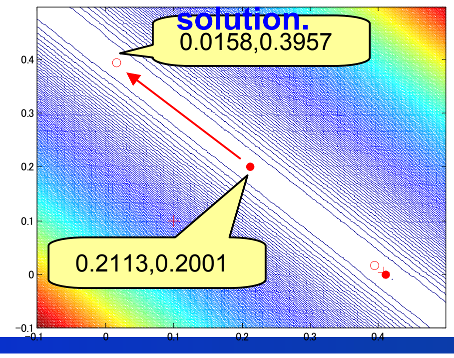
Search 1st type-I unstable equilibrium point from the obtained optimal solution.



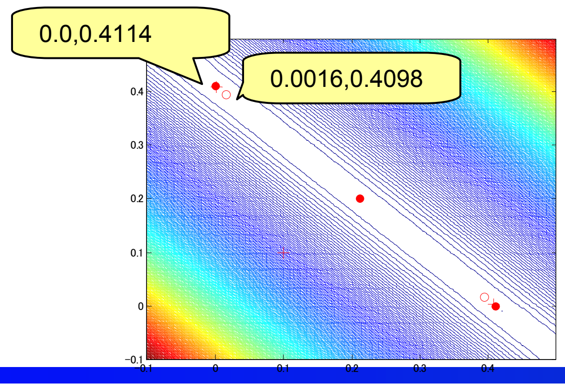
Search 2nd optimal solution from the 1st type-I unstable equilibrium point.



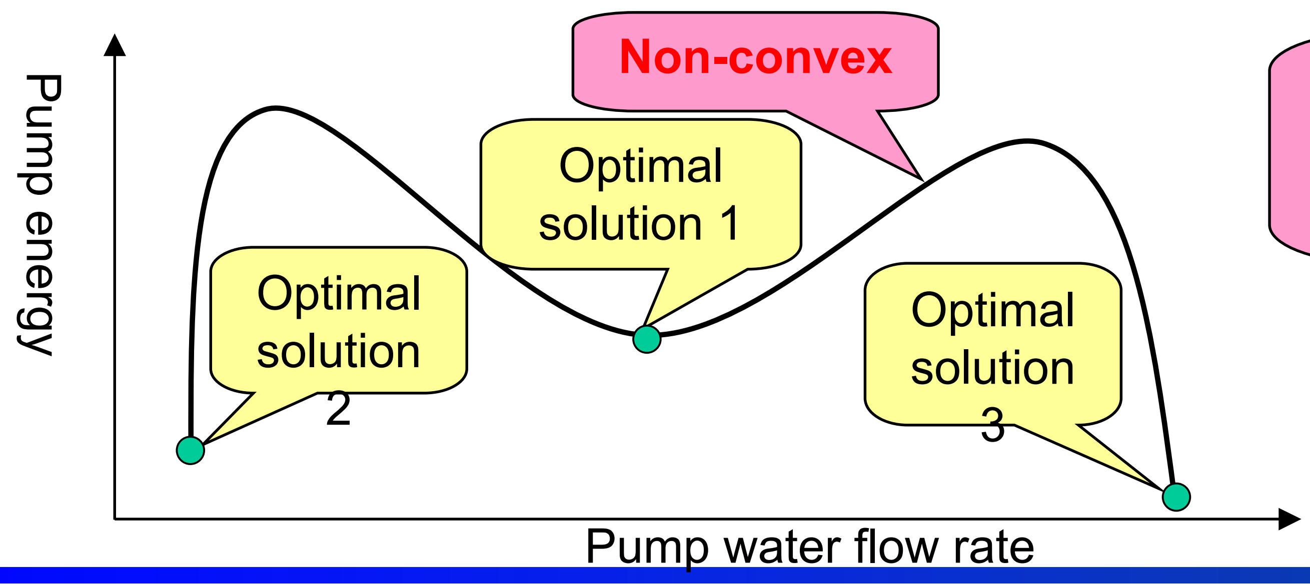
Search 2nd type-I unstable equilibrium point from the obtained optimal solution.



Search 3rd optimal solution from the 2nd type-I unstable equilibrium point.



No.	Water flow rate	Pump energy	Remarks
Optimal solution 1	No.1 pump:2367[m^3/h] (0.2113pu) No.2 pump:2241[m^3/h] (0.2001pu) Total water flow rate: 4608[m^3/h]	213.8[kW] (100%)	No.1 pump: running No.2 pump: running
Optimal solution 2	No.1 pump: 0.0[m^3/h] No.2 pump: 4608[m^3/h] (0.4114pu) Total water flow rate: 4608[m^3/h]	179.7[kW] (84.05%)	No.1 pump: shutdown No.2 pump: running
Optimal solution 3	**No.1 Pump: 4608[m^3/h] (0.4114pu)** **No.2 pump: 0.0[m^3/h]** **Total water flow rate: 4608[m^3/h]**	**170.5[kW]** **(79.75%)**	**No.1 pump: running** **No.2 pump: shutdown**



We usually select optimal solution 3. We also select other optimal solutions.

7. Concluding remarks

The paper presented the systematic optimization method based on topological and geometric properties of the objective function for obtaining multiple local optimal solutions of the inverter controlled pumps.

The proposed method has ability to search multiple local optimal solutions systematically and guarantees at least local optimality of the obtained solutions mathematically.

For the purpose of illustrating the proposed method, the inverter controlled two-pump system is studied numerically. The three local optimal solutions are obtained, and one of the obtained solutions leads the lowest energy.

The numerical results have shown the effectiveness of the proposed method.

Application to the practical drinking water and wastewater treatment systems is the future work.