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Total Optimization of Smart Community by Differential Evolutionary Particle Swarm Optimization

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Abstract: This paper proposes a total optimization method of a smart community (SC) by Differential evolutionary particle swarm optimization (DEEPSO). Various sectors of SC models such as an electric utility model, an industry model, and a building model are utilized in this paper. Whole of a SC is optimized in order to minimize energy costs, shift electric power load peak at high load hours, and minimize total CO_2 emission of the SC using the models. The simulation results by the proposed method are compared with those by Particle swarm optimization (PSO), Differential Evolution (DE), and Evolutionary particle swarm optimization (EPSO) based methods.

Keywords: Energy management systems, Optimization problems, Heuristic searches, Renewable energy system, Energy storage, Gas turbines, Boilers.

1. INTRODUCTION

Recently, although there are many environmental problems, global warming is one of the main issues in the world. One of the causes for the global warming is increase of greenhouse gas emission. Since efficient utilization of energy is necessary for reduction of the emission, SC demonstration projects have been conducted all of the world in order to reduce the CO_2 emission (Ministry of Economy, Trade, and Industry of Japan, 2014, Xcel Energy, 2007, Jaber, 2006). Using renewable energies such as solar and wind power generation, storage batteries, and recent information technologies, SC can realize a sustainable and low carbon emission community. All of countries attending UN climate change conference 2015 (COP21) reset its goal to reduce the amount of CO_2 in 2015. The importance of SC increases all over the world because reduction of the amount of CO_2 emission is recognized again at the COP21. In Japan, especially after Great East Japan Earthquake, introduction of SC considering CO_2 emission reduction has been investigated in Tohoku area (Tohoku Bureau of Economy, Trade and Industry, 2012). SC should be evaluated by models because it is difficult to evaluate how much the communities can reduce CO_2 emission in actual SCs. Various models have been developed at each sector such as an electric power utility, a natural gas utility, drinking water and waste water treatment plants, industries, buildings, residences, and railroads. Static models considering various energy balances and dynamic models considering transient phenomenon have been developed in various sectors (Marckle, et al., 1995, Henze, 2000, Suzuki, et al., 2012, Makino, et al., 2015). However, the models, which can calculate energy consumption and environmental loads among all of the sectors in SC considering communication among various sectors, had not been developed yet. Therefore, SC models have been developed in Japan so that they can evaluate energy costs or the amount of CO_2 emission of the whole SC (Yamaguchi, et al., 2015, Matsui, et al., 2015). However, the whole SC had not been optimized using the models yet. The authors have proposed total optimization of whole SC which minimizes energy costs and electric power loads at high load hours namely, peak load shifting by PSO (Sato, et al., 2016a) and DE (Sato, et al., 2016b), and reduction of search space considering not only facility characteristics, but also load and cost characteristics and continuity of weekday operation. However, there are rooms for improving solution quality and the optimization does not consider CO_2 emission reduction. Considering these background, this paper proposes total optimization of SC by DEEPSO considering reduction of search space to reduce energy costs, shift electric power at high load hours, and reduce CO_2 emission. The results by the proposed method are compared with those by PSO, DE, and EPSO (Miranda, et al., 2006) based methods.

2. SMART COMMUNITY

2.1 Concept of the Whole Smart Community (Yasuda, 2015)

SC models have been developed so that they can calculate energy costs and the amount of CO_2 emission in the SC. Various sectors are included in the model such as an electric power utility, a natural gas utility, drinking water treatment and waste water treatment plants, industries, buildings, residences, and railroads (see fig.1). The sectors of the SC models can be divided into supply-side and demand-side groups. The model can calculate energy flows among various sectors, energy costs, and the amount of energy supply, demand, and the amount of CO_2 emission in the whole SC.

2.2 Energy Supply Models (Yamaaguchi, et al., 2015)

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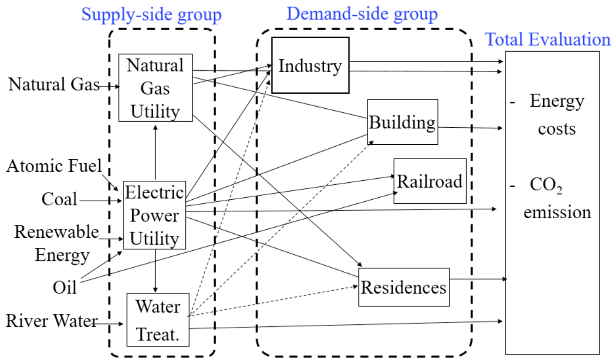

Fig. 1. A Configuration of a smart community model.

An electric power utility, a natural gas utility, and drinking water treatment and waste water treatment plants models are included in the supply-side group (see fig.1). The supply-side group models supply electric power, natural gas, and drinking water to the demand-side models interactively. The amount of each energy in supply-side sectors should supply the same amount of each energy consumption for demand-side sectors. The natural gas supply model can be treated as a natural gas energy source. Namely, required amount of natural gas by various demand-side sectors is supplied for the model. There are some methods for generating electric power: nuclear power, thermal power, hydroelectric power, and renewable energy generation. Energy costs and amount of CO_2 emission of the power generation plants can be calculated using the model. Since the community can purchase power generation fuels from outside of the community, the model can calculate fuel costs. Using the model, the amount of renewable energy and hydroelectric power generation output can be input per an hour as fixed numerical values. Summation of ratios of these power generation plants are set to 1. The average value of the

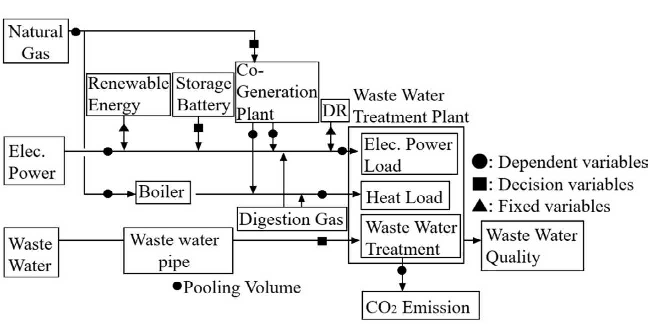

Fig. 2. A Configuration of a waste water plant model.

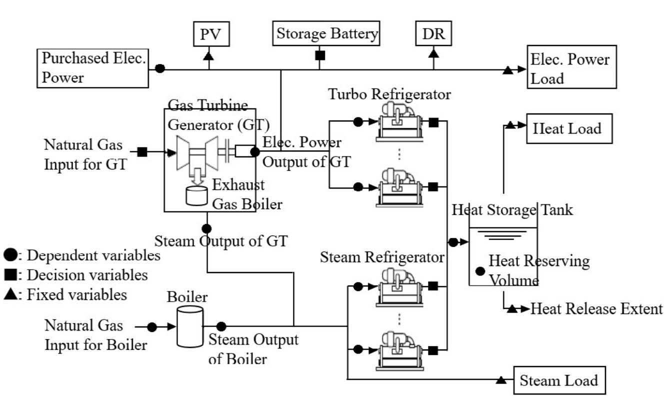

Fig. 3. A Configuration of an industrial model.

generation unit price with the generation unit price of each generation, the amount of each generation output, and ratio of each generation can be calculated using the model. Therefore, the model can evaluate the best ratio of the generation units for the total load of energy consumption models. The amount of water demands, the amount of renewable energy generation, and the amount of required demand response (DR) are set as fixed variables in the drinking water treatment plant model. In the waste water treatment plant model, the amount of inflow, the amount of renewable energy generation, and the amount of required DR are set as fixed variables (see fig.2).

2.3 Energy Consumption Models (Matsui, et al., 2014)

Industrial, building, residential and railroad models are included in the demand-side group. The models work interactively with energy supply models. Energy supply facilities and various energy loads are treated in energy consumption models. The energy supply models supply primary energies to the energy supply facilities and the energy supply facilities supply secondary energies to various energy loads. Therefore, if various hourly load values of one day (24 points) are given, the energy supply model supply required primary energy values. The industrial model deals with various energy facilities, a solar power system, a storage battery, and required DR amount (see fig.3). Large buildings and large shopping malls are treated as the building model. The building model has energy supply facilities like the industrial model and offices and shopping malls are treated as energy loads. In addition, the model treat hourly loads of various energies and the amount of required DR. Condominiums and detached houses are treated as the residential model. Both of condominium and detached house are treated with one model with different input data. A storage battery, a heat pump water heater, a heat storage tank, a fuel cell, a tank less water heater, and a natural gas stove are treated in the model. Electric power, hot water, and heat energies are supplied by these facilities.

3. PROBLEM FORMULATION OF TOTAL OPTIMIZATION OF WHOLE SMART COMMUNITY

3.1 Decision Variables

Decision variables are as follows:

(a) Drinking water treatment plant model: the amount of river inflow, the amount of water inflow to a service reservoir, the amount of electric power output by a co-generator, the amount of charged / discharged electric power of a storage battery.

(b) Waste water treatment plant model: the amount of waste water pumping to the waste water treatment plant, the amount of electric power output by a co-generator, the amount of charged / discharged electric power of a storage battery.

(c) Industrial model: the amount of electric power output by a gas turbine generator, the amount of heat output by turbo refrigerators, the amount of heat output by steam