THE OPTIMAL SCHEDULING OF A CAMPUS MICRO-GRID WITH CHP AND STORAGE DEVICES

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ABSTRACT

The MG is a relatively small-scale power system operated in either grid-connected or island modes. Recently, MGs using CHP systems is much interested. This paper deals with the optimization technique of campus MG that supplies energy for heat and power. A two stage optimization method using MILP is presented for MG real time dispatch.

I. INTRODUCTION

A micro grid(MG) refers to a group of interconnected loads and distributed energy resources (DERs) that acts as a single controllable entity with respect to the power grid [1]. The MG is a relatively small-scale power system operated in either grid-connected or island modes. MGs differ from traditional power grids by providing a closer between power suppliers and consumers, resulting in efficiency increases and transmission line reductions. The primary purpose of the MG power management is not only to ensure stable delivery of power to its local load customers but also to optimize power production cost.

MGs have its own loads and integrate with DERs such as solar, wind power, small hydro, and combined heat and power (CHP) systems. Recently, MGs using CHP systems is much interested . The primary motivation for installing CHP units is providing electrical and thermal energy, simultaneously. MG with CHP will not only result in the improvement of overall system efficiency but also reduce in the cost of thermal energy generation.

The intermittency of renewable energy sources raises the problem about the power balance control and reliable operation of MG. Energy storage systems(ESS) is a device which contributes to the stable operation of MG and shifting the load [1].

For optimal operation, generally, the charging and discharging time of the ESS is important, which is determined according to a day-ahead scheduling. ESS usually charge energy during off-peak hours and discharge it during peak-load hours to reduce the total cost. The day-ahead scheduling refers to making short-term generation plans based on forecasted load and renewable sources. A day-ahead deterministic scheduling is presented to minimized the operational cost of MG, but real time corrective dispatch is required because of unpredictable changes of MG like renewable source and load. Several methods have been reported on MG real-time dispatch which presents a heuristic dispatch method, the mesh adaptive direct search technique, An agent-based energy management technology, and a two-layer model. [2]

This paper deals with the optimization technique of campus MG that supplies energy for heat and power. The MG comprises PV, CHP, ESS, thermal storage tank(TST), power grid as well as electricity and heat demand as shown Fig. 1.

A two stage optimization method is presented for MG real time dispatch. The first stage determines hourly unit commitment of the distributed energy resources and energy storage device via a day-ahead scheduling. The second stage conducts re-dispatch of the resources, devices, and energy trading via a real-time scheduling.

The numerical simulations for the campus MG are provided and discussed about the impact of the most important parameters. It is shown that energy cost saving can be achieved through integrated scheduling.

II.ENERGY MAMAGEMENT FRAMEWORK

System architecture and functions

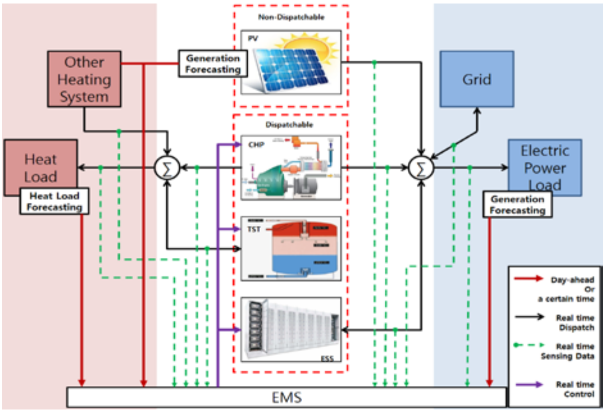

Figure 1 Schematic Diagram of MG

The system architecture of the MG is shown in Fig. 1. This MG is made of PV energy source, an energy consumer, an energy storage system based on battery and hot water and a connection to an electric utility to which the MG can buy and sell energy.

Generally, photovoltaic power generation are controlled to operate at its maximum power point, which is affected by different natural conditions. In this paper, it is assumed that the maximum output of these devices cannot be regulated. Therefore, the generation are considered to be negative loads.

The power and heat generation of the CHP are dependent and could not be controlled separately. There are the feasible operation regions of the CHP as two-dimensional polygons. In this paper, heat-power feasible region of CHP is considered as the constraints in the dispatch process. As CHP releases waste heat, TST is utilized to store the waste heat. TST constraint is taken into account of dispatch strategy. TST to cooperate with CHP and boiler must supply heat energy to meet heat load demand in MG.

One of the demand side management consists of time-of-use (TOU) prices, where customers are charged differently depending on the time of the day. There might be a difference between the buying and selling prices.

The state of charge(SOC) of the ESS prevents overcharging and undercharging of the battery. In this paper, the SOC should be maintained between 10% and 90% to prolong the ESS life. The SOC value at time t is determined by SOC value at time t-1. To control and operate the distributed ESS in an autonomous micro-grid in a cost-effective way, the charging / discharging efficiency needs to be taken into consideration.

The hot water is generated by the CHP and boiler and is used at dormitories and restaurants etc. The volume of the water in the thermal storage tank is constant but quantity of heat is different depending on incoming water temperature and hot water demand. The operational scheme of TST is similar to that of ESS.

III. ENERGY MANAGEMENT MODEL

This section describes the cost function and the constraints for energy management model of MG.

Objective Function

The objective of combined heat and power economic dispatch problem is to optimize the production cost through optimal power and heat production satisfying all inequality and equality constraints so as to meet to the power and heat demand of the MG.

In the paper, the cost function of the MG includes the operational cost for CHP and boiler, as well as cost of buying energy from the grid in the grid-connected mode or not. The corresponding OF can be mathematically stated as follow:

$$\mathrm{OF} = \sum_{t=1}^{96} \{ C_t^{CHP}(P_t^{CHP}, Q_t^{CHP}) + C_t^{GRID}(P_t^{GRID}) + C_t^{BOIL}(Q_t^{BOIL}) \}$$

Where C_t^{CHP} is the cost of CHP at t, $C_t^{GRID}$is the cost of buying and selling from grid at t, C_t^{BOIL} is the cost of boiler at t. Time, t is discretized into slots as indicated by 0, 1, …, 96. Each slot has a duration of 15 minutes.

The objective function can be calculated the sum of the cost obtained from every 15-minutes over 24-hour time.

Electrical Energy Storage Device

The storage device is generally charged when electricity is cheaper and is discharged when electricity is expensive, or the fluctuation of renewable energy or load demand is occurred. Energy balance constraint of the storage device can be explained as;

$$\mathrm{B}_{\mathrm{t}}^{\mathrm{ESS}} = \mathrm{B}_{\mathrm{t-1}}^{\mathrm{ESS}} + \eta_{\mathrm{cha}} \cdot \mathrm{P}_{\mathrm{t,cha}}^{\mathrm{ESS}} \cdot \Delta\mathrm{t} - \frac{1}{\eta_{\mathrm{dis}}} \cdot \mathrm{P}_{\mathrm{t,dis}}^{\mathrm{ESS}} \cdot \Delta\mathrm{t}$$

where η_{cha} and η_{dis} are charging and discharging efficiency of the battery, respectively. $\Delta\mathrm{t}$ is the duration of charging or discharging in 15 minute. $\mathrm{SOC}_{\max}(\mathrm{B}_{\max}^{\mathrm{ESS}})$ and $\mathrm{SOC}_{\min}(\mathrm{B}_{\min}^{\mathrm{ESS}})$ are the upper and lower boundaries for the state of charge of the battery. The initial SOC of the battery at the beginning time of day-ahead schedule on any day should be kept at the same value. $\mathrm{P}_{\mathrm{t,cha}}^{\mathrm{ESS}}$ and $\mathrm{P}_{\mathrm{t,dis}}^{\mathrm{ESS}}$ are the amount of charging and discharging power, respectively. It should be noted that the battery does not charge and discharge simultaneously because of the additional and unnecessary cost of charge and discharge efficiency deterioration. Therefore, binary variables $\alpha_{\mathrm{t}}$and β_{t} are implemented to model the status of energy storage. [3]

$$\mathrm{B}_{\min}^{\mathrm{ESS}} \le \mathrm{B}_{\mathrm{t}}^{\mathrm{ESS}} \le \mathrm{B}_{\max}^{\mathrm{ESS}}$$

$$B_0^{ESS} = B_{96}^{ESS}$$

$$\alpha_{\mathrm{t}} \cdot \mathrm{P}_{\mathrm{cha,min}}^{\mathrm{ESS}} \le \mathrm{P}_{\mathrm{t,cha}}^{\mathrm{ESS}} \le \alpha_{\mathrm{t}} \cdot \mathrm{P}_{\mathrm{cha,max}}^{\mathrm{ESS}}$$

$$\beta_{\mathrm{t}} \cdot \mathrm{P}_{\mathrm{dis,min}}^{\mathrm{ESS}} \le \mathrm{P}_{\mathrm{t,dis}}^{\mathrm{ESS}} \le \beta_{\mathrm{t}} \cdot \mathrm{P}_{\mathrm{dis,max}}^{\mathrm{ESS}}$$

$$\alpha_{\mathrm{t}} + \beta_{\mathrm{t}} = 1$$

Where $\mathrm{P}_{\mathrm{cha,min(max)}}^{\mathrm{ESS}}$ and $\mathrm{P}_{\mathrm{dis,min(max)}}^{\mathrm{ESS}}$ are the constraints about charging and discharging. $\alpha_{\mathrm{t}} = 1(\beta_{\mathrm{t}} = 1)$means that the energy storage is charging (discharging) at time interval t.

Power and Heat balance

The supply and demand balance of electricity and heat energy are considered as follows:

$$P_t^D = P_t^{CHP} + P_t^{GRID} + P_{t,dis}^{ESS} - P_{t,cha}^{ESS} + P_t^{PV}$$

$$Q_t^{TST} + Q_t^{CHP} + Q_t^{BOIL} = Q_t^D$$

Where P_t^D is the power demand, P_t^{CHP} is CHP generation, P_t^{GRID} is the grid power, $P_{t,cha}^{ESS}$ and $P_{t,dis}^{ESS}$ is charging and discharging ESS power, respectively, P_t^{PV} is PV power. Q_t^D is the heat demand, Q_t^{TST}, Q_t^{CHP} and Q_t^{BOIL} are the heat from TST, CHP and boiler, respectively.

CHP Units

It should be mentioned that the power and heat generations of the CHP units are dually dependent and could not be controlled separately. The total operation cost of a CHP unit could be defined as [3]

$$C_t^{CHP} = a_1 \cdot (P_t^{CHP})^2 + a_2 \cdot P_t^{CHP} + a_3 + b_1 \cdot (Q_t^{CHP})^2 + b_2 \cdot Q_t^{CHP} + c_1 P_t^{CHP} \cdot Q_t^{CHP}$$

Where P_t^{CHP}, and Q_t^{CHP} are electric and heat output respectively. $a_1, a_2, a_3, b_1, b_2,$ *and* c_1 are cost function coefficients of CHP units, which is function of both heat and power production of units. The cost model and the areas are differently modeled by CHP type, size and operation method. To simplify calculation and use MILP, the linearized variable costs in each area are formed as follows: [4]

$$C_t^{CHP} = a_2 \cdot P_t^{CHP} + b_2 \cdot Q_t^{CHP} + a_3$$

$$\gamma_t \cdot P_{min}^{CHP} \leq P_t^{CHP} \leq \gamma_t \cdot P_{max}^{CHP}$$
$$\gamma_t \cdot Q_{min}^{CHP} \leq Q_t^{CHP} \leq \gamma_t \cdot Q_{max}^{CHP}$$

where $\mathrm{P}_{\mathrm{min}}^{\mathrm{CHP}}$ and $\mathrm{P}_{\mathrm{max}}^{\mathrm{CHP}}$ are the maximum and minimum power generation. $\mathrm{Q}_{\mathrm{min}}^{\mathrm{CHP}}$ and $\mathrm{Q}_{\mathrm{max}}^{\mathrm{CHP}}$ are the maximum and minimum heat production. γ_t is an integer variable whether CHP is running.

Grid

The price of electricity from the energy market is obtained from utility. The price has three different values in each day, which is ₩76.1/kWh during the peak hours 10-12 and 13-17, ₩64.8/kWh during the mid-peak hours 09-10, 12-13 and 17-23, and ₩57.4/kWh during the remaining off-peak hours.

$$C_t^{GRID} = e_1 \cdot P_{t,buy}^{GRID}$$

Boiler

The boiler would be used to satisfy the thermal demand of the consumers.

$$C_t^{BOIL} = d_1 \cdot Q_t^{BOIL}$$

$$\delta_t \cdot Q_{min}^{BOIL} \leq Q_t^{BOIL} \leq \delta_t \cdot Q_{max}^{BOIL}$$

Where, d_1 is unit cost. Q_{min}^{BOIL} and Q_{max}^{BOIL} are the limited constraints.

Load demands

The forecasted demands are the hourly electricity consumption data of a University in Korea for typical spring week [5]. Its maximum power is scaled to be 1.2MW. The real-time demands are randomly generated from the forecasted data. with zero-mean errors which follow uniform distributions

PV

The output power of a PV cell changes with solar intensity and environment temperature, but there is only one maximum power point(MPP) for a specified situation. A PV system usually uses the maximum power point tracking(MPPT) to make PV module work at MPP in a varying environment. The predicted value of the PV source's active power of MG in the specified period is defined as

$$PV = [P_1^{PV}, P_2^{PV}, \cdots, P_{96}^{PV}]$$

Thermal Storage Tank

The thermal storage tank is a heat storage device to get heat from the CHP units and the boiler units. Hence, the available heat in the thermal storage tank H_t^{TST} could be calculated as [3]

$$H_t^{TST} = (1 - \eta_{TST}) \cdot H_{t-1}^{TST} + Q_t^{TST} \cdot \Delta t$$

where η_{TST} is the heat loss rate for the thermal storage tank. Moreover, the capacity of heat storage is restricted as

$$H_{min}^{TST} \leq H_t^{TST} \leq H_{max}^{TST}$$

In this paper, the practical state of heat storage system is simulated by considering the ramping rates as follows:

$$Q_{min}^{TST} \leq Q_t^{TST} \leq Q_{max}^{TST}$$

Q_{max}^{TST} and Q_{min}^{TST} is denote the ramping up and down capabilities for TST in a time period respectively. The heat system of the MG always maintained the same amount of water. When the customer used the hot water, the same amount of cold water fill in the heat system.

Operating strategy

Non-CHP generation units provide the required level of spinning reserve capacity to cope with system contingencies.

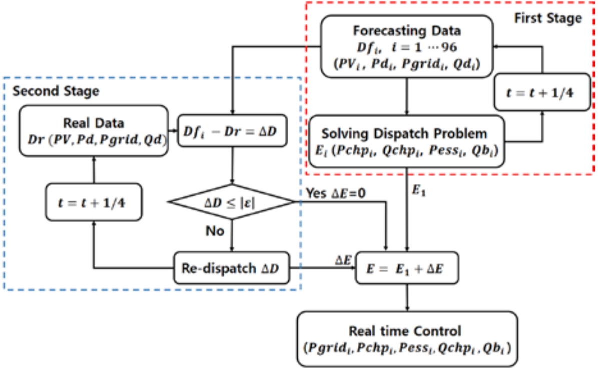

Figure 2 Two-Stage dispatch algorithm

The flowchart of the iterative algorithm is shown in Fig. * including the following two stages.

In the first stage, with the forecast of electricity and heat demand and PV output for next day, the optimal solution, E_1, is calculated every 15 minute for next 24 hours by minimizing the expected operating cost.

In the second stage, because of variations and uncertainties in the demand and PV supply, the real-time data may be different from the forecast data in the first stage. If the deviation between the real-time data and the forecast data is larger than a certain value(ε), the optimal solution is recalculated for the energy generation scheduling using the real-time data. And then the results is updated to E_1.

IV. SIMULATION STUDIES

In this section, Using the MG shown in Fig.1, the simulation results of optimal operation scheduling are presented. The MG contains PV, CHP, ESS, TST and boiler. The simulation has been implemented in GLPK mixed integer linear programming. Fig.3 and Fig.4 are the load profile and the PV generation profile, respectively. The Heat load is more flexible than power, thus it is not used in the second stage.

The real-time economic dispatch performed in the first stage aims to optimize the amount of energy generated, stored and traded based on one day-ahead forecast data.

The second stage optimization contributes to a higher operating cost compared to that when only the first stage optimization is applied. Depending on the mismatch between forecasting data and real time data, the CHP and ESS reserve is allocated. Using the reserve the mismatch value is re-dispatched.

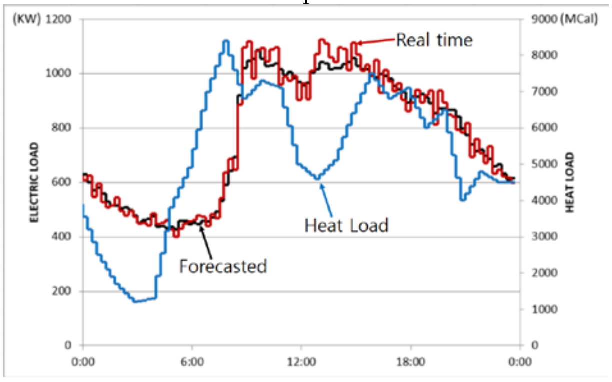

Figure 3 Load Profile

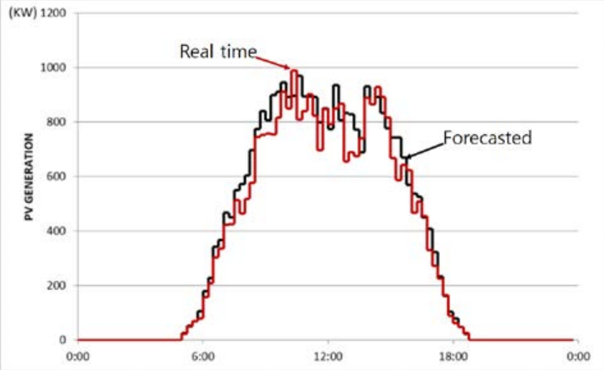

Figure 4 PV Generation Profile

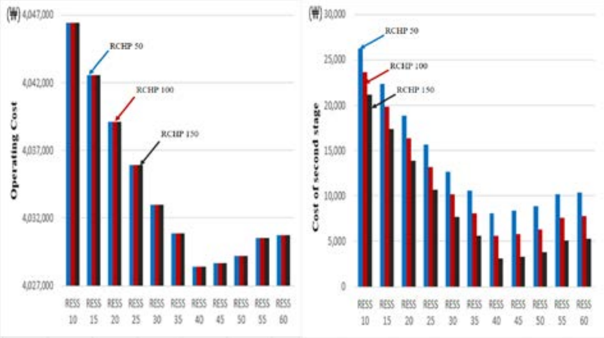

Figure 5 Cost of two stage dispatch

As shown in Fig.5, the cost of the second stage is decreased by increasing the reserve, but the cost of the first stage is increased.

Fig.6 shows outcome of real time scheduling of the MG for a day. In the day time, electric power is supplied to Grid because of PV generation. The CHP produce maximum power from 10AM to 10PM because the market price is high and PV power drop at 6 PM.

ESS is charged when electricity is cheaper and is discharged when electricity is expensive.

As day-ahead forecast errors of the demands and renewable generation are increased, the impacts to the generation schedule are reflected in the increase of the total operating cost.

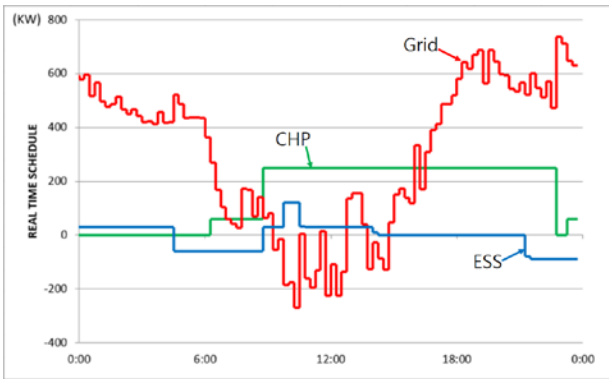

Figure 6 Real Time Scheduling

V. CONCLUSION

The dispatch strategy is able to minimize the operating cost of MG in real-time dispatch. A two stage model for MG real-time dispatch is proposed in this paper. The outcome of the simulation result demonstrates the effectiveness of the proposed real-time control and shows the possibility of autonomous operation of a MG. The simulation studies have shown that the performance of two stage real-time control depends on the reserve. The proposed real-time dispatch method is proved to be effective in improving the economy and reliability of MG.

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