OPTIMAL PLANNING AND CONTROL OF MICORGRIDS WITH DISTRIBUTED ENERGY RESOURCES ON SMART GRID

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ABSTRACT

The microgrid concept assumes a cluster of loads and microsources operating as a single controllable system that provides a new paradigm for defining the operation of distributed generation. To the smart grid the microgrid can be thought of as a controlled cell of the power system. For example this cell could be controlled as a single dispatchable load, which can respond in seconds to meet the needs of the transmission system. To the customer the microgrid can be designed to meet their special need; such as, enhance local reliability, reduce feeder losses, support local voltages, provide increased efficiency through use waste heat, voltage sag correction or provide uninterruptible power supply functions to name but a few.

This paper presents the engineering method to construct microgrid economically with optimization model and the control method of distributed generators for stable operation with AGC (Automatic Generation Control) and ED (Economic Dispatch).

Ⅰ. INTRODUCTION

Environmental issue is one of the key factors to industry area using fossil fuels, because it accelerates the global warming. This issue is especially for the power industry. During the 1970s, increases in the price of oil and natural gas and concerns about the finite nature of reserves, coupled with increasing awareness of the environmental damage caused by the burning of fossil fuels, stimulated interest in alternative, renewable sources of energy. As a result, many kinds of research and development to enlarge the use of renewable energy resources which can be able to replace fossil fuels are accelerated. Consequently, it is supposed to reduce greenhouse gases around the developed nations of the world at times go.

However, there are still technical issues to apply DERs (Distributed Energy Resources), including renewable energy resources, to the conventional power system. Especially, because of intermittent power output and difficulty of control, there are many problems to be solved regarding the spread of renewable energy resources such as wind turbine and photovoltaic. In addition, DERs are not economically practical yet. Under this background, the microgrid system that consists of DER systems, such as natural power system (wind turbine, photovoltaic) and fuel-cell, co-generation, also known as CHP (Combined heat and power) generation, has been developed greatly during the last 10 years. The microgrids are small power supply system located on-site that can supply both the electricity and the heat simultaneously.

Ⅱ. MICROGRID OPTIMIZATION MODEL AND CONTROL

With the rise of the concept of smart grid, micorgrid as an important component of smart grid, has played an increasingly important roles such as enhance local reliability, reduce feeder losses and support local voltages in power market. Furthermore, the microgird also offers opportunities for optimizing DERs through CHP, which is currently the most important means of improving energy efficiency.

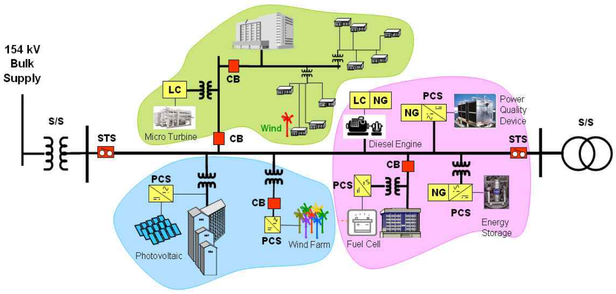

Fig. 1. Concept of microgird

The microgrid usually consists of a cluster of distributed generators, energy storage systems and loads, and can operate in the grid-connected mode and the islanded mode.

A. Optimal Planning Model

The optimal planning model is applied to select DERs providing optimal fuel mix and economic dispatch schedule. Due to the nature of the optimal planning, the objectives are minimizing the fixed cost and variable cost. The objective function is subject to various operating constraints such as energy balance equations and generation functions.

1) **Objective function**

The operation cost of microgrid depends largely on the planning in advance of construction and operational policy on power market. Because of its components, the variable cost of the objective function, Z_r, can be expressed by the following equation with the annual operational hours T_D^m,

$$Z_r = \sum_{m=1}^{M}(C_G x_G^m + C_A x_A^m + C_Q x_Q^m + C_P p_P^m)T_D^m = \sum_{m=1}^{M}(C_G \sum_{n=1}^{N} x_G^m + C_A \sum_{l=1}^{L} x_A^m + C_Q \sum_{k=1}^{K} x_Q^m + C_P p_P^m)T_D^m \quad (1)$$

Where, for the m-th energy-demand pattern C_G, C_A, C_Q and C_p represent unit cost of electricity generation of fuel generator, hot water generation of auxiliary boiler and cold water generation of chiller and purchased power from utility each. And x_G^m, x_A^m, x_Q^m and p_P^m represent fuel consumption and purchased power each.

Based on the annual cost method, the fixed cost of the objective function, Z_f, can be written as,

$$Z_f = \sum_{n=1}^{N} R_G I_{G,n} + \sum_{l=1}^{L} R_A I_{A,l} + \sum_{k=1}^{K} R_Q I_{Q,k} + \sum_{n=1}^{N} \Upsilon_G I_{G,n} + \sum_{l=1}^{L} \Upsilon_A I_{A,l} + \sum_{k=1}^{K} \Upsilon_Q I_{Q,k} \quad (2)$$

Where, I denotes the initial equipment cost and Υ is the ratio of the annual maintenance cost to the initial equipment cost. In the above equation, the rate of return for the components, e.g., R is given by,

$$R = (1-\rho)\frac{r(1+r)^{-\tau_G}}{1-(1+r)^{-\tau_G}} \quad (3)$$

Where, r is the annual interest rate, ρ is the remainder rate of the equipment at the end of expected life, and τ is the expected life of the equipment. By adding the annual variable cost from Eq.(1) to the annual fixed cost from Eq.(2), the objective function is given by,

$$Z = \min(Z_r + Z_f) \quad (4)$$

2) **Constraints**
Unlike the conventional power system, several equipments such as CHP and gas directly fired unit in the microgird have two products, electricity(5) and heat(6) or hot water(7) and cold water(8). So, each of these equipments has two performance characteristics that can be approximately represented by following linear equations,

$$p_{G,n}^m = a_{G,n} x_{G,n}^m + b_{G,n} \quad (5)$$

$$y_{G,n}^m = \alpha_{G,n} x_{G,n}^m + \beta_{G,n} \quad (6)$$

$$q_{Q,n}^m = a_{Q,n} x_{Q,n}^m + b_{Q,n} \quad (7)$$

$$y_{Q,n}^m = \alpha_{Q,n} x_{Q,n}^m + \beta_{Q,n} \quad (8)$$

Where, p, y and q are electrical output and thermal output (heat and cooling), respectively.

Each equipment has the upper and lower bounds of the fuel consumption,

$$x^l \le x \le x^u \quad (9)$$

Other types have one performance characteristic with electricity or heat, respectively.

In the optimal planning of the microgrid considered in this study, it is assumed that the annual demands of electricity and heat are given a priori. That is, for the m-th energy-demand pattern, the electricity demand is given by P_D^m (MW), and the heat demand by Y_D^m (MW), and the cooling demand by Q_D^m (MW) with the annual operational hours T_D^m. Thus, the energy balance equations are,

$$\sum_{n=1}^{N} p_{G,n}^m + p_P^m = P_D^m \quad (10)$$

$$\sum_{n=1}^{N} y_{G,n}^m + \sum_{l=1}^{L} y_{A,l}^m + \sum_{k=1}^{K} y_{Q,k}^m \ge Y_D^m \quad (11)$$

$$\sum_{k=1}^{K} q_{Q,k}^m + \sum_{j=1}^{J} q_{C,j}^m \ge Q_D^m \quad (12)$$

3) **Case study**
In this case study, the each kind of annual demand, electricity and heat (hot/cold), is given as 2.7MW, 7.83MW, 3.84MW and shown in Fig. 2.

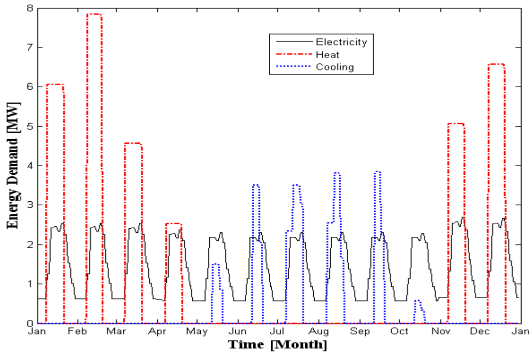

Fig. 2. Annual energy demand patterns

The components data for simulation are shown in Table 1.

Table. 1. Component data

Type	Capacity[kW]	Initial Cost($)
Gas turbine 1	750/1174(elec./heat)	830,000
Gas turbine 2	865/1091(elec./heat)	1,070,000

Auxiliary boiler 1	930	30,000
Auxiliary boiler 2	1160	36,100
Turbo chiller 1	540	71,000
Turbo chiller 2	650	77,600
Gas directly fired unit 1	440/540(heat/cooling)	20,000
Gas directly fired unit 2	620/740(heat/cooling)	24,000
Photovoltaic equipment	300	140,500

The optimal configuration of the microgird is three GTG1s, three Aux1s, three Turbo chiller2s, three GDF2s. The optimal planning of the microgird system corresponding to the electricity and heat demands are shown in Fig. 3, 4.

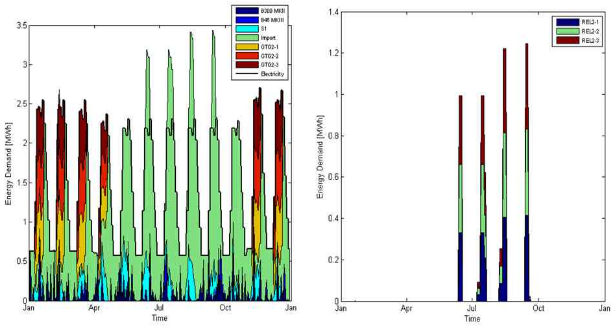

Fig. 3. Generated/supplied electricity (left hand) & consumed electricity from turbo chillers (right hand)

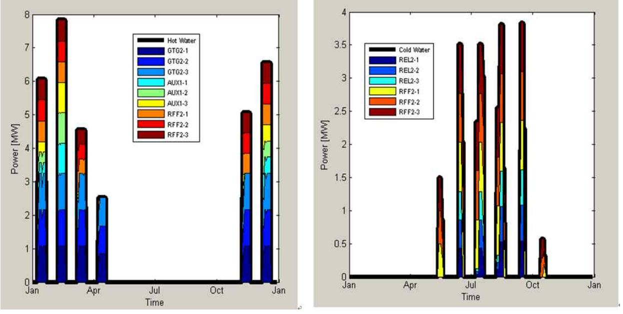

Fig. 4. Generated hot water (left hand) & cold water (right hand)

B. Automatic Generation Control

As mentioned earlier, some DERs like wind turbine are adversely affecting the power system. With the number of DERs increasing rapidly and the trend of developing microgird, it is possible to control DERs to provide constant power (good citizen) to the power system. It means that the microgrid can be used for their immense benefits, for example, improve power quality and reliability, defer or avoid system expansion. Moreover, for the ISO, the microgirds have the potential to provide the ancillary services, such as AGC services. This paper presents constant power control on grid connection point using AGC in the microgird system.

1) ACE (Area Control Error) and ED (Economic Dispatch)

The AGC consists of ACE and ED. The ACE of an interconnected group of systems is the resultant error in area interchange compared to the desired or scheduled interchange, including time error.

$$ACE = 10 * B(F - Fs - TE) + (Int - IntS) \qquad (13)$$

Where, B is the frequency bias factor, F is the system frequency and Fs is the scheduled frequency. TE is the time error, Int is the power flow and Ints is the scheduled power flow.

ED is the method of determining the most efficient, low cost and reliable operation of a power system by dispatching the available electricity generation resources to supply the load on the system.

$$\begin{aligned} & Min\sum_{i\in G}(C_i(P_i)) + \sum_{j\in CHP}(CHP_j(Ph_j)) + \sum_{k\in B}(B_k(h_k)) \\ & s.t. \sum P_i + \sum Ph_j = Load \\ & \sum \alpha_j Ph_j + \sum h_k = Heat \end{aligned} \qquad (14)$$

Where, C, CHP and B are the cost function of generators, CHPs, boilers, respectably. P is the purchased power, Ph is the generation power and h is generation heat.

$$AGC = BP + ACE*RPF + TEDME*EPF \qquad (15)$$

Where, BP is the base point from ED result. RPF is the reregulate participation factor, EPF is the economic participation factor. The AGC flow-chart is shown in Fig. 5.

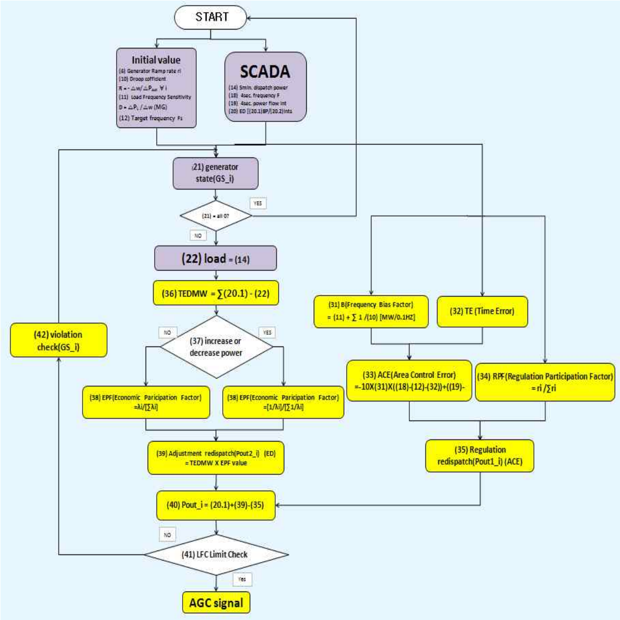

Fig. 5. Automatic generation control flow-chart

2) **Case study**

In this case study, the simulation aims to test constant power control on grid connection point with three control cases, AGC, AGC with ED to follow electricity demand and AGC with ED to follow heat demand, respectably. The average electricity demand of microgird is 80kW and the target value of the power flow on the grid connection point is 15kW.

Table. 2. Result of case study

CASE	CASE 1	CASE 2	CASE 3
5 min mean (kW)	15.92	16.88	16.54
30min mean (kW)	14.45	16.64	16.37
Error rate (%)	11.69	13.38	11.41
Max (kW)	29.00	26.70	24.60
Min (kW)	7.60	9.30	10.10

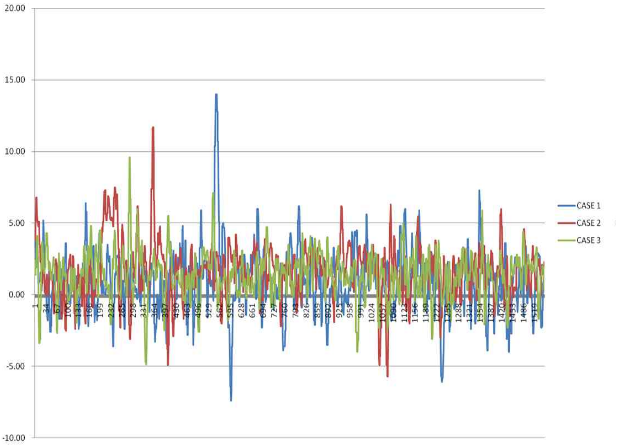

Fig. 6. Constant power flow control on grid connection point

Ⅲ. CONCLUSION

In this paper, we discuss the optimal planning before the construct of microgrids and AGC to control the grid connection point. By introducing the concept of microgrid, an optimal planning model can provide the economic advantages. Moreover, for the system operator, microgrids have the potential to provide the ancillary services with AGC.

Acknowledgments

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