Control Technology for Renewable Energy Sources and Micro-Grid

Authors: *Tomihiro Takano** and *Yasuhiro Kojima**

1. Introduction

To curb global warming, renewable energy sources such as wind power, solar power and biomass generation are dramatically increasing. The use of cogeneration systems is also growing to reduce energy costs for factories, buildings and homes where thermal loads tend to be high.

However, as these dispersed generators grow, their negative impact on the quality of the commercial power system becomes non-negligible: their unstable output causes the network voltage and frequency to fluctuate. Micro-grid technology is one approach to solve the problem and many demonstration field tests are now being conducted around the world.

2. Control of Micro-Grid

2.1 Concept of Micro-Grid

The micro-grid concept can be generally defined as follows: "A small-scale power supply system, which consists of small electrical power and heat facilities, loads, and their controller, and which manages them as a group and has one connection to a commercial power system." Figure 1 shows the typical configuration of a micro-grid, which consists of renewable energy generators, cogeneration facilities, electric storage facilities, thermal storage facilities, distribution network facilities, thermal infrastructure, communication networks, control devices including protection devices, thermal loads, and electric loads. The energy management system, which is a control device, plays an important role in a micro-grid and has the following effects:

- Efficient operation of electric and thermal energy
- Power flow control on the tie line (to protect power utilities from disturbances in the micro-grid)

2.2 Control System of Micro-Grid

To strike a balance between economics and power quality, optimum operation control of facilities, called "supply and demand control" is essential. To design the optimum solution, it is necessary to consider many variables including long-term factors such as efficiency and short-term ones like power quality. The authors have developed four stage control algorithms: 1) weekly operation planning, 2) economic load dispatching, 3) tie-line control, and 4) local frequency control, as shown in Fig. 2. The first and second serve to improve the economics and environment, in other words, to minimize the fuel cost and CO_2 emissions, while the third and fourth compensate for the power quality.

The operation planning and economic load dispatching are formulated as a combinatorial optimization problem including both continuous and discrete variables, and so the Problem Space Search method and QP (Quadratic Programming Problem) method can be applied. For tie-line control and frequency control, PID (Proportional Integral Derivative) control theory can be applied.

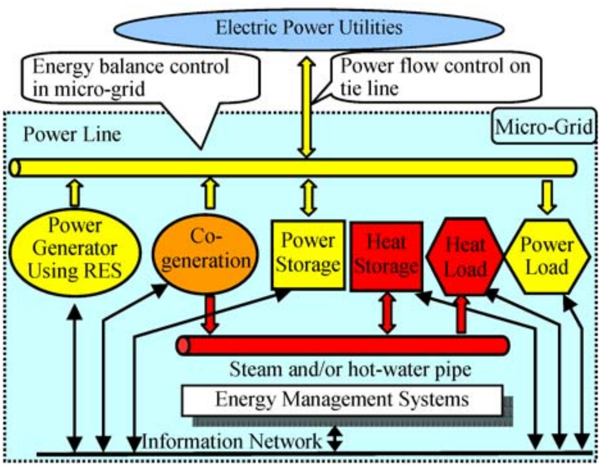

Fig. 1 Basic structure of micro-grid with RES

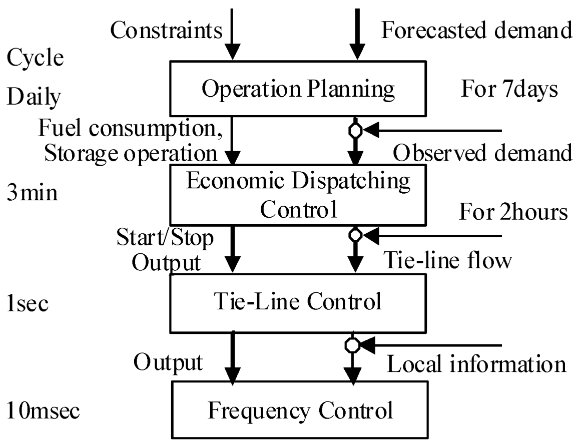

Fig. 2 Control hierarchy of micro-grid

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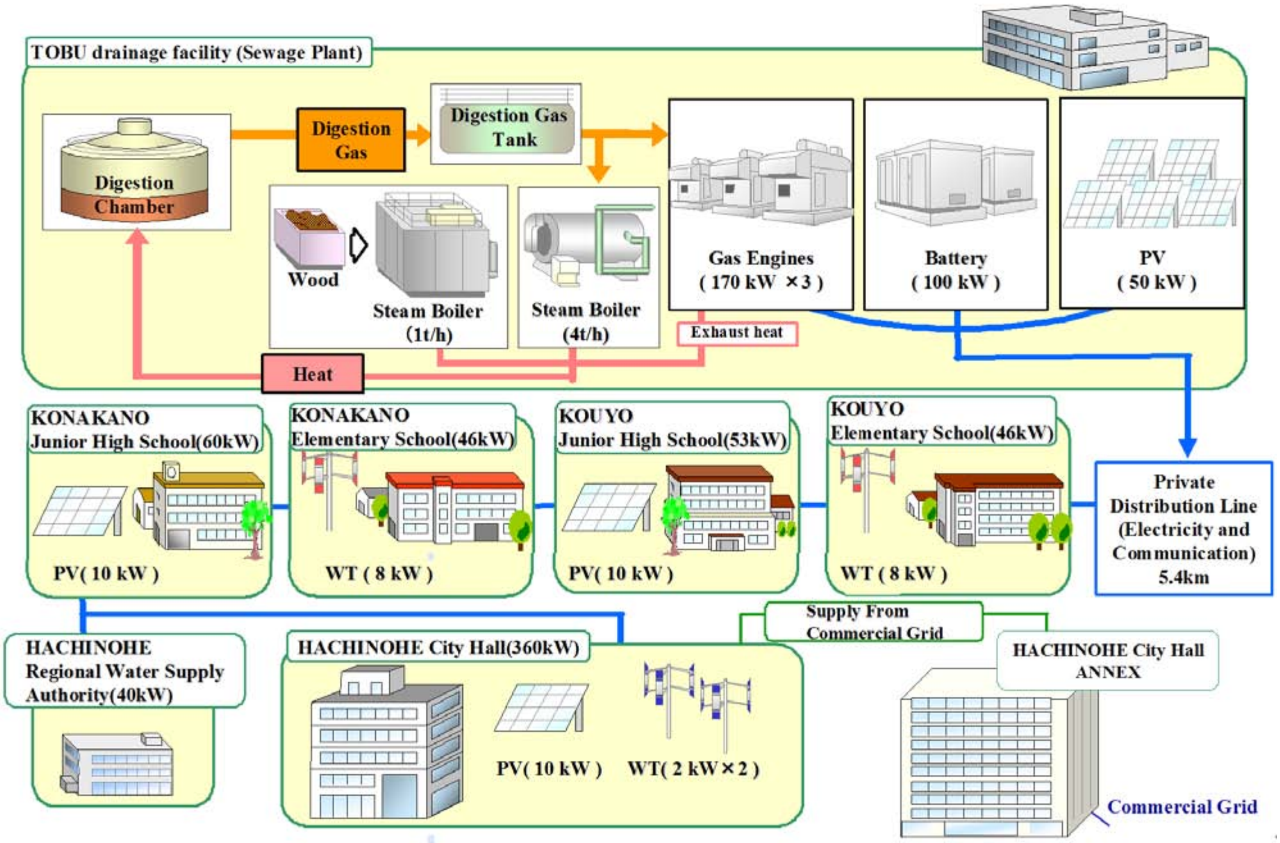

Fig. 3 Hachinohe-city micro-grid

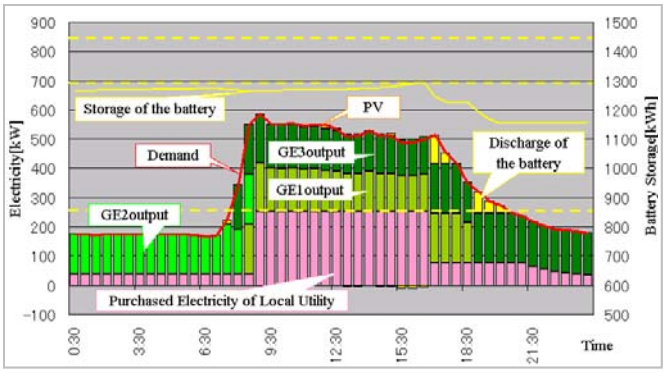

Fig. 4 Electric power operation planning

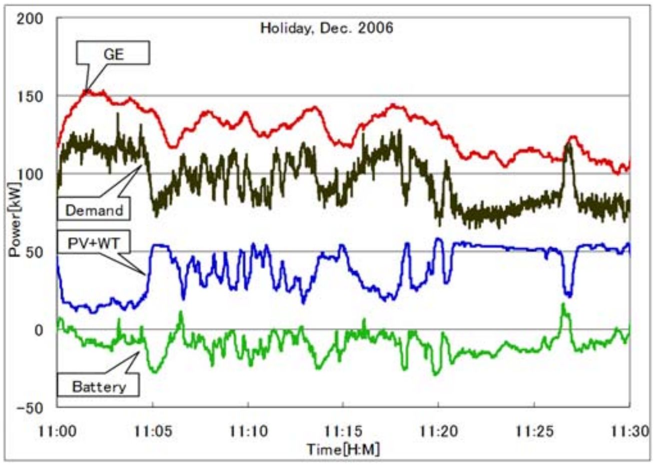

Fig. 5 Follow-up control for quick load change

3. Activities on Micro-Grid

3.1 Hachinohe Micro-Grid Project

The above control algorithm was first developed for the Hachinohe city micro-grid project, which is a joint project among Mitsubishi Research Institute, Hachinohe City and Mitsubishi Electric Corporation, under the Demonstration Projects for Regional Power Grids with Various New Energies, supported by NEDO (New Energy and Industrial Technology Development Organization). This demonstration field test ran from October 2005 to March 2008.

Electricity is supplied to six end-users through a private 6.6-kV overhead distribution line with a total length of about 5.4 km. Laid along the power distribution line is an optical-fiber cable carrying an IP network for monitoring and controlling the system. Both the power network and the information network have a radial configuration.

The system connects to the utility distribution grid at a single point, Hachinohe City Hall Annex, where reverse power flow into the utility grid is not allowed according to an agreement with the utility. The energy management system controls the power flow at the point between Hachinohe City Hall and its annex, where the power flow is to be maintained at a scheduled value.

The system can transfer to isolated operation, disconnected by manual control from the utility grid at the point between Hachinohe City Hall and its annex. Under the isolated operation, the gas engines, which are synchronous machines, take over as the "frequency source" within the system.

Although the calculation time span of the weekly operation planning is seven days, we focus on the day-ahead schedule that is carried over into the online economic dispatching control. Figure 4 is an example of electric power operation planning in the winter season when the load reaches a peak.

In this case, the planning results in an increase in purchased power in the daytime because of a limitation on the total amount of available digestion gas. For usage of the battery, the system compares loss of battery charge/discharge and the low efficiency of generators under partial load, and the minimum output of the battery is obtained. A similar result is obtained by thermal planning, considering reusing the waste heat energy from the gas engines. All constraints such as supply and demand balancing and the upper/lower limits of the chamber's temperature are met.

Figure 5 shows the results of cooperative control of the Economic Dispatch Control and the Tie-line Control stages during the interconnection operation, illustrating the control performance for fluctuations of demand throughout a typical day.

Changes in demand and output of weather-dependent generators can be roughly classified into six types: (1) demand increases in the morning and decreases in the evening, (2) weather-dependent energy (PV) output increases in the morning and decreases in the evening, (3) demand fluctuations over a few minutes, (4) sudden output fluctuations caused by weather changes, (5) spikes at the start-up of equipment lasting a few seconds, and (6) spikes at the start-up of equipment that last less than one second (too slight to be seen in Fig. 5). Of these six types, the control system deals with types (1) through (4) when the system is interconnected to the utility grid. In Fig. 5, the six-minute moving average of the control error (the difference between scheduled and actual power flow) is also shown. The target set by this project of maintaining the error within ±3% of the total demand was achieved with a probability of 99.99% during the latest two months.

3.2 Residential Micro-Grid

This is another example of a micro-grid project, which is a collaborative development with Japan Research Institute under the Development Work of the Global Warming Prevention Technology supported by the Ministry of the Environment, for cluster housing. In recent years, home cogeneration systems are being introduced in the private sector to reduce energy bills and CO_2 emissions. Unlike industrial or commercial consumers, however, the characteristics of power and heat loads differ among homes, so the effect of these cogeneration systems greatly depends on the daily load. For instance, in the case of large power but small heat consumption, the family does not reap economic benefits from the cogeneration system because it will soon stop when the heat demand is satisfied for the family and it can not be used at full value.

This project attempts to solve this problem by integrating some residential users to form a residential micro-grid. This enables residential users to extend the cogeneration working time through flexible energy interchange among a cluster of houses, and thus to reduce CO_2 emissions.

Figure 6 shows an overview of a residential micro-grid. The control center handles some cluster sites. One micro-grid site can handle up to 100 homes and their cogeneration systems. Each site is connected to a commercial distribution system as Hachinohe city and many other micro-grids do, and buys any shortfall of power from the electric power company. Especially in this project, the micro-grid has two physical control layers to reduce the control system cost. The functions of operation planning and economic load dispatching for several sites are combined at a central controller, whereas the functions of data aggregation from homes and dispatching for cogeneration systems are retained at each site.

Table 1 shows an example of environmental assessment for three energy supply types: 1) conventional supply without cogeneration, 2) with cogeneration, and 3) with micro-grid. A micro-grid reduces CO_2 emissions by 28.6% compared with the conventional type.

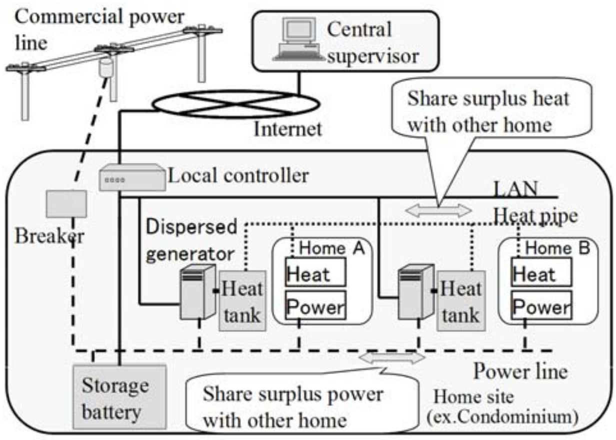

Fig. 6 Outline of residential micro-grid

Table 1 CO_2 emission for one home (kg-CO_2/year)

Conventional	Cogeneration	Micro-Grid
4,490	3,399 (-24.3%)	3,207 (-28.6%)

3.3 Wind Farm Control

As an extension of a micro-grid, the control technology is used to stabilize the output from wind farms. The Japanese government has set a target of installing 3,000 MW of capacity of wind power generators by 2010, but capacity had reached only 926 MW by 2004.

Wind power generation completely depends on the weather. As the proportion of wind and solar power generation increases, the potential imbalance between power supply and demand rises. This leads to frequency fluctuations from the reference 50/60 Hz. Some electric utilities recently published their assumption of wind power boundaries in their power systems. According to them, the amount introduced has almost reached the limit in Hokkaido and Tohoku where wind conditions are good, so Tohoku Electric Co. has begun to place strict constraints on new wind farms to stabilize their power output with storage batteries. Wind farms must keep a financial balance, while complying with the constraints by minimizing the storage battery capacity and the energy losses of charging and discharging.

The micro-grid technology predicts the generation for each source based on weather forecast simulations, and controls the actual output and storage battery to smooth the output as shown in Fig. 7.

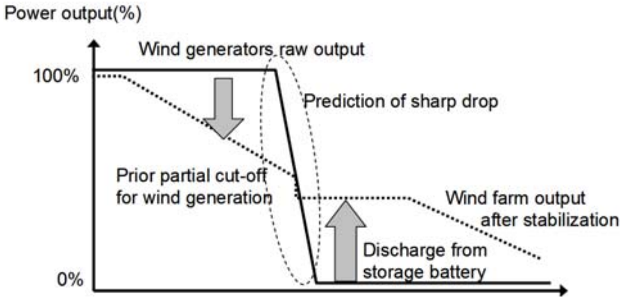

Fig. 7 Wind power stabilization using output prediction

4. Conclusion

The use of dispersed generators will continue to increase to improve energy efficiency as environmental awareness grows. The micro-grid concept is regarded as an essential technology for the efficient and reliable use of dispersed and renewable generators. Many demonstration test projects are now underway not only in Japan but also in Europe, the US, Australia and Korea.

These control technologies could be extended to saving energy in factories and office buildings through further development for practical use.

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