Strategies for Short-Term Balance of Supply and Demand Applied to Microgrids in Small Buildings

INTRODUCTION

Microgrid Status in Japan

There has been an increasing awareness in Japan about the need of a safer energy supply system after the Fukushima Daiichi nuclear disaster in 2011. Besides the need of CO2 emission reduction, Japan now also faces the challenge to reform its electricity network without heavily depending on nuclear generation. In this context, the government is now promoting the utilization of renewable generation, such as solar and wind, which do not emit greenhouse gases, and the adoption of a distributed generation structure for specific areas or regions in the country. This will also make the system less vulnerable to the effects of possible shutdowns of the conventional centralized systems in the case of natural disasters. Therefore, Japan is facing now a favorable condition for the implementation of a clean, safe and independent power supply system [1].

Conventional Power Systems and Smart Power Systems

The conventional power system has evolved to the current state since more than one hundred years ago. It is composed of a centralized structure, where rotating synchronous generators, located generally far away from the points of consumption, are adjusted in order to compensate the imbalances between supply and demand. The demand changes are smooth since the generators "see" only the total aggregate demand of the mostly not correlated load changes. Most of the conventional generators burn fossil fuels which emits greenhouse gases which can affect negatively the environment [2].

In contrast, smart power systems are composed of smaller and distributed power grids, called microgrids, where the generators are located close to the points of consumption and with the capacity of being interconnected and mutually cooperate. Due to this, they are safer, less dependent on external energy supply and have negligible impact on the environment. However, since the same level of electricity quality is expected, the maintenance of proper frequency and voltage levels becomes a particular challenge [3].

Supply-Demand Balance and System Frequency

If the microgrids are interconnected each other, since the aggregated intermittent generation outputs and load variations are of low correlation, the overall system imbalance can be compensated by proper storage devices or by small engine generators. On the contrary, if a microgrid is completely isolated and independent, the variations in load (e.g., the switching of a household appliance such as hair drier, etc.) tends to produce a larger imbalance and the possibility of a larger degradation in the frequency quality of the microgrid.

Since the uncertainty in the forecast of future power generation (i.e., wind and solar generation) and future demand variation in a reduced time frame, measures should be taken to rapidly compensate the unbalances that can occur in the system in this short time span.

Also, in a low-inertia system with high percentage of solar generation with no rotating parts or wind turbines connected to the grid by power converters which decouples the inertia of their rotating parts from the grid, an additional mechanism is necessary to compensate the rapid supply-demand imbalances in the system. Fast charging-discharging sodium-sulfur batteries (NAS batteries) or flywheel storage systems are two alternatives for this compensation [4]. The addition of storage devices increases the cost of the system. Due to this, they should be the smallest as possible.

In addition to the cost, another aspects should be taken into account, such as the necessary space for installation, the safety for the people and the impact on the environment during the life span of the storage device.

SCOPE AND METHODOLOGY

The objective of this work is to compare two of the fastest storage systems, i.e., NAS battery and flywheel storage, for the compensation of short-term imbalances in a microgrid applied to small buildings such as office buildings or houses. The following main aspects are used as points of comparison between the two types of storage systems: frequency regulation performance and cost. To evaluate the performance, a model of a small building is constructed and simulations are performed using Matlab/Simulink. The cost is evaluated taken into account the current information in the literature and the marketplace about this type of devices.

TARGET SYSTEM

In this work, a typical household in Japan is employed as the target system in order to evaluate the performance of the two types of storage systems: NAS battery and flywheel storage system.

The system is assumed to be composed of a gas-engine generator, a PV system and the corresponding storage system, with the capacities and characteristics shown in Table 1.

Table 1 Parameters of the target system

<table>
<thead>
<tr>
<th></th>
<th>Storage System</th>
<th>Generation System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rated Capacity</strong></td>
<td>NAS Battery</td>
<td>Flywheel Storage</td>
</tr>
<tr>
<td>Response time</td>
<td>2 kW</td>
<td>2 kW</td>
</tr>
<tr>
<td></td>
<td>30 – 100 ms</td>
<td>5 – 10 ms</td>
</tr>
<tr>
<td><strong>Rated Output</strong></td>
<td>Gas Engine Generator</td>
<td>PV System</td>
</tr>
<tr>
<td></td>
<td>4 kW</td>
<td>2 kW</td>
</tr>
<tr>
<td><strong>Moment of Inertia</strong></td>
<td>0.17 kg.m²</td>
<td>No rotating parts</td>
</tr>
</tbody>
</table>

Keywords: Renewable Energy, Wind Power, Solar Power, Sodium-Sulfur Battery, Flywheel
The gas-engine generator is modeled based on the generic internal combustion engine model of Matlab/Simulink [5]. The solar power dynamics is assumed as a first-order system with a time constant of 100 μs, with constant output during simulations.

NAS batteries and flywheels are essentially different types of storage systems. NAS batteries are molten-salt batteries constructed from liquid sodium and sulfur, and operating at high temperature (300 to 350 ºC). Flywheel storage systems are rotating mechanical devices that store kinetic energy in their rotating parts. In both of them, the injection and absorption of energy are controlled according to the need in the network, such as frequency smoothing [6]. In this work, the NAS battery and the flywheel are modeled as first order systems with time constants according to the response times of Reference 4.

RESULTS AND DISCUSSION

Performance for Frequency Regulation

Two sets of simulations were performed in order to show, first, the importance of the gas generator’s inertia in the system and, second, to evaluate the performance of the storage systems for frequency regulation. A strong increase in the system load at t=10s was considered: The actual load pattern of the starting of a hair dryer of 1150 W, obtained by measurement, as shown in Figure 1.

![Fig. 1 Strong demand increase in the system](image)

Figure 2 shows the results of the simulations of the gas-engine generator, with and without augmented moment of inertia.

![Fig. 2 Effect of inertia in the frequency deviation](image)

As shown in Figure 2, when the inertia of the generator is increased 5 times, there is a considerable reduction in the frequency deviation. Frequency variation mitigation by increasing rotating machine’s moment of inertia can be considered as an approach for this type of tasks. As the frequency still goes out of the permitted range of ±0.3 Hz, further increase in the inertia or the utilization of storage devices can be considered.

The results of the simulations performed for the NAS battery and the flywheel storage are shown in Figure 3. As can be seen, the flywheel, due to its faster dynamics, can keep the frequency inside the permitted limits. The NAS battery also can reduce the deviation very close to the maximum allowed limit. The power injected by the two types of storage systems are shown in Figure 4.

![Fig. 3 Frequency deviation for storage device application](image)

![Fig. 4 Power injected by the storage devices](image)

Cost

One of the most important aspects to be considered in the selection of a storage device is its cost. In this regard, the “present value installed cost” is higher in the case of NAS battery, in the order of 50 % more. A detailed analysis of costs, together with other aspects to be taken into account for the selection of a storage system, can be found in [6].

CONCLUSIONS

Fast charging-discharging storage systems can be utilized in independent microgrids to balance supply and demand, especially in the case of large demand variations, such as in the case of the starting of household appliances with near step profiles. The strategy may be combined with an augmented engine generator’s moment of inertia which decreases also the frequency variation. This strategy can be useful because the fast-dynamics storage devices are of high cost and an increased inertia can reduce the need of large storage devices.

REFERENCES


(3). SmartGrid.gov, What is a Smart Grid?. https://www.smartgrid.gov/the_smart_grid#smart_grid

