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Short communication

Managing peak loads in energy grids: Comparative economic analysis

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HIGHLIGHTS

- Cost of managing peak energy demand employing different technologies are estimated.
- Traditional technologies, stationary battery storage and V2G are compared.
- Battery storage is economically justified for peak demand periods of <1 h.
- V2G appears to have better efficiency than stationary battery storage in low voltage power grids.

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ABSTRACT

One of the key issues in modern energy technology is managing the imbalance between the generated power and the load, particularly during times of peak demand. The increasing use of renewable energy sources makes this problem even more acute. Various existing technologies, including stationary battery energy storage systems (BESS), can be employed to provide additional power during peak demand times. In the future, integration of on-board batteries of the growing fleet of electric vehicles (EV) and plug-in hybrid electric vehicles (PHEV) into the grid can provide power during peak demand hours (vehicle-to-grid, or V2G technology).

This work provides cost estimates of managing peak energy demands using traditional technologies, such as maneuverable power plants, conventional hydroelectric, pumped storage plants and peaker generators, as well as BESS and V2G technologies. The derived estimates provide both per kWh and kW year of energy supplied to the grid. The analysis demonstrates that the use of battery storage is economically justified for short peak demand periods of <1 h. For longer durations, the most suitable technology remains the use of maneuverable steam gas power plants, gas turbine,reciprocating gas engine peaker generators, conventional hydroelectric, pumped storage plants.

1. Introduction

Currently, the energy policies of all developed countries encourage the use of renewable energy sources and fuels. One of the goals of this policy is to reduce the dependence on imported fossil fuels. Another important goal is to protect the environment, in accordance with the Kyoto Protocol, which requires member states to limit greenhouse gas emissions. In 2012, the share of renewable sources in the global energy balance was 3.7% (Fortov and Popel, 2014). In Germany, one of the world's leaders in environmentally friendly energy technologies, the share of renewable energy in gross energy supply reached 22.9% by 2012 and is expected to reach 30% by 2020 and 80% by 2050 (Yildiz, 2014).

The fluctuation and unpredictable nature of solar and wind power lead to substantial changes in the operation of the power grid. The variability of power generation associated with renewable energy sources additionally exacerbates the imbalance between energy generation and demand in the electrical grid. As a result, the grid becomes less manageable, requiring additional means for balance and control. Further, matching the power supply and demand is crucial to a number of other tasks in managing modern energy systems (Sandia National Lab, 2015), such as Electric Energy Time-shift, Transmission Support, Voltage Support, Substation On-site Power, etc. (Fig. 1).

The traditional means of solving the variability problems are utilizing maneuverable steam-gas power plants and gas turbine or reciprocating gas engine peaker generators, as well as hydroelectric power plants and hydro pumped storage power plants. Compensating for short-term (seconds to few minutes) fluctuations requires placing power generators in a spinning reserve, which inevitably results in an inefficient use of fuel and power generating equipment.

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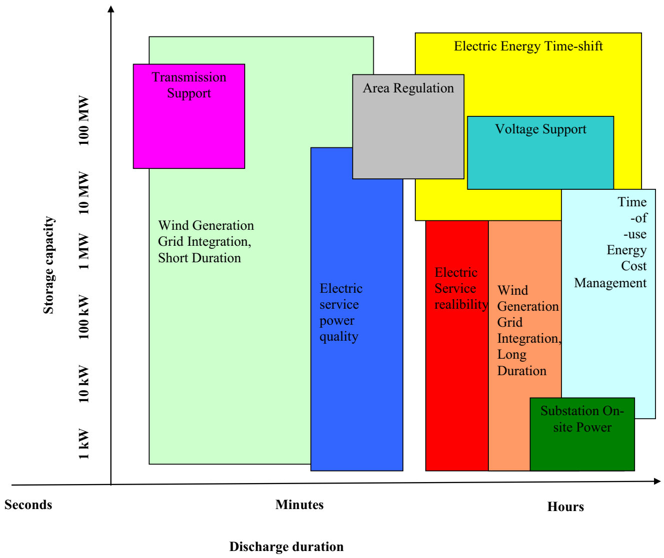

Fig. 1. Main tasks in regulating peak demand in energy grids. Data from Sandia National Lab (2010).

Refinement of the existing gas turbine technology is one avenue that can be used to regulate power generation in the energy grid. In particular, steam-injected gas turbine installations with water injection into the turbine inlet, compressor, or combustion chamber allows for a substantial increase in the flexibility of existing power plants, especially at high ambient air temperatures (Favorskii et al., 2014). Nevertheless, traditional technologies are often inadequate for efficient regulation of power supply in energy grids. Current trends require wider integration of energy storage systems into the power grids (Fortov and Popel, 2014; Nair and Garimella, 2010).

Among various methods of energy storage, high capacity batteries have a number of advantages over other technologies:

1. Compact, modular design.
2. Functional adaptability, responsiveness, and operational flexibility of the energy storage system.
3. Wide opportunities for control automation.
4. Easy integration into Smart Grids.

Experimental and commercial battery storage units have been developed and successfully deployed by a number of research and commercial entities, such as NGK Insulation, GE, Toshiba Corporation, Sumitomo Electric, and Altair Nanotechnologies Inc. (Zhuk et al., 2014; NGK Insulators Ltd., 2014).

Another attractive, although still not commercialized, method of balancing energy grids is the use of electric vehicles and plug-in hybrid electric vehicles as a distributed electric energy storage system, known as the "V2G" (vehicle-to-grid) concept (Kempton and Letendre, 1997; Tomi and Kempton, 2007; Peterson et al., 2010). One of the principles behind V2G is the integration of electric vehicles into the grid, allowing them to return part of the stored energy into the grid during peak demand times. Wide deployment of V2G is possible in the medium term, when a sufficiently large fleet of electric vehicles becomes available (Zhuk et al., 2015).

Other energy storage technologies, such as fly-wheels, supercapacitors, and SMES are only employed to cover relatively short, up to a few seconds, peak loads (Sandia National Lab, 2011) and cannot be used for regulating longer peak loads.

The goal of this study was to present a comparative cost analysis of managing peak demand periods of various durations using both traditional technologies, such as maneuverable power, conventional hydroelectric, pumped storage plants and peaker generators, as well as battery storage-based solutions, including V2G.

Unlike previous studies (Sandia National Lab 2015, 2011), the focus of the present analysis was to evaluate the cost-effectiveness of these technologies as a function of peak load duration and to determine the limits of economic effectiveness of each technology. In addition, the cost-effectiveness of V2G technology was analyzed and compared to stationary storage systems and conventional power plants.

2. Method

2.1. Calculation costs of regulating peak demand using various technologies

The comparison of the cost effectiveness of various technologies was conducted based on yearly operating cost estimates per kW of installed peak power, $C^{\text{kW year}}$, as well as per kWh of energy generated, C^{kWh}. Estimates were obtained for maneuverable steam gas power stations, gas turbine, reciprocating gas engine peaker generators, conventional hydroelectric, pumped storage, stationary battery storage, as well as V2G technology accounting for the depreciation of capital investment.

A power station is considered maneuverable if it is capable of deep (up to 50%) and rapid ramping up and down of power output in a reasonably cost effective manner. A typical steam gas turbine power plant has an operating power of 400 MW or more. Large steam gas turbine plants are widely used as an efficient primary and secondary means of frequency regulation in energy grids. Maneuverable power plants constitute the spinning reserve.

Peaker gas turbine and reciprocating gas engine power generators capable of rapid start-up and shut down cover relatively short, 1–3 h, demand spikes, and are widely used as non-spinning operating reserve. Typical utilization of the installed power generators is 500–2000 h a year. Usually, peaker power generators are installed specifically to provide power during peak demand and are not used to generate heat. The typical power of peaker gas-turbine plants is 10–20 MW. Reciprocating gas engine generators have lower power levels, 5–10 MW, since higher power reciprocating gas engines are technologically and economically impractical. Conventional hydroelectric plants usually have high power, up to a few GW, and can be efficiently used in peak regime. Pumped storage plants are specifically designed to cover peak loads. However, not all regions are equally suited for the construction of both hydroelectric plants and pumped storage plants, which is related to the availability of water sources and local topography. They also require allocation of significant land resources for water reservoirs, which in addition may pose significant adverse ecological problems.

The current analysis utilizes the following simplifying assumptions:

- Only costs associated with the construction and maintenance of the excess energy sources and storage facilities to cover peak loads. Accordingly, the costs of fuel for the electrical plants and of electricity for the storage units and the batteries of V2G are not included in the calculations. With fuel and electricity costs excluded, different technologies could be compared directly, without consideration of specific regions or countries, where these costs can differ substantially.
- For each technology, the service life of its main hardware components determines the economic life span.