Economic Evaluation of Storage System in a Multi-energy System

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Abstract. The integrated energy system, is to comprehensively plan, coordinately control, intelligently dispatch and multiply interact with multiple energy flows such as cold, heat, power and gas, which has broken the existing models of individual plan, design and operation of each energy supply system, and becomes a new model of future energy utilization. From the economic viewpoint, the energy storage system plays a quiet important role in this kind of grid structure. This paper presents a platform to assess the economic impact of different energy storage capacity and type on a district multi-energy grid operation cost. A multiple time-scale cooperative optimization is firstly proposed for the control optimization of energy storage, cold storage and heat storage to fulfill the minimization of total operation cost of integrated energy system. Then the economic benefits of different battery types and capacity are compared. For each scenario, the battery characterizes are also analysed and compared.

1. Introduction

Integrated energy system is the next-generation intelligent system, which deeply combines and closely interacts the resource, grid, load and storage of multiple energies. The renewable energy integration reduces power grid equipment investment, improve grid peak valley performance and decreases air pollution. Meanwhile, it also reduces power quality, leads to some harmonics and increases the control difficulty of the grid. It’s necessary to choose an appropriate energy storage system, regulate supply-demand relationship between power generation and users [1]. Therefore, it’s of great significance for the reliability and economy to study the modelling of multi-type energy storage system and multi-level control strategy considering the operation cost. The optimization strategy for ESS in an integrated energy system requires computing an optimal schedule for storage system while taking both technical and operational constraints into account. Concerning on the economic aspect, how to choose a reasonable storage capacity and have a best economic payback is now also a hot research topic.

A wide range of battery control strategies have been developed in the last decade [2, 3]. Model predictive control (MPC) has been presented as a method to reach a valuable compromise between short and long-term decision horizons [4, 5]. It has been shown in Refs [6] that the proposed operation and schedule strategy can lead to an improved microgrid economic dispatch with the help of BESS. Refs [7] proposes a new smart microgrid configuration and an innovative power control concept for future grids, which utilizes model predictive control (MPC) to assist in coordinating the plethora of generation and load combinations.
In this paper, a cooling-heating-electricity energy system modelling is firstly introduced and a real-time control architecture is proposed to co-ordinately control the system operation. The economic assessment is then carried out regarding energy storage and other factors, like electricity tariff and the ratio of load and PV. In the end, the monitoring platform is presented, including the hardware and software.

2. Integrated energy system description

2.1 The architecture and main components of the integrated energy system

Figure 1 shows the framework of this integrated energy system, it integrates micro-turbine, ice storage air conditioner, electric refrigeration equipment, gas boiler, waste heat boiler, lithium bromide compressor, heat storage device and energy storage device. The scenario is located in a university in Beijing, China and is a Hardware-In-The-Loop (HIL) control platform. The electrical load is Electrical Engineering Department building and solar panel is installed in the rooftop of this building. The heating and cooling demand is estimated based on weather information. All the rest equipment, like micro-turbine, gas-fired boiler, and ice storage air conditioning are virtual and modelled in MATLAB/Simulink. Monitor-control data including real-time operations waveforms and relevant power parameters are transmitted to Labview for display. Important data are stored in the local hard disk for later analysis.

The energy flow is marked by arrows in different colors. Electrical load is supplied by PV, wind, battery and public grid. Heating demand is satisfied by micro-turbine and gas-fired boiler. Cooling comes from electric refrigerator, ice storage are conditioning and LIBr chiller.

In this integrated energy system, the installed capacity of photovoltaic power generation is 58.25kWp, which is composed by 6 photovoltaic arrays. The installed capacity of main transformer of electric building is 1MW, the actual peak of load power is about 300MW, and the average of load power is about 200MW. The parameters of other components in this system are as following. The financial subsidy of photovoltaic generation is 0.42RMB/kWh, the financial subsidy of wind generation is 0.5RMB/kWh, and the output of wind generation and photovoltaic generation are not over 40% load demand, therefore, the generated power is not sold to power grid, which is supplied to domestic load completely. Electricity price in Beijing is showed in table 2.
Table 1: TOU electricity price in Beijing

| Time period | 0-6h  | 7-10h | 11-15h |
|-------------|-------|-------|--------|
| Electricity price (CNY/kWh) | 0.3726 | 0.6330 | 0.9004 |

Short-term MPC control is adopted as energy optimization strategy to minimize the operation cost, which includes three parts, electricity purchasing cost, gas purchasing cost and carbon emission cost. Objective functions and constraints of optimization strategy are linear, which the variables of optimization are real number or deformed number. Therefore, optimization algorithm can apply mixed-integer linear programming model and solve this kind of problem with MATLAB intlinprog.m.

The optimization progress is shown in figure 2. The system controller computes a new optimal control sequence every 15 minutes using most recent one-day-ahead load and PV forecasts. The load forecasting uses artificial neural network technique. Solar panels output is obtained using a two-level forecasting horizon for weather. Weather forecast is updated every 12 hours from an external forecast module with the new 36-hour-ahead prevision. Every 15 minutes, a 4-hour-ahead weather forecast is computed and used to refine the previous weather forecast. The optimal operation strategy for next 24 hours is obtained by MPC method. After 15 minutes of operations, measured system state (PV, load, energy stored in the battery) is retrieved by sensors and sent to the controller for the next time step.

2.2 Energy storage modelling

There are four types of battery in the modelling, lithium battery, lead acid battery, lead carbon battery and super capacitor. The modelling in Simulink can precisely simulate the real operation state of the battery and the operation data is real-time transmitted to MPC algorithm. Using virtual energy storage system to evaluate the economy in a real district energy system could reduce the investment cost and propose a best integrated energy system configuration, including battery type and battery capacity. Lead carbon battery, a new type super battery, combines the technology of lead acid battery and super capacity battery. It has the advantages of power charging curve and also a good charging and discharging performance, which greatly extends the battery life.
3. Monitoring platform
The function of this platform includes data collection, real-time monitoring and system operation display. Real-time data collection of load and PV is realized based on Modbus protocol. The monitoring information includes battery control strategy and operation state of all equipment. The revenue brought by different batteries is also calculated and displayed in this platform. The hardware structure is shown in the following figure.

The platform is shown in figure 4. By clicking the tabs in the top of the figure, different operation state and payback evaluation under different scenarios could be seen. There are 10 scenarios in total, two time-of-use electricity, and four types of batteries (Lithium battery, lead-acid battery, lead-Carbone battery and lead-acid&SC battery), two capacities for each battery(100kWh, 150kWh) and two capacities for CCHP(75kWh, 120kWh).
Figure 5: monitoring platform

Figure 5 shows the operation results of one scenario, where the battery capacity is 100kWh, the capacity of CCHP is 75kWh and the electricity tariff is the one used in Beijing. The below graph in figure 5 shows the operation state of all the equipment. The initial investment cost is 1067500CHY shown in the blue circle and the right top corner is payback period of different types of battery. We can say that in this scenario lead-acid&SCbattery has a minimum payback period about 4.85 years and Lithium battery has the longest payback period about 6 years. This corner has includes the info of real-time revenue and SOH. Figure 6 shows the real time revenue for Lithium battery and SOH for these four kinds of batteries. We can notice that although lead-acid&SCbattery has a minimum payback period, the life time is shorter than the others.
Figure 6: operation results

Figure 7: (a) real-time revenue (b) SOH evaluation
4. Conclusions
This paper presents a platform to evaluate energy storage system payback for different kinds of batteries under different scenarios. Combining the real collected data and virtual modelling in SIMULINK is an economic way to help the future decision-maker choose an appropriate battery storage in an integrated energy system. The established optimized operation model (MPC) takes electricity purchasing cost, gas purchasing cost and carbon emission cost into consideration. The coordinated optimized operation of various energy conversion equipment could promote multi-energy complementary and local renewable energy consumption.

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