

A Portfolio Approach of Demand Side Management

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Abstract: Demand-side management, involving energy efficiency, demand response, and distributed generation, is an efficient and effective way to improve the security of electricity via changing the profile of power demand, but portfolio management of these resources still lack systematic and comprehensive investigation. In this paper, a optimization-based framework of demand-side management is proposed, with resource optimization at the bottom level and portfolio optimization at the top level. Resource optimization is modeled in terms of energy efficiency, demand response, and distributed generation. Portfolio optimization is also generalized into four categories, and for each category an instance of application is studied. Reported results shown that the portfolio approach is essential to reach full potential of demand-side resources and to achieve the best energy and cost savings.

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1. INTRODUCTION

The increasing power demand, especially the peak demand, brings forth challenges to grid security and need of new power plants, which are only required to start on and meet the peak demand in the peak period. If the peak demand is reduced by certain ways, the construction investment associated with the so-called peak plants, facilities of distributions and transmission could be effectively saved, and meanwhile the risk cost of grid can be suppressed to some extent or eliminated possibly. The deployment of demand-side resources, e.g., energy efficiency (EE), demand response (DR), and distributed generation (DG), is considered as one of the most useful alternative solutions for reducing peak demand, power demand, and greenhouse gas emissions caused by electricity generation.

As is well known, EE, DR and DG are three popular demand-side resources, which can contribute to the efficient, flexible operation of power balance. Compared with conventional power plants at supply side, demand-side resources only require small amount of investment to achieve the satisfaction of demand. Demand-side resources are also capable to improve the reliability of power system with promising reserve capability (Keane et al., 2011). The resource optimization of EE, DR and DG has been widely studied to sufficiently and safely explore such resources for decades (Xia and Zhang, 2010; Behrangrad, 2015; Tan et al., 2013), which can be regarded on the bottom level of demand-side management (DSM). However, less emphasis has been put on studying portfolio optimization of demand-side resources. Portfolio optimization of demand-side resources is to determine the optimal resource mix for delivery and to schedule activities for achieving the operational and financial goals in consideration of con-

straints imposed by supplier, customers or other external factors. Although resource optimization can ensure the optimal operation of separate DSM resource, it cannot manage the coordination of multiple resources which will significantly influence the overall performance. Very recently, researchers in this area start to focus on portfolio optimization, which is in fact on the top level of demand-side management.

Although demand-side management has been successfully applied in many countries over the world, only limited research work has covered the comprehensive framework of demand-side management. A systematic study on the whole picture of DSM is urgent for maximal exploration of demand-side resources. In this paper, the bottom-up framework is proposed in terms of resource optimization and portfolio optimization. Three basic models of resource optimization on the bottom level are formulated, and portfolio optimization on the top level is categorized and illustrated with 4 instances. It can be observed that portfolio management could sufficiently enlarge the overall potential of energy conservation, peak shifting, peak clipping, valley filling, and load building.

The paper is organized as follows. In the next section, literature review on demand-side management is given. In Section 3, resources of EE, DR and DG are modeled. In Section 4, the portfolio management of demand-side resource is studied in 4 categories. The case studies are reported in Section 5. This paper is concluded in the last section.

2. LITERATURE REVIEW

In literature, many DSM applications reported are related with EE, DR and DG. For better exploration of each kind of demand-side resources, approaches of optimization and control are often employed in the system design and operational schedule.

With respect to EE applications, EE is studied in a general POET framework (performance, operation, equipment, and technology) (Xia and Zhang, 2010). Building energy efficiency retrofit, for light, water heater, air conditioner, and other facilities, has been widely studied (Asadi et al., 2012; Karmellos et al., 2015; Malatji et al., 2013; Ye et al., 2013). Maximal energy saving will be achieved via optimal design of retrofitting strategy. Some other concerns on payback period, budget constraint, and carbon emission are also taken into consideration (Wang et al., 2014; Wu et al., 2015b; Wang et al., 2016; Wu et al., 2016).

With respect to DR applications, many approaches have been proposed to facilitate system operation, electricity market, generation/transmission/distribution, energy retailing (Behrangrad, 2015). A DR model is proposed to facilitate independent system operators to identify and employ proper DR programs (Aalami et al., 2010). An optimization model is proposed to adjust the hourly load of a given consumer in response to hourly electricity prices (Conejo et al., 2010). Residential demand response is studied through the scheduling of typical home appliances in order to minimize electricity cost and maximize incentive (Setlhaolo et al., 2014).

With respect to DG applications, optimal allocation, sizing and coordination problems are studied in different DG models (Tan et al., 2013). Consensus schemes using only local information are employed in a distributed grid framework considering decentralized energy coordination and generation, and flow control (Kim et al., 2015). The problem of placement and sizing is formulated to optimize the voltage stability margin under constraints, such as, system voltage limits, feeding capacity, and DG penetration (Abri et al., 2013). The placement and sizing problem is also studied to improve the performance of the system with respect to the power loss reduction and voltage profile improvement (Jamil and Anees, 2016). Distributed renewable hybrid systems with or without grid connection are optimally designed and scheduled to reduce the electricity cost for customers (Wu et al., 2015a; Wu and Xia, 2015; Zhu et al., 2015).

Besides aforementioned applications, the portfolio management has got increasing popularity among researchers and engineers. Portfolio standards that include energy efficiency, renewable energy, and thermal resources have been implemented in many countries. United States energy portfolios for the year 2030, developed from seven different perspectives characterized by different weights placed on fourteen defining values (e.g., cost, social acceptance), are constructed to achieve three primary goals, i.e., energy independence, energy security, and greenhouse gas reductions (Tonn et al., 2009). After evaluating typical real-time electricity markets respectively in the North America, Australia and Europe, the authors summarize market architectures and incentive policies for integrating

the portfolio management of distributed energy and DR (Wang et al., 2015). In Francés et al. (2013), researchers focus on energy security and renewable energy resources for a given energy mix using the portfolio theory.

The portfolio optimization, with respect to reward, cost and risk, is the most important problem in the portfolio management. The optimal portfolio of renewable energy is obtained by the bottom-up energy system analysis model of electricity generation sector in South Korea (Park et al., 2016). Using mean variance portfolio theory, a framework for electricity trading portfolio optimization is proposed to secure the future trading in electricity market and emission markets, in which uncertainties of electricity, fuel and emission are considered (Mathuria et al., 2015). The mean-variance portfolio theory is implemented to evaluate the average costs and the associated volatility of alternative energy combinations (Marrero et al., 2015). Net profit of distributed storage is maximized by choosing an optimal multi-service portfolio, while providing distribution network congestion management, energy price arbitrage and various reserve and frequency regulation services through both active and reactive power control (Moreno et al., 2015). A medium term power portfolio optimization model, considering regional electricity prices and risk management, is proposed for a power producer in a competitive electricity market (Álvaro Lorca and Prina, 2014). A methodology is formulated to optimize energy portfolios for independently operated grids in the consideration of structure and constraints of grid (Corrand et al., 2013).

3. DEMAND-SIDE RESOURCES

There are many models appeared in different resource optimization applications. In general, three basic models with respect to energy efficiency, demand response, and distributed generation are presented respectively in this section.

3.1 Energy efficiency

The first kind of demand-side resource is the improvement of EE, which can be generally decomposed into four efficiency components, i.e., performance, operation, equipment, and technology (POET) (Xia and Zhang, 2010). Technology efficiency refers to efficiency of energy conversion, processing, transmission, distribution, and usage. Equipment efficiency refers to efficiency of isolated individual energy equipment with respect to given specifications. Operation efficiency is an efficiency measure that is related with physical, time, and human coordinations. Operational efficiency can promote further energy savings for new technologies and equipments, and existing energy systems. Performance efficiency is determined by external but deterministic indicators (technical and non-technical). As summarized in Xia and Zhang (2015), many models and applications of operation efficiency have been studied by the approaches of optimization and model predictive control. In this part, more focus will be given on technology and equipment efficiency. As is known, technology and equipment efficiency has been widely applied in the lighting projects. For the example, the out-of-date incandescent lamps are replaced by compact fluorescent lamps (CFL)

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