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Reward/Penalty Design in Demand Response for Mitigating Overgeneration Considering the Benefits from both Manufacturers and Utility Company

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Abstract

The high penetration of renewable sources in electricity grid has led to significant economic, environmental, and societal benefits. However, one major side effect, overgeneration, due to the uncontrollable property of renewable sources has also emerged, which becomes one of the major challenges that impedes the further large-scale adoption of renewable technology. Electricity demand response is an effective tool that can balance the supply and demand of the electricity throughout the grid. In this paper, we focus on the design of reward/penalty mechanism for the demand response programs aiming to mitigate the overgeneration. The benefits for both manufacturers and utility companies are formulated as the function of reward and penalty. The formulation is solved using particle swarm optimization so that the benefit from both supply side can be maximized under the constraint the benefit of customer side is not sacrificed. A numerical case study is used to verify the effectiveness of the proposed method.

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Keywords: Renewable Sources; Overgeneration; Reward/Penalty; Demand Response.

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1. Introduction

Electricity is the main energy input for many manufacturing systems. It is considered one of the world's fastest-growing form of end-use energy consumption [1]. By International Energy Outlook 2016 Reference case, world net electricity generation will increase 69% by 2040, from 21.6 trillion kilowatt-hours (kWh) in 2012 to 25.8 trillion kWh in 2020 and 36.5 trillion kWh in 2040. It can be expected that the Greenhouse Gas (GHG) emission will also witness a significant increase if all the increase portion of electricity generation is from traditional fossil fuel sources.

To address such a concern of GHG emission in future decades, the use of renewable sources, e.g., wind and solar, to generate electricity is of high interests of government, industry, and academia. It is considered one of the promising alternatives that can meet the energy challenge of 21st century to create a truly sustainable energy ecosystem for the planet. Although fossil fuel is still the main source of electricity generation, the generation mix has been changed significantly over the past several decades. The energy generated from the renewable sources accounts for about 13.4 percent of nation's total electricity production [2].

Solar cells, also called photovoltaic (PV) cells, currently represent the fastest growing renewable energy technology, making them a major player in the mix of global electricity generation. With steady improvements in new materials, and scaled up manufacturing, solar energy technologies are more affordable than ever. All these benefits accelerate the growth of the adoption of solar energy system. However, due to uncontrollable property of renewable sources, it creates sudden imbalance between high supply and low demand during overgeneration period during which the solar energy ramps so fast that the generation is higher than the demand. This asynchronous generation in terms of demand limits operational flexibility and degrades the reliability of the grid. Thus, further integration of large scale renewable sources becomes a challenge with respect to cost effectiveness and grid reliability.

Curtailment of renewable energy supply during overgeneration period can be a straightforward measure to deal with overgeneration. It can relieve imbalance situation and improve the reliability. There has been a great deal of research focusing on renewable energy supply curtailment strategies for different types of renewable resources. For example, Viganò et al. analyzed the active power supply curtailment strategies for renewable distributed generation [3]. Luhmann et al. illustrated the approach of excessive supply curtailment of distributed renewable energy for cost-efficient grid integration [4]. Tonkoski et al. showed the effective way of coordinated active power supply curtailment of grid using PV inverters for overvoltage prevention [5]. Kane L. and Ault G. reviewed renewable energy supply curtailment schemes in transition towards business [6].

However, the curtailment of excessive supply sacrifices the benefits of the stakeholders and weakens their confidence for further investment. Some analysis shows that if the curtailment is around 5 percent—owners of renewable projects face a significant risk of not being able to pay off loans for existing projects or secure financing for new projects [7].

Another measure to handle overgeneration is to incur more energy demand to fully utilize of the over generated electricity from the renewable sources. Some existing research focusing on this management technique has been reported. For instance, Rad et al. developed the autonomous demand-side management technique based on game-theoretic energy consumption scheduling for the future smart grid [8]. Yan et al. developed demand response support under weather impacts of renewable sources. They both integrated the PV generation and electric vehicle energy storage to mitigate the negative impact [9]. Nguyen and Le introduced optimal energy trading strategy for building microgrid with electric vehicles and renewable energy resources [10].

These demand side management programs can be helpful to address the overgeneration problem without any curtailment of renewable energy. To implement these programs successfully, the demand behavior of the manufacturers, a major customer group who contributes around 1/3 of total energy consumption around the U.S. [11], needs to be adjustable according to the overgeneration profile of the renewable sources. However, there needs some driving force that can encourage them to shift their load. Therefore, developing an optimal incentive strategy to encourage the manufacturers to participate in the program is the motivation of the paper.

In this paper, we focus on the design of reward/penalty mechanism for the demand response program aiming to encourage the manufacturers to participate in the program dealing with overgeneration to enhance the grid performance in a cost-effective and safe manner. A certain number of manufacturing customers will be selected at each time interval during overgeneration periods to provide the additional energy consumption to mitigate overgeneration so that the benefits of the utility company can be maximized. Different parameters such as the over generated electricity at the interval, the value created by each manufacturer consuming unit electricity, the consumption capability of each