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Dissertation Outline

Chapter 1: Introduction

A consensus is reached on that the emission of CO2 by human beings are the dominant cause of global warming. Within recent decades, humans' activities, especially electricity generation, have to take almost all the responsibilities for global warming. To reduce the emission amount of the specific greenhouse gas, renewable energy (RE) as the replacement source has received worldwide attention. This thesis focuses on the solar power as a representative of non-dispatchable REs. Since we are in a market deregulation revolution, it is reasonable to expect an explosive growth of the residential photovoltaic (PV) system capacity. However, according to the data, the proportion of the residential capacity is predicted to be nearly fixed comparing with the non-residential and utility ones. Motivated by the above issues, this thesis is about to investigate the residential-based PV-included day-ahead market systematically.

Chapter 2: Configuration of The Market Player

Having the introduction in Chapter 1, chapter 2 introduces an energy market player called energy aggregator. The aggregator is a composition in which the energy consumers and producers working cooperatively in a limited territory. Specifically, within the target aggregator, the four elements in the following list play a critical role in the energy regulation procedure.

1. Households' daily energy demands: In this thesis, we focus on the common energy consumers (households), not including the high energy-consuming factory and the utility company. Besides, we suppose that the energy utilizing pattern for each household is independent.

2. Photovoltaic system: Solar power in this thesis is transformed into electric energy via photovoltaic (PV) panels installed on the roof of each household. Ignoring the miscellaneous degradations, the PV system can be regarded as a

generator dominated by the solar irradiation. Moreover, within the energy aggregator of interest, the size of solar panels is supposed to be public.

3. Storage system: As an energy buffer, like the products of Tesla Powerwall, LG Chem and PowerVault2, the energy storage system has been gradually applied in the individual houses. In this thesis, we suppose that the storage systems within the target aggregator cooperate mutually to pursue as much profit as possible. To achieve this goal, the system is to charge and discharge under the particular physical or logical constraints. Moreover, the degradation which occurs during the operation is carefully considered.

4. Generator: The fossil fuel generator also appears in our case as a temporary power supplier. Due to the restriction of the CO2 emission and the cost of the diesel fuel, the equipment is launched only in an emergency.

Chapter 3: Uncertainty-Averse Energy Scheduling

In this chapter, we analyze a situation in which the energy aggregator is averse to the so-called PV realization uncertainty (PVRU) and sensitive to the associated consequence. Regarding the specific attitude, a worst-case logic is proposed to fulfill the aggregator's requirement. Once the worst condition is acceptable, the market player is robust enough to handle the other mild situations. To this end, we implement a nested strategy mainly based on robust optimization (RO) approach to maximize the profit of the energy aggregator in the day-ahead electricity market (DAM) while staying in a PVRU situation.

Based on the proposed strategy, the aggregator will operate its dispatchable assets to seek for an ideal profit by submitting the optimal energy profile to the DAM. To deal with a non-convexity issue stemming from the robust optimization problem, we reformulate the problem as its Lagrange dual counterpart. Then, we describe the uncertain range of the PV output by one polyhedral set. To solve the problem above, we implement a constraint-generation method to solve the newly formulated problem by splitting it into another two subproblems. Based on an iterative scheme, the two subproblems are solved in sequence, and the solution of the robust optimization problem is obtained when the optimal results of the two subproblems are equal.

The research contribution of this chapter is that we propose a strategy to deal with the specific RE uncertainty. Accordingly, the strategy can be decoupled into two

aspects concerning the specific functionalities. For instance, to deal with the aggregator's conservative attitude, a cost minimization procedure based on robust optimization is conducted; to adopt the time sequence of the day-ahead market under an uncertain condition, we implement a two-stage decision-making framework.

Chapter 4: Budget-Based Energy Scheduling

In this chapter, considering the budget of the energy aggregator, we maximize the profit based on the stochastic programming (SP) framework in the day-ahead market. Unlike the strategy dealing with the worst-case scenario in the previous chapter, here we focus on the average value of the cost concerning the PVRU. Likewise, the budget-based strategy also follows the two-stage decision-making framework.

Specifically, we compare the results yielded by the RO-based and SP-based strategies. Although the RO-based strategy can avoid the risk brought by the uncertainty, the associated profit in the DAM is unexpectedly low or even negative. On the contrary, despite the SP-based strategy bringing higher profit in the DAM, it has to undertake the risk of deficit when the extreme scenario appears in real-time. Therefore, the common drawback of the two strategies is the unitary objective framework, which focuses on either the risk aversion or the profit pursuing. However, due to the PVRU, it is also not wise for a market player to settle his decision without resorting to a suitable strategy.

The contribution of this chapter is that we propose a tradeoff framework considering the risk and profit simultaneously by regarding the budget as a parameter. In the proposed strategy, we maximize the expectation of the profit, using the aggregator's budget to bound the profit variance.

Chapter 5: Noncooperative Game in Microgrid

In this chapter, we analyze a multiple-aggregator scenario in which each market player focuses only on its profit selfishly. The content of this chapter is on a different standpoint from that of the previous two chapters.

In more detail, within a microgrid system, we establish a game-theoretic framework for modeling the strategic behavior of the energy aggregators (microgrid components) which are connected to solar energy resources. Likewise, we model the profit function of each aggregator (market player) with a two-stage stochastic structure. Then, according to the power flow equation, a coupled constraint

equilibrium is derived, and some properties are studied. To compute the specific equilibrium, we recast the problem with its Karush–Kuhn–Tucker (KKT) conditions. Furthermore, the numerical simulation illustrates the existence of the coupled constraint equilibrium.

The main contribution of this chapter is that we analyze a game-theoretic framework where there is no coordinator to conduct the social welfare maximization. Specifically, we derive a two-stage profit model, in which each market player has to decide his energy scheduling before the exact PV profile is known. Rather than just dealing with a particular game-based application, our work tackles a non-cooperative competing issue in which the utility function of the player has a two-stage structure.

Chapter 6: Concluding Remarks

The main contribution of this thesis is that, by providing uncertain solar energy, we systematically investigate the energy scheduling issue of an energy aggregator who joins the day-ahead electricity market. Additionally, motivated by a real-world event, network economics issues would be my research interests in the future.