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Limiting gaming opportunities on incentive-based demand response programs

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HIGHLIGHTS

- An aggregator-consumer DR contract based on probability of call is developed.
- Voluntary participation and asymptotic truthfulness are induced in this contract.
- Aggregator keeps the probability of call close to zero for truth-telling behavior.
- Marginal utility information is not required, making it easier to implement.

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ABSTRACT

Incentive-based demand response is a program where participant users are paid to reduce energy consumption from an established baseline. Counter-factual models to estimate the baselines are vulnerable for gaming. In this paper, a novel demand response contract between a user and an aggregator is developed to induce individual rationality (voluntary participation) and asymptotic incentive-compatibility (truthfulness) through the probability of call, which is the chance of a consumer to be selected by the aggregator to serve as demand response resource at a given period. In this approach, a consumer self-reports his baseline and reduction capacity, given a payment scheme that includes cost of electricity, incentive price, and penalty caused by any deviation between self-reported and actual energy consumption. Another important feature of this approach, different from the classic solutions, is that a participant agent does not require reporting marginal utility (energy preference), and only announces information in terms of energy. A two-stage stochastic programming problem is proposed from the demand side to understand the consumer rational decisions under this contract. As result, the aggregator decides randomly what users are called to perform the energy reduction in order to manage the truth-telling behavior of each agent through the probability of call. Mathematical proofs and numerical studies are provided to demonstrate the properties and advantages of this contract in limiting gaming opportunities and in terms of its implementation.

1. Introduction

Demand Response (DR) is one of the most vital parts of the future smart grid [1–4], which is a tool to manage the demand profile, by controlling the noncritical loads [5] at the residential [6], commercial and industrial levels. There are different ways to active DR in the power systems. Broadly defined, controllable programs [7,8] and indirect methods [9,10] are found as DR solutions, which are required by the system operator (SO) to maintain a fine balance of electricity supply and demand by means of load modification. Particularly, indirect methods are performed by changing energy price or giving an incentive payment to the consumers.

In incentive-based DR, participating agents are paid for diminishing their energy consumption from established baseline (e.g. Peak Time Rebates, Interruptible Capacity Program and Emergency DR). There are three key components of an incentive-based DR program: (1) A baseline, (2) A payment scheme and (3) Terms and conditions (such as penalties) [11]. The baseline is defined as an estimation of the energy usage that would have been consumed by demand in the absence of DR [12] (see Fig. 1). This quantity is often based on the average historical consumption of a consumer or a customer group on days that are similar to the forthcoming DR event. Therefore, a counter-factual model is developed to estimate the customer baseline.

With regarding the baseline, in [13], some methods are presented to

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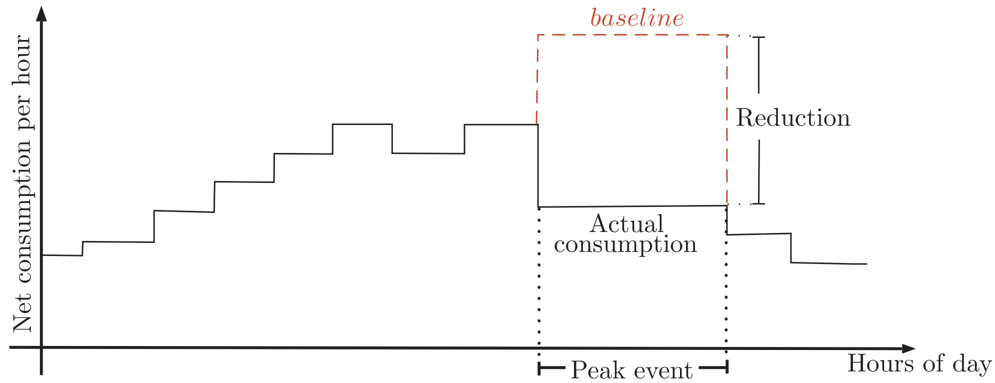

Fig. 1. Baseline definition.

estimate the customer baseline. The performance of DR baselines are studied and new methods are proposed to obtain a reasonable compensation for consumers in [14–16]. Baseline model error associated with DR parameter estimates are studied in [17]. In addition, in [18], the critical facts on the selection of customer baseline are highlighted, showing that counter-factual forecasts are vulnerable for gaming and could result in illusory demand reduction, then author proposes a baseline focusing on administrative and contractual approaches in order to get an efficient DR. Accordingly, literature and practice[19] have exhibited that consumers have incentives to alter their consumption patterns and baseline setting in order to increase their well-being, see e.g. [20,11,21,9]. Consequently, inaccurate baselines can derive in over-payment, compromising the cost-effectiveness of the DR program, or in under-payment, negatively affecting the participation of consumers in DR program. Thus the problem is how to establish correctly the baseline.

Given the fact that the incentive-based DR presents gaming concerns, a mechanism design or a contract is required to address these problems in order to guarantee that any participant agent reveals his truthful baseline and private information. Some solutions for DR are found in the literature by designing programs in a market framework. A revelation mechanism is developed in [22], which requests agents to select the best choice for themselves among a menu of incentives in electricity markets, however, a forecasted baseline consumption is employed in the formulation. In [23], a forward market is proposed, where users permit a deferred service in exchange for a reduced price of energy in order to manage the variability in supply from renewable generation, as well, this mechanism shows that prices are incentive-compatible. This approach does not include the baseline problem due to this mechanism is based on prices. Furthermore, In [24], a two-stage mechanism is devised to share the cost of electricity among participants based on their day-ahead allocations and demand is depicted by a set of appliances. This mechanism is asymptotically incentive-compatible and ex-ante weakly budget balanced under certain conditions. Furthermore, a methodology is developed in [25] for implementing microeconomic theory on contract designs for ancillary services in which incentive compatibility and individually rational are guaranteed in the presence of imperfect information between the consumers and the aggregator. In addition, in [26], two kinds of mechanisms are applied for a dynamic day-ahead market based on DR. One is the Vicrey-Clarke-Groves (VCG), which is ex-post incentive compatible and individually rational. Another mechanism is Arrow, d'Aspremont and Gérard-Varet, which is Bayesian (interim) incentive compatible and budget balanced. The previous solutions are focused on the integration of mechanism designs directly to electricity market without detailing the behavior of each consumer. Additionally, the baseline is not taken into account as part of consumer's preference.

Other solutions are found in literature at the level of consumer and aggregator. In [27], a truthful mechanism is designed that uses a reward-bidding approach where the mechanism adopts a fixed penalty for non-response for all selected agents, and consumers are selected in increasing order of their minimum acceptable rewards given the penalty. A model of consumer behavior in response to incentives is proposed in a mechanism design framework in [20], where aggregator collects the price elasticities of the demand as bids and then it selects the users most susceptible to incentives such that an aggregate reduction is obtained. In [28], truthful contracts are designed for DR, which maximize the utility benefit function subject to individual rationality and incentive-compatible constraints. A VCG mechanism applied in DR is presented in [29], where the authors verify some properties such as efficiency, user truthfulness, and nonnegative transfer. However, there are several major obstacles implementing VCG mechanisms, see e.g. [30]. Other work of VCG approach is found in [31]. In [32], a game theoretic DR strategy is developed, which consists of a distributed load prediction system by the participation of users that guarantee cheat-proof (truth-telling) behavior. Furthermore, in [33,34], a contract between a customer and an aggregator for incentive-based DR is proposed. This mechanism is composed of two parts: a share of aggregator profit and a compensation paid to customer due to load reduction.The above literature overview does not contemplate a self-reported baseline model. Nevertheless, in [11], an incentive-based DR mechanism is proposed, where each consumer reports his baseline consumption and his marginal utility to the aggregator. Deviations are penalized, hence, the true estimation is guaranteed. A linear utility function is assumed for each user. Furthermore, it is shown individual rationality for every consumer. However, some concerns raise regarding to the model and implementation. In economics, utility curve is usually modeled as strictly concave function [35] to depicts consumer's preference. In addition, from the implementation point of view, marginal utility information could be a difficult parameter to bid by a user because it is an abstract concept and it could not be easy to estimate by a regular consumer.

In this paper, a novel contract is proposed by addressing the gaming problem through a new concept called the probability of call for each participant consumer to limit the baseline alteration. The probability of call can be understood as the chance of agent to be chosen by the aggregator to serve as DR resource during peak times. A user submits his baseline and reduction capacity. This contract does not require marginal utility information as in traditional mechanisms, which could be a private parameter difficult to estimate by a consumer. Accordingly, agents bid two quantities in terms of energy, then this contract is a more intuitive procedure and can be suitable to be implemented in practice. In this approach, the main goal of the aggregator is to select randomly which participant agents are called to performed DR. The contribution is summarized as follows:

- The optimal decision problem is presented by 2-stage contract. The result is obtained backward in time to find the optimal choice that