Cooperative Virtual Power Plant Formation Using Scoring Rules

(Extended Abstract)

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ABSTRACT

The growing focus on sustainable and environmentally friendly energy production has resulted in the proliferation of distributed energy resources (DERs), mainly based on renewable sources like wind and sunlight. However, their small size and the intermittent nature of their supply means that such generators cannot easily be assimilated into the current electricity network (Grid) like conventional generators. Against this background, Virtual Power Plants are fast emerging as a solution to this problem whereby a large number of small energy generators may be aggregated together such that they exhibit the characteristics like a traditional generator in terms of predictability and robustness. In this work, we propose a method to promote the formation of such "cooperative" VPPs (CVPPs) using multi-agent technology. In particular, we design a payment mechanism that encourages DERs to join CVPPs with large overall production. Our method is based on strictly proper scoring rules and elicits accurate probabilistic estimates of energy production from the CVPPs—and in turn, the member DERs—which aids in the planning of the supply schedule at the Grid.

We empirically evaluate our approach using the real-world setting of 16 commercial wind farms in the UK, and we show that our mechanism incentivises real DERs to form CVPPs and, moreover, it outperforms the current state of the art payment mechanism developed for this problem.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems

General Terms

Economics, Experimentation

Keywords

energy and emissions, scoring rules, smart grid

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1. INTRODUCTION

In recent years, a number of strands in intelligent and multiagent systems research have taken up the challenge of creating smart and robust electricity supply networks, which can make efficient use of all available energy resources, thereby reducing dependence on carbon-intensive conventional generators [4]. One representative example for this effort is the research performed as part of the iDEaS project at the University of Southampton [4, 1, 2].

In this work, we consider the problem of integrating number of distributed energy resources (DERs) into existing electricity grid. In the last decade, *distributed energy resources (DERs)*—essentially small to medium capacity (2kW-2MW) renewable energy generators—have begun to appear in greater numbers in the network. Though their deployment could in principle reduce reliance on conventional power plants significantly, their integration into the Grid is problematic since the DERs, given their small size, are largely "invisible" to the Grid. This means they cannot readily be taken into account while planning production schedules, even if their total energy production represents a significant amount. Even if visible, the uncertainty and uncontrollability of renewable energy sources inhibits individual DERs from profitably dealing with the Grid directly, because they are often unable to meet the set generation targets. On the other hand, if individual DERs could be aggregated together to form larger energy generating entities, these entities would then have the opportunity to become economically sustainable by overcoming such invisibility and unreliability problems. This has led several researchers to propose the creation of *Virtual Power Plants (VPPs)*, consisting of large numbers of DERs, which can be viewed as the virtual equivalents of conventional power stations. In previous work (Chalkiadakis *et al.* [1]), we proposed a pricing mechanism that can be used by the Grid to promote the creation of *cooperatives* of DERs, and constitutes an alternative to feed-in tariffs. However, in that approach, each CVPP only reports to the Grid a point (mean) estimates of its production. An alternative that is more useful to the Grid is that production estimates are provided in the form of probability distributions, specifying the *confidence* individual entities place in their estimates.

In mechanism design literature, scoring rules with specific properties, have long been used to design payment mechanisms that incentivise agents to report private probabilistic predictions truthfully and to the best of their forecasting abilities [3]. Thus, in this paper we propose a novel pricing scheme that serves a dual goal: (i) Incentivising DERs to join forces to form CVPPs, (ii) Incentivis-

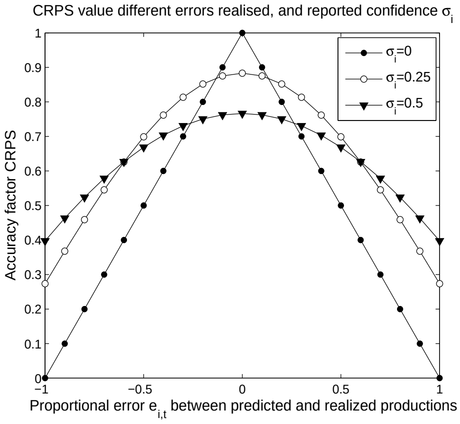

Figure 1: Example accuracy factors generated by using the scoring rule for different levels of prediction confidence

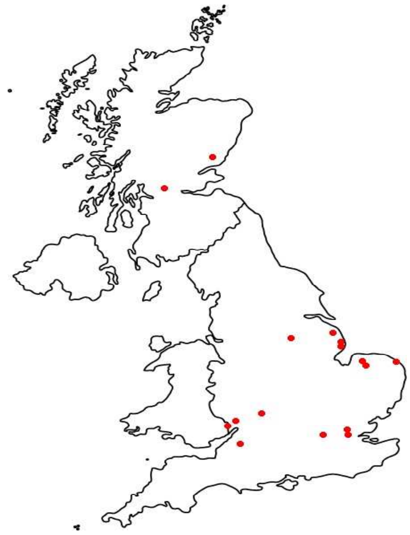

Figure 2: Map of Ecotricity farm locations

ing DERs to provide truthful probabilistic estimates of their future production, given the best information they have available.

2. SCORING RULES-BASED PAYMENTS

In our mechanism, for each half-hourly interval (called a clearing period in electricity markets), the DERs are asked to report not only an estimate of their production, but also an expected error, which reflects how accurate (in percentage terms) they expect their estimates to be. The confidence that an agent places in its own predictions is modeled through the standard deviation σ_i of its expected prediction error. Using scoring-rule based payments, the amount an agent receives from the Grid (or the CVPP if it has joined a CVPP), depends not only on how accurate the mean prediction at each clearing period t is, but also on the confidence the agent (representing a DER) reports in its predictions.

To illustrate this concept intuitively, Figure 1 exemplifies a scoring rule-based accuracy factor (which forms a part of our payment functions) for different values of σ_i vs. actual error $e_{i,t}$, for a clearing period t. What is interesting to observe here is how this error varies for different values of the reported standard deviation σ_i. If DER i is highly confident in its predictions (reporting $\sigma_i = 0$), the maximum reward for accuracy can be achieved, but only if the actual error is also close to 0. However, if the actual relative error is high, then reporting a higher σ_i (i.e., less confidence) provides a better reward.

In our formal analysis, we prove that, in all cases, our payment functions are *strictly proper*. This is a crucial property in this setting, which means that all agents will accurately declare their privately calculated distributions, reflecting their confidence in their own forecasts. Without a strictly proper payment mechanism in place, agents may be untruthful or simply not bother to provide the most accurate estimates they have available.

3. EXPERIMENTAL STUDY

We study the performance of the proposed pricing functions in a real-life, renewable electricity generation scenario. Specifically, we consider the setting of Ecotricity, one of the largest renewable generation and distribution companies in the UK[1]. Ecotricity owns 16 wind farms distributed across the UK, with installed nominal capacities ranging from 0.5 MW to 16 MW. The geographical distribution of these turbines is shown in Figure 2.

[1] `www.ecotricity.com`

For our experiments, we collected half-hourly wind speed data for a 10-week period from 15 February to 30 April 2011. The data was collected from the website `uk.weather.com`. Both the actual and predicted wind data for each half hour were collected using the geographical locations of the 16 wind farms of Ecotricity. These were then converted into power outputs using the power curve formulas obtained from a large wind turbine manufacturer.

We conducted several sets of experiments, where we studied both the performance accross the 16 wind farms, and across the prediction horizon (i.e. number of hours in advance the wind prediction is made). We observe that, for all settings, our pricing functions incentivise DERs to join CVPPs, as their profit is always higher in a cooperative. Comparing the scoring rules-based method to our previous method [1] (which only requires DERs to declare pointwise estimates of their productions), we see that agents prefer the scoring rule based scheme. In fact, we found that DERs facing higher degree of uncertainty (such as those predicting their output with a longer prediction horizon) stand to benefit the most from the new mechanism. This is because allowing agents to report the uncertainty in their estimates allows them to avoid being harshly punished in settings with high uncertainty. Thus, our payment mechanism is especially well-suited for settings where predictions may be prone to large errors, such as wind-based energy generation.

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