# Coalition–based Bidding Strategies for Integrating Renewable Energy Sources in Electricity Market

Sunghwan Bae, Seunghyoung Ryu, and Hongseok Kim
Department of Electronic Engineering
Sogang University, Seoul, Korea
Email: {usher731, shryu, hongseok}@sogang.ac.kr

***Abstract*—In this paper we propose a cooperation framework to analyze coalition-based bidding strategies in electricity market when participants have renewable energy sources such as solar photovoltaic and wind farms. Along with quantile bidding strategy using probabilistic distribution of renewable generation, we also consider a forecast bidding strategy. We show that the grand coalition incentivizes all participants when the market rule forces participants to bid their minimum commitment, which incurs penalty if not fulfilled, and excess generation may be spilled for free or at no cost. Simulations show that the forecast bidding outperforms the previous quantile bidding, e.g., individual and social welfare can increase by up to 97% and 67%, respectively.**

## I. Introduction

To set out a framework for greenhouse gas (GHG) emission reduction, 195 countries participated in the 2015 United Nations Climate Change Conference (also known as COP 21 or CMP 11) at Paris, and established, by consensus, the goal of limiting global warming below 2°C. Since the energy sector accounts for roughly two–thirds of GHG emissions, these countries might not be able to effectively deal with climate change without fundamentally shifting the way of producing energy (e.g., electricity). New York State has recently implemented its Reforming the Energy Vision (REV) strategy to create a greener, more resilient and affordable energy system by utilizing renewable energy sources (RES) in community-based microgrids [1]. In the UK, 10 million households will have solar panels installed on their roofs by 2020, and will be more likely to reformulate electricity market structures as prosumers, that is, both producers and consumers [2].

Although RES can contribute to reducing overall energy costs and carbon emissions, its inherent generation volatility still remains to be resolved as the RES penetration level continues to increase. To stabilize output variability of wind power producers (WPPs), for example, integrating large-scale WPPs is highly utilized, and aggregated wind power is treated almost as any other *conventional* generators with the existing market and technical rules in Spain and UK [3]. The existing wholesale electricity market follows the competitive electricity pool where an independent system operator (ISO) manages a two settlement system [4]; an *ex-ante* day-ahead (DA) forward market and an *ex-post* real-time (RT) (or imbalance settlement) market to financially penalize deviations from a contractual obligation of *ex-ante*. However, the intermittent nature of RES leads to the question how RES can maximize both individual participant's revenue and social welfare.

To deal with fluctuations of RES, optimal offering schemes have been studied in the two-settlement system [5]–[7]. The profit maximizing contract was introduced in electricity markets by using the time-averaged density and distribution of wind power generation [5]. As an auction framework [6], the authors have shown that bidding probability distribution of generation is more cost-efficient for WPP than bidding cost functions (balancing cost) in the proposed stochastic resource auction paradigm that is comparable with the existing two-settlement system. To improve the DA reliability, various unit commitment formulations have been investigated under different wind penetration levels in terms of operating cost and computing time [7].

Moreover, integrated bidding strategies for RES at different geographical sites are effective to reduce the uncertainty level of RES [8]–[12]. In [8]–[11], cooperative game theory, namely coalitional game theory has been used to maximize the expected utility of participants by forming alliances or groups. Based on an optimal contract [5], group bidding with quantile function could theoretically maximize the expected profit, and sharing mechanisms were verified to fairly allocate the total revenue to coalition members [8]. Direct trading of electricity between small-scale electricity suppliers with RES and consumers was studied as a coalitional game [9]. In [10], unique competitive equilibrium (CE) was achieved in a non-cooperative risky power market where WPPs are allowed to trade uncertain future power generation with each other, and total revenue of CE also corresponded to that of the grand coalition. A power transaction algorithm enabled micro-grids (MGs) to form coalitions so that multiple RES in MGs could alleviate the unexpected power losses and save the cost of purchasing extra electricity [11]. A recent work [12] has proposed a control and bidding strategy for a virtual power plant (VPP) where integrating the output of renewable distributed energy resources (DERs) as a single profile to minimize the cost in the DA and RT markets.

*Contributions:* Inspired by hybrid renewable energy system (HRES) [13], we first verify a theoretical framework of solar-wind integration in electricity market to mitigate penalty fees caused by renewable variability. The advantage of cooperation is that the grand coalition enables all participants to be fully incentivized through coalition-based bidding strategies. In practice, we utilize renewable data from Belgium's transmission system operator (TSO) under realistic market environments.

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Our empirical simulations show that the reliable forecast and the grand coalition create a synergy effect to compensate for inherent renewable volatility, which in turns implies that HRES can get huge profit gains without any additional effort.

## II. System Model

### A. Model of Renewable Distributed Energy Resources (DERs)

Since the amount of generation in renewable DERs is random, we define a continuous random variable $R_i$ as real-time power generation for renewable DER owner $i$. The function $f_{R_i}(r_i)$ and $F_{R_i}(r_i)$ are the probability density function (PDF) and the cumulative distribution function (CDF) of $R_i$, respectively. We assume that renewable DER owners are geographically separated enough and have different kinds of renewable energy sources. Then, $R_i$ is independent for all $i$ and has the interval $[0, \bar{r}_i]$, where $\bar{r}_i$ is the maximum capacity of renewable DER owner $i$. Due to stochastic characteristics of renewable DERs, the forecasting real-time generation is obviously erratic and thus the discrepancy between forecasting and measured data is inevitable.

### B. Electricity Market

We consider the conventional wholesale electricity market where renewable DER owners can contract with ISO to sell their renewable generation in a certain period of the day. ISO operates its wholesale electricity market based on the two settlement mechanism; an *ex-ante* DA forward market and an *ex-post* RT market to financially penalize deviations from a contract offering of *ex-ante*. Let $t$ be a discrete period, and $t = 1, \ldots, T$, where $T$ is usually considered as 24 hours within a day. With forecasting methods, renewable DER owner $i$ informs ISO of its expected power generation $e_i^t$ at a given ISO's unit price $p > 0$ for $t$ period in DA market. However, the owner must pay a penalty fee at a unit price $q > 0$ for its shortfall in the RT market. Since the storage is not considered, for simplicity, we assume that any surplus of $e_i^t$ is spilled for free or at no cost [6], [12]. We also assume that $q > p$ holds. Thus renewable DER owners should carefully choose their offering to avoid the penalty and maximize the revenue. When $r_i^t$ is a real-time power generation for a period $t$, the expected revenue of renewable DER owner $i$ is given by

$$\begin{aligned} U_i^t &= pe_i^t - \mathbb{E}\left[q\left[(e_i^t - R_i^t)^+\right]\right], \\ &= pe_i^t - q\int_0^{\bar{r}_i}\left[e_i^t - r_i\right]^+ f_{R_i}(r_i)dr_i. \end{aligned}$$

where $(x)^+ = \max(x, 0)$.

### C. Individual Bidding Strategies

In electricity market, renewable DER owner $i$ can use two bidding strategies for $e_i^t$; quantile function based bidding and forecast based bidding (hereafter, simply called *quantile bidding* and *forecast bidding*, respectively). In [5], [8], once $p$ and $q$ are known, based on the time-averaged CDF and its quantile function, quantile bidding for renewable DER owner $i$ is given by $\hat{F}_{R_i}^{-1}(p/q)$, where $\hat{F}_{R_i}^{-1}$ is the associated quantile function (e.g., the inverse function of CDF) from an empirical distribution $\hat{F}_{R_i}$. In contrast, forecast bidding implies that, rather than using a probabilistic approach like quantile function methodology, it uses a non-probabilistic bidding based on forecast. The effect of quantile bidding and forecast bidding on cumulative revenue will be investigated with real data under cooperation and non-cooperation scenarios, respectively in Section V. Next, when renewable DER owner $i$ determines $e_i^t$ based on bidding strategies, we verify advantages of cooperation under uncertainty so that all renewable DER owners (players) in coalition can utilize risk pooling in finance.

## III. Coalitions in Cooperative Games

### A. Formulation of Coalitions

A coalition in cooperative games is defined by a set of players and a value (utility) function, quantifying how well each coalition of players can do for itself [14]. In our cooperative game, we define $\mathcal{N}$ and $N$ to be the union set of players and the cardinality of the set, respectively, i.e., $N = |\mathcal{N}|$. A value function for any coalition $\mathcal{N}' \subseteq \mathcal{N}$, is denoted by $U_{\mathcal{N}'}^t$ at a certain period $t$. From now on, for notational simplicity, we drop time index $t$. For coalition $\mathcal{N}'$, $U_{\mathcal{N}'}$ can be expressed as

$$U_{\mathcal{N}'} = pe_{\mathcal{N}'} - \mathbb{E}\left[q\left(e_{\mathcal{N}'} - \sum_{i\in\mathcal{N}'} R_i\right)^+\right], \quad (1)$$

where $e_{\mathcal{N}'}$ is the *sum* of expected power generation from players in $\mathcal{N}'$, e.g., $e_{\mathcal{N}'} = \sum_{i\in\mathcal{N}'} e_i$.

### B. Social Welfare Maximization

Now we show that the grand coalition $\mathcal{N}$, where all players join the same coalition group as $\mathcal{N}$, is optimal in terms of the total revenue (social welfare) maximization in wholesale electricity market. To do so, we first define the super-additivity of the expected revenue $U$.

*Definition 1:* $U$ is super-additive if for all disjoint sets $\mathcal{N}_1$ and $\mathcal{N}_2$, $U_{\mathcal{N}_1\cup\mathcal{N}_2} \geq U_{\mathcal{N}_1} + U_{\mathcal{N}_2}$.

In cooperative games, the following proposition demonstrate that $U$ for any coalition is super-additive.

*Proposition 1:* For a coalition $\mathcal{N}'$, $U_{\mathcal{N}'}$ in (1) is super-additive.

*Proof:* We consider two disjoint and exhaustive subsets $\mathcal{N}_1'$ and $\mathcal{N}_2'$, where $\mathcal{N}_1' \cap \mathcal{N}_2' = \varnothing$ and $\mathcal{N}_1' \cup \mathcal{N}_2' = \mathcal{N}'$ for any coalition $\mathcal{N}'$. Then we can represent $U_{\mathcal{N}_1'} + U_{\mathcal{N}_2'}$ as (2) (see the top of the next page). The inequality in (3) follows from the fact that $(x)^+ + (y)^+ \geq (x+y)^+$ for any $x$ and $y$. After reorganizing (3), we obtain (4) which is $U_{\mathcal{N}'}$ by definition. Since $\mathcal{N}' = \mathcal{N}_1' \cup \mathcal{N}_2'$, we have $U_{\mathcal{N}_1'} + U_{\mathcal{N}_2'} \leq U_{\mathcal{N}_1'\cup\mathcal{N}_2'}$. Therefore, $U_{\mathcal{N}'}$ in (1) is super-additive. ■

*Remark 1:* Forming the grand coalition $\mathcal{N}$ can guarantee social welfare maximization in wholesale electricity market because $U_{\mathcal{N}}$ is super-additive.

### C. Existence of the Core in Coalitions

Even if the grand coalition can maximize social welfare of players, a distribution mechanism is also needed to induce participants' cooperative behavior in wholesale electricity

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$$
\begin{aligned}
U_{\mathcal{N}_1'} + U_{\mathcal{N}_2'} &= p e_{\mathcal{N}_1'} - \mathbb{E}\left[ q \left( e_{\mathcal{N}_1'} - \sum_{i \in \mathcal{N}_1'} R_i \right)^+ \right] + p e_{\mathcal{N}_2'} - \mathbb{E}\left[ q \left( e_{\mathcal{N}_2'} - \sum_{j \in \mathcal{N}_2'} R_j \right)^+ \right] & (2)\\
&\leq p\left(e_{\mathcal{N}_1'} + e_{\mathcal{N}_2'}\right) - \mathbb{E}\left[ q \left( e_{\mathcal{N}_1'} - \sum_{i \in \mathcal{N}_1'} R_i + e_{\mathcal{N}_2'} - \sum_{j \in \mathcal{N}_2'} R_j \right)^+ \right] & (3)\\
&= p e_{\mathcal{N}'} - \mathbb{E}\left[ q \left( e_{\mathcal{N}'} - \sum_{k \in \mathcal{N}'} R_k \right)^+ \right] & (4)
\end{aligned}
$$

market. Through the grand coalition, $U_{\mathcal{N}}$ should be fairly allocated to the participants so that neither any subgroup $\mathcal{N}'$ of $\mathcal{N}$ nor individual participation can provide players with higher revenue by deviating from the grand coalition. Otherwise, there is no incentive for players to involve in the grand coalition due to its instability. The stability of the fair allocation is verified by using the concept of the core, and later the amount of allocated revenue to each player in the grand coalition is calculated by using Shapley value [14]. The core is the feasible allocation of revenue which cannot be further improved by dividing the grand coalition into subsets [15].

*Definition 2:* The core of the game, $\mathcal{C}_{core}$, is

$$\mathcal{C}_{core} = \left\{ \mathbf{x} \in \mathbb{R}^{|\mathcal{N}|} : \sum_{i \in \mathcal{N}} x_i = U_{\mathcal{N}} \text{ and} \sum_{i \in \mathcal{N}'} x_i \geq U_{\mathcal{N}'}, \forall \mathcal{N}' \subseteq \mathcal{N} \right\},$$

where $\mathbf{x}$ is a vector of payoff allocation and each component $x_i$ is interpreted as the revenue to player $i$.

If the core of the game is non-empty, then there exists a feasible allocation of revenue among the participants in which no group of players has an incentive to abandon the coalition, i.e., the grand coalition is stable [9].

*Proposition 2:* The core of the considered cooperative game is non-empty.

*Proof:* This proposition can be proved by using the Bondareva-Shapley theorem [9], [16]. Let $\mathcal{P}$ be the power set of $\mathcal{N}$, which is the set of all subsets. Then we define $\mathcal{P}(i)$ as the set of all subsets which include $i$ as one of their elements. The Bondareva-Shapley theorem states that the core of the game is non-empty, if and only if for a function $\gamma(\cdot)$ that satisfies $\sum_{\mathcal{N}' \in \mathcal{P}(i)} \gamma(\mathcal{N}') = 1, \forall i \in \mathcal{N}$ and $0 \leq \gamma(\mathcal{N}') \leq 1$, the following inequality holds

$$\sum_{\mathcal{N}' \in \mathcal{P}(i), \mathcal{N}' \neq \varnothing} \gamma(\mathcal{N}') U_{\mathcal{N}'} \leq U_{\mathcal{N}}, \forall i. \tag{5}$$

We can show (5) based on the super-additivity as follows:

$$
\begin{aligned}
\sum_{\mathcal{N}' \in \mathcal{P}(i) \setminus \varnothing} \gamma(\mathcal{N}') U_{\mathcal{N}'} &\leq \sum_{\mathcal{N}' \in \mathcal{P}(i) \setminus \varnothing} \gamma(\mathcal{N}') \left( U_{\mathcal{N}'} + U_{(\mathcal{N}')^c} \right) \\
&\leq \sum_{\mathcal{N}' \in \mathcal{P}(i) \setminus \varnothing} \gamma(\mathcal{N}') U_{\mathcal{N}} \\
&= U_{\mathcal{N}}.
\end{aligned}
$$

Thus, the core is non-empty in the cooperative game. ■

## IV. Fair Revenue Distribution by Shapley Value

### A. Shapley Value

Shapley proposed a fair division of revenue, called Shapley value, in a coalitional game, based on a measure of the contribution of each participant to the coalition assuming three axioms: 1) efficiency, 2) symmetry, and 3) balanced contribution [9]. Let $\phi_i(\mathcal{N}, U)$ be the Shapley value of participant $i$ in coalition $\mathcal{N}$ with utility function $U$. Then, based on three axioms of the Shapley value, our $\phi_i(\mathcal{N}, U)$ can be computed as

$$\phi_i(\mathcal{N}, U) = \frac{1}{|\mathcal{N}|!} \sum_{\pi \in \Pi} [U_{\mathcal{N}(\pi,i) \cup \{i\}} - U_{\mathcal{N}(\pi,i)}], \tag{6}$$

where $\Pi$ is a set of all $|\mathcal{N}|!$ orderings and $\mathcal{N}(\pi, i)$ is a subset of $\mathcal{N}$ that includes the participants whose order precedes $i$ in the ordering $\pi$. By allocating revenue to each participant according to Shapley value, total revenue of the grand coalition is fairly divided based on player's own contribution.

### B. Coalition–based Bidding Strategies in Electricity Market

Algorithm 1 explains how coalition-based bidding strategies operate in day-ahead and real-time markets.

**Algorithm 1** Coalition–based bidding algorithm

*Day–ahead (DA) forward market*

**Require:** $p$ and $q$, and $q > p > 0$.
**Ensure:** Forming the grand coalition $\mathcal{N}$. ▷ *super-additivity*
Select either forecast bidding or quantile bidding for $\mathcal{N}$.
**if** forecast bidding is selected **then** ▷ *forecast bidding*
    Use DA forecasting data for $e_i$, and $e_{\mathcal{N}} = \sum_{i \in \mathcal{N}} e_i$.
**else** Calculate $\hat{F}^{-1}_{R_{\mathcal{N}}}(p/q)$ for $e_{\mathcal{N}}$. ▷ *quantile bidding*
**end if**
Bids for 24-hour periods are submitted to the ISO.

*Real–time (RT) market (imbalance settlement market)*

**Require:** Monitoring real-time power generation data.
Calculate revenue of $\mathcal{N}$ by $p e_{\mathcal{N}} - q\left(e_{\mathcal{N}} - \sum_{i \in \mathcal{N}} r_i\right)^+$.
**procedure** *fair revenue distribution*
    Calculate Shapley value $\phi_i$ for all $i$ by (6).
    All participants receive their cumulative $\phi$ for 24-hrs.
**end procedure**

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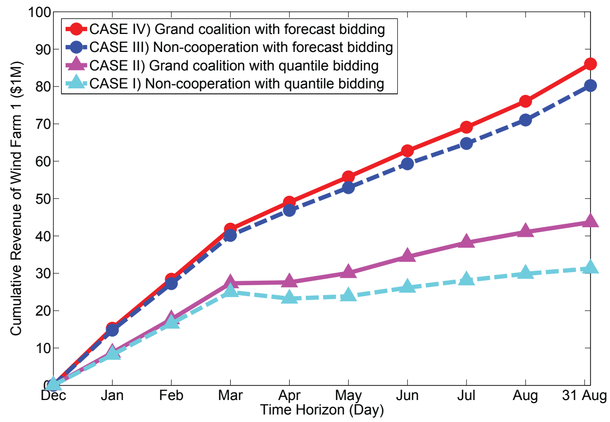


Fig. 1. Cumulative revenue for wind farm owner 1 from 1 Dec 2015 to 31 Aug 2016 [17]; individual revenue without coalitions and Shapley value with the grand coalition are presented under two bidding schemes.

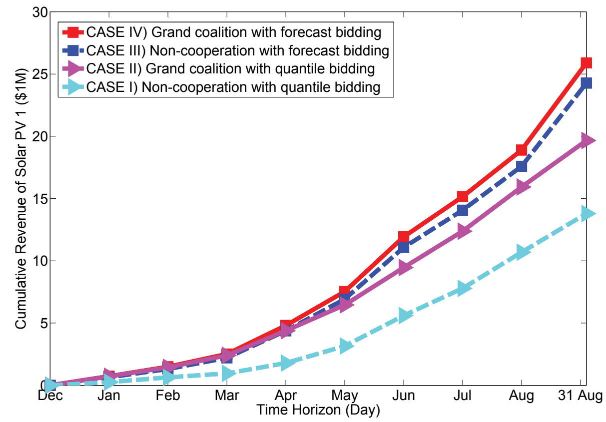


Fig. 2. Cumulative revenue for solar PV owner 1 from 1 Dec 2015 to 31 Aug 2016 [17]; individual revenue without coalitions and Shapley value with the grand coalition are presented under two bidding schemes.

TABLE I
CUMULATIVE REVENUE OF WIND FARM 1 ($1M)

| | Quantile bidding | Forecast bidding | % increase |
|---|---|---|---|
| Non-cooperation | (CASE I) 31.27 | (CASE III) 80.24 | 156.61% |
| Grand coalition | (CASE II) 43.66 | (CASE IV) 86.02 | 97.02% |
| % increase | 39.62% | 7.20% | |

TABLE II
CUMULATIVE REVENUE OF SOLAR PV 1 ($1M)

| | Quantile bidding | Forecast bidding | % increase |
|---|---|---|---|
| Non-Cooperation | (CASE I) 13.80 | (CASE III) 24.28 | 75.91% |
| Grand coalition | (CASE II) 19.66 | (CASE IV) 25.89 | 31.69% |
| % increase | 42.46% | 6.65% | |

## V. CASE STUDY WITH REAL DATA

So far we have focused on a cooperative game analysis of integrating renewable DERs to maximize total revenue in wholesale electricity market. Next, through extensive computer simulations we investigate how cooperative players can be better off in terms of individual revenue as well as social welfare. We utilize cooperative game to integrate renewable DERs in wholesale electricity market by using Elia's DA forecasting and real-time measured data [17]. Three wind farms and four solar PV farms cooperate to form the grand coalition from 1 December 2015 to 31 August 2016 (9 months). We set $p = \$50/\text{MWh}$ and $q = \$100/\text{MWh}$ in our wholesale electricity market by considering the realistic market environments [5], [6], [8]. Shapley values with the grand coalition and individual revenue without cooperation are compared under two bidding schemes. For fair comparison, we construct an empirical distribution $\hat{F}_{R_i}$ through the same methodology (92-days window size and 1-day sliding) in [8].

As can be seen in Fig. 1, the empirical cumulative revenue of wind farm 1 is presented. The results are also valid for the rest of wind farm owners, even though we omit them due to space limitation. The wind farm 1 is connected to Elia's offshore systems, and its maximum capacity is 712.20 MW. Intuitively, the wind farm owner 1 can achieve higher cumulative revenue in the grand coalition (CASE II, IV) rather than in individual participation (CASE I, III) regardless of bidding schemes. We summarize all cases of the wind farm 1 at the end of 9 months in Table I. Compared with non-cooperation (CASE I) in cumulative revenue, although the wind farm 1 using quantile bidding shows a significant increase of about 39.62% ($12.39 million additional revenue) through the grand coalition (CASE II), quantile bidding, per se, is not necessarily effective in terms of revenue maximization. Among all scenarios, we observe that the DA forecast from Elia is quite reliable, and cooperation with forecast bidding (CASE IV) is the most profitable option by achieving an increase of about 97.02% compared to CASE II.

Similary, Fig. 2 represents the empirical cumulative revenue of solar PV 1. In Belgium, Wallonia's solar PV farm 1 has the maximum capacity of 736.00 MWp (peak) [17]. No matter what kind of bidding scheme is used, it is worth cooperating with other renewable DER owners in the grand coalition. According to Table II, even if the effect of cooperation can be marginal because of the reliable forecast, CASE IV is practically best and its nominal cumulative revenue can increase up to 31.69% compared to CASE II.

From the social welfare perspective, Fig. 3 represents the sum of all cumulative revenues from both individual participation and the grand coalition under two bidding schemes; the difference of the social welfare between *the grand coalition* and *individual participation* monotonically increases over time. At the end of 9 months, CASE II and CASE IV have achieved $43 million and $17.60 million additional revenue, respectively. Forming the grand coalition increases the sum of cumulative revenues by mitigating uncertainty of renewable

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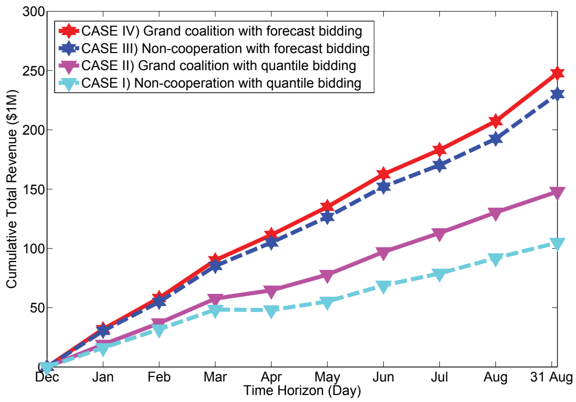


Fig. 3. Social welfare for all renewable DER owners consisting of three wind and four solar PV farms from 1 Dec 2015 to 31 Aug 2016 [17]; the sum of all revenues without coalitions and the sum of all Shapley value with the grand coalition are presented under two bidding schemes.

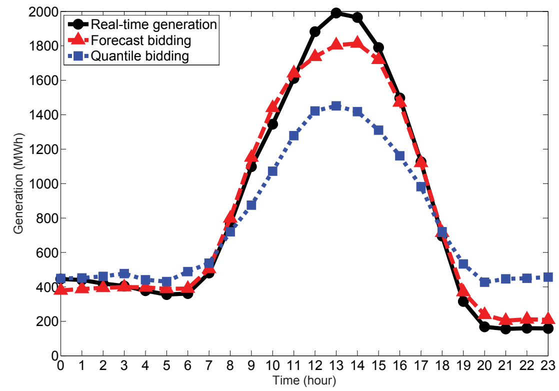


Fig. 4. Data on 1 May 2016 represent coalition–based quantile and forecast biddings as well as real-time measured power in the grand coalition [17].

TABLE III
THE RRMSE FOR ALL SCENARIOS (%)

| | Quantile bidding | Forecast bidding |
|---|---|---|
| WPP 1 | 83.37 | 27.87 |
| WPP 2 | 83.69 | 29.7 |
| WPP 3 | 89.03 | 32.46 |
| Solar PV 1 | 87.02 | 37.54 |
| Solar PV 2 | 88.55 | 39.3 |
| Solar PV 3 | 85.57 | 33.88 |
| Solar PV 4 | 87.73 | 41.49 |
| Grand coalition | 52.36 | 17.98 |

generation. Hence, CASE IV is the most desirable choice for wholesale electricity market in terms of social welfare by increasing up to $67.48\%$ compared to CASE II.

Fig. 4 shows coalition-based bidding data and real-time power generation data when renewable DERs form the grand coalition. To compare the accuracy of two bidding schemes, we also calculate the relative root mean square error (RRMSE) between actual wind power generation and quantile bidding as well as forecast bidding in Table III. Non-cooperation and the grand coalition have higher RRMSE values for quantile bidding relative to forecast bidding. The RRMSE for grand coalition with forecast bidding is about three times lower than that in quantile bidding, which in turns not only improves social welfare, but also provides a significant incentive for every participant in grand coalition.

## VI. Conclusion

To reduce the risk of penalty fees in the wholesale market, we applied cooperative games to hybrid renewable energy system by forming the grand coalition. By doing so, coalition-based bidding strategies contributed to the improved social welfare which could be fairly distributed to all participants based on Shapley value. Our theoretical and practical analysis indicated that the reliable forecast and the grand coalition created a synergy effect to compensate for the inherent volatility, which in turns implies that renewables could get huge revenue gains through cooperation without any additional effort.

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## References

[1] New York State Department of Public Service, *Reforming the Energy Vision*. [Online]. Available: http://rev.ny.gov/
[2] Y. Parag and B. K. Sovacool, "Electricity market design for the prosumer era," *Nature Energy*, vol. 1, no. 4, pp. 1–6, 2016.
[3] J. R. Abbad, "Electricity market participation of wind farms: the success story of the spanish pragmatism," *Energy Policy*, vol. 38, no. 7, pp. 3174–3179, 2010.
[4] D. S. Kirschen and G. Strbac, *Fundamentals of power system economics*. John Wiley & Sons, 2004.
[5] E. Y. Bitar, R. Rajagopal, P. P. Khargonekar, K. Poolla, and P. Varaiya, "Bringing wind energy to market," *IEEE Transactions on Power Systems*, vol. 27, no. 3, pp. 1225–1235, 2012.
[6] W. Tang and R. Jain, "Market mechanisms for buying random wind," *IEEE Transactions on Sustainable Energy*, vol. 6, no. 4, pp. 1615–1623, 2015.
[7] H. Pandi, Y. Dvorkin, T. Qiu, Y. Wang, and D. S. Kirschen, "Toward cost-efficient and reliable unit commitment under uncertainty," *IEEE Transactions on Power Systems*, vol. 31, no. 2, pp. 970–982, 2016.
[8] E. Baeyens, E. Y. Bitar, P. P. Khargonekar, and K. Poolla, "Coalitional aggregation of wind power," *IEEE Transactions on Power Systems*, vol. 28, no. 4, pp. 3774–3784, 2013.
[9] W. Lee, L. Xiang, R. Schober, and V. W. S. Wong, "Direct electricity trading in smart grid: A coalitional game analysis," *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 7, pp. 1398–1411, 2014.
[10] Y. Zhao, J. Qin, R. Rajagopal, A. Goldsmith, and H. V. Poor, "Wind aggregation via risky power markets," *IEEE Transactions on Power Systems*, vol. 30, no. 3, pp. 1571–1581, 2015.
[11] J. Ni and Q. Ai, "Economic power transaction using coalitional game strategy in micro-grids," *IET Generation, Transmission & Distribution*, vol. 10, no. 1, pp. 10–18, 2016.
[12] Q. Zhao, Y. Shen, and M. Li, "Control and bidding strategy for virtual power plants with renewable generation and inelastic demand in electricity markets," *IEEE Transactions on Sustainable Energy*, vol. 7, no. 2, pp. 562–575, 2016.
[13] V. Khare, S. Nema, and P. Baredar, "Solar–wind hybrid renewable energy system: A review," *Renewable and Sustainable Energy Reviews*, vol. 58, pp. 23–33, 5 2016.
[14] R. B. Myerson, *Game theory*. Harvard university press, 2013.
[15] Z. Han, D. Niyato, W. Saad, T. Baar, and A. Hjrungnes, *Game Theory in Wireless and Communication Networks*. Cambridge Univ. Press, 2012.
[16] L. S. Shapley, "On balanced sets and cores," *Naval Research Logistics Quarterly*, vol. 14, no. 4, pp. 453–460, 1967.
[17] Elia–Belgium's electricity TSO, *Grid data–power generation*. [Online]. Available: http://www.elia.be/en/grid-data/power-generation