A Study of Energy Procurement Strategies for Intermittent Sources

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Abstract. In this study project, we have done an extensive literature review of energy markets and studied various models proposed by different papers regarding the problem of energy procurement strategies for the integration of renewable, intermittent sources in the supply side of energy markets. Based on our literature survey, we then suggest a few strategies which should be considered while making procurement contracts by the utility companies to ensure maximum reliance on renewable sources while meeting the required energy demands at the same time.

1 Introduction

The penetration of renewable energy sources like wind, thermal, solar thermal and solar Photo-voltaic has increased manifold over the last decade, especially after the conception of Smart Grid based electrical system. These sources provide enchanting benefits since they have extremely low running costs and more importantly, do not deplete the natural fuel resources which are on the verge of extinction. However, they also pose significant challenges for their integration into the present electrical grid due to their intermittent, unpredictable nature. Therefore, in order to maintain balanced operation of the electrical grid, a suitable amount of "reserve" capacity of conventional generation must be procured to offset or account for the volatility and uncertainty introduced by the uncertainty in power generation from renewable sources. This requires a modification in the current infrastructure of electrical grid, which assumes highly predictable supply and slightly less predictable demand. Integration of intermittent sources into the current system can raise serious stability issues. Therefore, many models have been proposed to devise a suitable mechanism and set of rules for the integration of renewable sources into the current system, ensuring the same level of grid security and stability. We intend to study a couple of these studies in our course project. These studies show how to use supplies from both nonrenewable and renewable sources and the set or rules which determine what proportion of power should be drawn from each source depending on the uncertainty in the renewable power generation. [2] The ultimate goal is optimizing contract offering strategies in a two-settlement market structure in the face of renewable power production uncertainty.

Our study aims at:
(*i*) Exploring various models presented in the literature for the energy procurement strategies
(*ii*) Understanding the mathematical models presented in the strategic models
(*iii*) Suggest some strategies for the integration of renewable generation units in the light of our literature review

2 Literature Review

There is a considerable literature covering many important aspects of renewable power ranging over comprehensive integration studies, forecasting methods and technological challenges. Some of these references include [1],[2], [3], [4], [5], and [6]. However, we have selected [1],[2] and [3] for our study of future electrical markets since they give a comprehensive overview of the problem and give solutions backed by proper mathematical foundations. A brief survey of these papers is given in the following section.

3 Energy Procurement Strategies in the Presence of Intermittent Sources

This paper studies the problem of conventional energy procurement in the presence of intermittent renewable resources. It models the problem as a variant of the news-vendor problem, in which the presence of renewable resources introduces uncertainty on the supply side, and in which conventional energy may be bought in three stages *long-term market, intermediate market and real-time market i.e. spot market* to balance demand and supply. They also compute closed form expressions for the optimal energy procurement strategy and study the impact of increasing renewable penetration, and of proposed changes to the structure of electricity markets. They explicitly characterize the impact of a growing renewable penetration on the procurement policy by considering a scaling regime that models the aggregation of unpredictable renewable sources. Current markets are designed for reliable sources and uncertainty only appears as failures, which are treated as faults rather than inherent qualities. Demand forecasting ensures that the uncertainty in demand is small. However, uncertainty in the supply can be highly variable depending on the natural factors etc. This paper seeks to provide insights into the impact of increasing supply side uncertainty on the 'efficiency' of procurement. Utility companies typically procure electricity via two modes of operation

- *bilateral long-term contracts*
- *competitive electricity markets*

Currently, most utility companies purchase bulk of their generation through long term bilateral contracts. This is feasible because the aggregate demand is highly predictable and because most conventional generators have very little uncertainty. To account for daily or hourly fluctuations in demand, the utility companies purchase the remainder of their electricity in competitive electricity markets. Wind Energy is finding its way into the energy market as:

- *Competitive Markets*
- *Selling farms to utility companies on long term lease*

Main Contributions of the paper are:

- Characterization of the optimal procurement strategy in the presence of long-term contracts for intermittent, unpredictable generation.
- Study the impact of increasing renewable penetration and proposed changes to market structure on the optimal procurement strategy.

3.1 Model

Assumptions

1) They ignore issues such as generator ramping constraints and transmission network capacity constraints in their model
2) It is assumed that prices are lowest in the long-term market and ramp up as we move to the real-time market.i.e.

$$\mathbb{E}[p_{rt}] > \mathbb{E}[p_{in}] > p_{lt}$$

3) The error in wind capacity estimates decreases as we move closer to real-time markets
4) We make the assumption that the utility cannot sell power in any market and thus the quantities procured in all three markets must be non negative.
5) As the decision making time t' moves closer to real-time, we have to rely more on spot markets than the long term markets

Optimal Strategy

$$\begin{aligned} q_{lt}^* &= d - \hat{w}_{lt} + r_{lt}, \\ q_{in}^* &= [\mathcal{E}_1 - r_{lt} + r_{in}(p_{in})]_+ \,, \\ q_{rt}^* &= [\mathcal{E}_2 - r_{lt} + \min\{\mathcal{E}_1, r_{lt} - r_{in}(p_{in})\}]_+ \end{aligned}$$

Where q represents energy share in respective markets, denoted by subscripts, d is the total demand, r is the energy reserves in a particular market, E1 and E2 denote error in renewable capacity estimates modeled by zero-mean gaussian random variables, while p denotes prices respectively.

3.2 Factors affecting the optimal strategy

The paper also discusses some of the important factors which might affect the optimal strategy derived in the previous section.

1) Increasing Renewable Penetration
This refers to the problem of increasing renewable sources in the supply side of the energy chain. This is the current trend in the energy markets, shifting from conventional to renewable sources. However, this introduces problems like greater uncertainty in the supply capacity, and increase in scalability. Also we have to take into account the correlation between these sources since geographically closely situated sources will show similar changes in their supply in response to external conditions. In the light of factors stated above, the paper proposes a modified strategy by modeling the scalability using parameter gamma and correlation using a factor theta:

$$q^*_{lt}(\gamma) = d - \gamma\alpha + \gamma^\theta \tilde{r}_{lt},$$
$$q^*_{in}(\gamma) = \gamma^\theta \left[\tilde{\mathcal{E}}_1 - \tilde{r}_{lt} + \tilde{r}_{in}\right]_+,$$
$$q^*_{rt}(\gamma) = \gamma^\theta \left[\tilde{\mathcal{E}}_2 - \tilde{r}_{lt} + \min\{\tilde{\mathcal{E}}_1, \tilde{r}_{lt} - \tilde{r}_{in}\}\right]_+$$

The parameter theta takes values from [1/2, 1] where a value of 1 denotes perfect correlation, for example if the sources are geographically clustered together. Whereas a value of 1/2 shows the sources are modeled as independent zero-mean gaussian random variables; and then we can take the limit of large sources and then apply central-limit theorem to get the aforementioned results.

Therefore the paper suggests that while making contracts with renewable companies, correlation should be minimized. This can be done by making contracts with many companies in different geographical locations. Also contracts should be made with different types of renewable generation sources, like solar, solar-thermal and wind.

2) Optimal placement of the intermediate market
It is commonly suggested that as the penetration of renewable sources increases, the system operator may decide to move the intermediate market closer to real time to allow for better prediction of the wind. However, the paper mathematically proves that this increase in prediction accuracy is offset by the increase in energy prices as one moves closer to the real-time markets. hence the placement of intermediate market has no significant in the optimal strategy.

3) Additional intermediate markets
The paper also mathematically shows that additional markets do not always reduce the amount of conventional generation procured; it depends on the estimating error in generation prediction. This emphasizes the importance of generation

forecasts; they are important as the procurement of energy from intermediate and bilateral markets depends on the then price of energy in the spot market (cost benefit analysis i.e. would it be beneficial to acquire long term projects or just buy it at marginally higher rates from the spot market). At the current time, the company does not know what would be the renewable generation levels, nor does it know what would be prices in three tiered markets namely bilateral, intermittent and spot markets.

A key insight from their results is that there is a separation between the impact of the stochastic nature of supply market aggregation and the impact of market structure and forecast accuracy.

4 Bringing Wind Energy to Market

The paper analyzes the setting in which wind power producers *WPP* make their contracts in conventional two-settlement electricity markets. The author formulates and solves the problems of optimal contract size that a producer should offer in order to maximize his profit, in competitive electricity pool with a two-settlement day ahead market. The paper then goes on to analytically quantify the relationship between the optimal contract size and the value of improved forecasting, value of local auxiliary generation, value of storage, and cost of increased reserves needed to accommodate the uncertainty in wind power production.

4.1 Model

The electrical energy market system considered in this paper has a post imbalance settlement mechanism to penalize deviations from contracts scheduled. Both Negative and positive deviations are charged at different prices that can take both positive and negative values depending on system conditions. The paper models wind power as a scalar-valued stochastic process referred as w(t). Using the time averaged density and distribution functions of w(t) the authors then derive the expressions for

$$\Pi(C, \mathbf{w}, q, \lambda) = pCT - q\ S_{-}$$
$$S_{-} = \int_{t_0}^{t_f} [C - w(t)]^{+}\, dt$$

Where p is the offered price, C is the offered contract size, q is the penalty price and T is total time. The optimal Contract C is then found by maximizing the expression for Expected profit for a general case.
Authors then restrict their attention to the case where the time averaged distribution function of Wind energy is a uniform distribution and continue to find the exact value of the optimal expected profit to be

$$J^* = pT\left(\mathbb{E}[W] - \sigma\sqrt{3}(1-\gamma)\right) \quad , \qquad \gamma = \frac{p}{\mu_q}$$

Where E(W) is the expected available wind power and sigma is the measure of uncertainty in wind power.

4.2 Results

Here it can be seen that the value of expected profit is dependent on the penalty price, **q** that a producer has to bear whenever it deviates from the contract. A direct consequence is that the expected profit's sensitivity to uncertainty in available wind power increases as the penalty price q increases as can be seen from the following equation.

$$\frac{dJ^*}{d\sigma} = -pT\sqrt{3}(1-\gamma)$$

After deriving these results for a simple market the authors then consider a wind power producer which procures ancillary services to balance potential deviations between generation and load. As Wind power is inherently difficult to forecast. Moreover, it exhibits variability on multiple time scales so ancillary services like regulation, load following and reserve services will be necessary to compensate imbalances resulting from fluctuations in wind. In this paper all these services are lumped as one and their cumulative effect is studied. This study is particularly important because when capacity penetration of wind increases, its effect on operating reserve margins will become more pronounced and the power producer will have to bear the added cost of these reserve margins. This paper considers a scenario in which the producer procures its reserve margin from a small locally located power generator. This generator can be used to decrease the shortfall risk by producing contract shortfalls up to a limit at a cost qL. For shortfalls larger than this limit, the Producer has no choice but to pay the shortfall imbalance price.

The paper integrates this effect into our already formulated equations for Expected profit and solves them. The marginal expected optimal profit with respect to local generator power capacity L is found to be

$$\left.\frac{dJ_L^*}{dL}\right|_{L=0} = \left(1 - \frac{q_L}{\mu_q^+}\right) pT$$

The result shows that if the cost of auxiliary local generation is lesser than the imbalance price that the producer has to pay then an increase in the auxiliary local generation capacity, L, will result is an increased expected profits and a higher offered contracts.

Using the data set of the 14 wind power generation sites the distribution model of wind power is calculated. Then using this distribution it is shown that as the penalty price q, increase the optimal contracts offered by the producers decreases. Moreover from their results it is evident that producers tend to offer larger contracts during morning/night periods when wind speed is typically higher than during mid-day because of higher available wind power. These results are consistent with already calculated results above. These results provide key insights into the tradeoffs between a variety of factors such as expected imbalance penalties and cost of local generation and their role in determining the optimal contracts offered that yield maximum profits for the producers.

5 Optimal Contract for Wind Power in Day-Ahead Electricity Markets

This paper also studies how a wind power producer can bid optimally in existing electricity markets. We derive optimal contract size and expected profit for a wind producer under arbitrary penalty function and generation costs. The differentiating feature of the paper is to use the model that allows the wind producer to strategically withhold production once the DA (Day ahead) contract is signed. Such strategic behavior is detrimental to the smooth functioning of electricity markets. The paper focuses on a scenario in which a wind power producer participates in a DA market, in which each producer (buyer) submits a bid to the Independent service operator to supply electricity for the next day. The results produced by the authors using the above models show that if allowing for wind power producers to be strategic, we show that as long as the marginal imbalance penalty is higher than the offered price, the wind power producer will produce as much wind power as is available in real-time. This shows that the ISO can schedule wind power producers without worrying about their strategic behavior.

6 Conclusion

In this study we have did an extensive literature review for the problem of finding optimal strategies for energy procurement in the presence of renewable, intermittent sources in the supply side of the energy chain.

The main messages that follow from our study are the following. First, as is commonly recognized, reducing the dependence between the renewable sources (by locating different renewable sources geographically far apart) is key to ensuring efficient utilization of renewable generation. Moreover, it turns out that the optimal placement of the intermediate market does not change as renewable penetration increases. Further, the impact of the intermediate market on the total procurement can be either positive or negative depending on the the distribution of forecast errors. Therefore there are many important, and counterintuitive issues with respect to the incorporation of renewable generation into electricity markets.

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