Contracts for Difference and Risk Management in Multi-agent Energy Markets

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Abstract. The liberalization process of the power sector has led to competitive wholesale and retail markets. Market participants are exposed to risks associated with price volatility and uncertainties regarding production and consumption. This paper addresses these issues by analyzing and evaluating the role of contracts for difference (CFDs) as a financial product used to hedge against risk. The article presents several key features of software gents able to negotiate CFDs, paying special attention to risk management, notably risk attitude, and price negotiation. It starts with a contextualization of the subject, which is followed by the definition of a model to negotiate CFDs, involving several trading strategies and tactics. It starts with a contextualization of the subject, which is followed by the definition of a model to negotiate CFDs, involving a group of strategies to control the exposure of risk by software agents. Finally, a set of case studies is described to assess the performance of CFDs as a risk management tool and to compare their performance to forward bilateral contracts.

Keywords: Electricity markets · Bilateral contracting · Contracts for difference · Risk management · Trading strategies · Autonomous software agents

1 Introduction

The power sector covers four main activities: generation, transmission, distribution and retail of electricity. The way this sector has been organized changed throughout the last century and is customary to distinguish four main models: a regulated natural monopoly, single buyer, competition in a wholesale market, and competition in both wholesale and retail markets [1]. Two key mechanisms for purchasing and selling electrical energy are electricity pools and bilateral contracting. A pool, or market exchange, involves basically a specific

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form of auction, where participants send bids to sell and buy electricity, for a certain period of time. A bilateral contract is an agreement between two parties where one party commits to deliver energy and the other to pay for it. The advantage of this type of agreement is that the terms (such as quantity of energy and price) are custom-made to the parties' needs.

Bilateral contracts can also help to mitigate the position of power of bigger producers in the spot market by not allowing buyers to be dependent on them to fulfill their energy needs and looking elsewhere for a better deal. Another advantage of bilateral contracts is the support given to renewable generation. Renewable energy is characterized by high capital costs and outputs heavily dependent on weather conditions, problems that traditional energy sources do not have. Potential investors require a guaranteed stream of future revenues in order to obtain financing for those resources. Hence, if they engage in bilateral contracts to sell their energy output they have a guaranteed flow of revenue independent of market prices [2].

Electrical energy needs to be consumed within a tenth of second of generation. Consequently, offer has to match demand to ensure efficiency, stability and reliability. Market participants are, therefore, exposed to several risks since they have to work with predictions. These include financial risks related to high volatility of prices due to demand fluctuation which can reach peaks in periods of insufficient generation. Also, important to mention are the risks related to energy volume due to the inherent uncertainty regarding both demand and renewable generation. Risk hedging is essential to market participants and several financial instruments can be used when two parties with opposite views are willing to exchange risk. The most common are future contracts, forward contracts, options contracts and contracts for differences. These contracts can either require the physical delivery of electricity or have a purely financial settlement.

Future contracts include an obligation to buy or sell a specified quantity of energy at a certain future time for a certain price. These contracts have financial daily settlements between the agreed price and the variable spot market price. The parties do not interact directly and a central counter-party guarantees the fulfillment of obligations. The physical delivery is optional. Forward contracts imply a commitment between the parties to sell or buy a specific amount of electricity at a certain future time for a certain price. Unlike future contracts, they involve commitments regarding the date on which the energy is delivered and the payment is done [3]. In these cases, there is no financial settlement and the physical delivery is always required. Option contracts include a right (not an obligation) to buy or sell a specific quantity of an asset at a certain future time for a certain price. A call option gives the right to buy an asset and a put option the right to sell it in a certain future time.

Contracts for difference (CFDs) involve no physical delivery of energy by sellers. The parties fulfill their energy needs in the spot market during the duration of the contract [4]. They establish a bilateral agreement regarding the provision of an amount of energy for a fixed price called the strike price. Also, they come to an agreement regarding the reference price which is used to calculate the differences. If the reference price is higher than the strike price, then the seller will pay the difference to the buyer. Conversely, the buyer pays an amount equal to the difference between the strike price and the reference price. In some cases, contracts for difference can be one way contracts, when the difference payments are made only by one of the parties [3].

Electricity markets are a complex evolving reality—there is now a number of market participants, each one with their own set of objectives, strategies and exposure to risk. One way to model such a complex system is by using autonomous software agents. Software agents are computer systems capable of flexible autonomous action in order to meet their design objectives. They can to respond in a timely fashion to changes that occur in the environment, exhibit goal-directed behavior, and interact with other agents in order to reach their design objectives.

In particular, each agent can be characterized by a set of key features, including [5]:

- A set of beliefs that represent information about the agent and the market;
- A set of goals representing words states to be achieved;
- A library of plan templates to be used in order to reach the goals;
- A set of plans for execution, either immediately, or in the near future.

Against this background, this paper presents several key features of software gents able to negotiate contracts for difference, paying special attention to risk management, notably risk attitude, and price negotiation.

2 Energy Contracts and Bilateral Negotiation

2.1 A Bilateral Negotiation Model

The negotiation model described in this section is based on our previous work in the area of automated negotiation [6–10]. Let $\mathcal{A} = \{a_1, a_2\}$ be the set of autonomous agents participating in negotiation. Let $Agenda = \{x_1, \dots, x_n\}$ be the negotiating agenda representing the set of issues to be deliberated. Each issue is quantitative and defined over a continuous domain $D = [min, max]$. The price limit of each agent for an issue x is denoted by lim.

One of the key aspects of negotiation is the adoption of a negotiation protocol that settles the rules of trading. In the present case, we consider an alternating offers protocol. The agents determine an allocation of the issues by alternately submitting proposals at times in $\mathcal{T} = \{1, 2, \dots\}$. This means that only one offer is submitted in each period $t \in \mathcal{T}$, with an agent, say $a_i \in \mathcal{A}$, offering in odd periods $\{1, 3, \dots\}$, and the other agent $a_j \in \mathcal{A}$ offering in even periods $\{2, 4, \dots\}$. The agents have the ability to unilaterally opt out of the negotiation when responding to a proposal made by the opponent.

The negotiation process starts with a_i submitting a proposal $p^1_{i \to j}$ to a_j in period $t = 1$. The agent a_j receives $p^1_{i \to j}$ and can either accept the offer (`Yes`), reject it and opt out of the negotiation (`Opt`), or reject it and continue bargaining (`No`). In the first two cases, negotiation comes to an end. Specifically, if $p^1_{i \to j}$

is accepted, negotiation ends successfully and the agreement is implemented. Conversely, if $p^1_{i\to j}$ is rejected and a_j decides to opt out, negotiation terminates with no agreement. In the last case, negotiation proceeds to the next time period $t=2$, in which a_j makes a counter-proposal $p^2_{j\to i}$. This process repeats until one of the outcomes mentioned above occurs.

Conceptually, each offer is a vector of issue values sent by an agent $a_i \in \mathcal{A}$ to an agent $a_j \in \mathcal{A}$ in period $t \in \mathcal{T}$:

$$p^t_{i\to j} = (v_1, \ldots, v_n) \tag{1}$$

where $v_k,\ k=1,\ldots,n,$ is a value of an issue $x_k \in Agenda$. The decision to accept or reject an offer depends on the rating that agents give to each issue taking into account their preferences. Each agent has a multi-issue utility function:

$$U_i(x_1, \ldots, x_n) = \sum_{k=1}^{n} w_k \times V_k(x_k) \tag{2}$$

where w_k is the weight for an issue x_k (a number representing the preference of an agent for x_k) and $V_k(x_k)$ is the marginal utility function that gives the score a_i assigns to a value of x_k. This function is used by agents to rate incoming offers and counter-offers. Specifically, offer acceptance will occur when the utility given to a received offer is higher than the utility of the offer that an agent is willing to counter-propose.

2.2 Contracts for Difference and Negotiation

This section extends the above model to simulate typical procedures associated with CFDs. Consider that negotiation involves the prices and quantities of energy for a generic n-rate tariff. Typical tariffs involve two levels (off-peak and on-peak) and three levels (off-peak, mid-peak and on-peak). More refined tariffs backed by legislation can also be imagined and considered if, instead of three rates, suppliers offer four, or even an hour-wise tariff. Accordingly, the agenda includes n energy quantities, i.e., $\{Q_1, \ldots, Q_n\}$, where each quantity represents the consumption of a specific part of a day. The agenda also includes n strike prices and n reference prices. In particular, CFDs require that the parties agree on a set of strike prices:

$$Sp = (sp_1, \ldots, sp_n) \tag{3}$$

where:

(i) Sp is the vector of strike prices (in €/MWh);
(ii) $sp_k,\ k=1,\ldots,n,$ is the strike price for the specific quantity q_k of Q_k.

CFDs also require that the parties agree on a set of reference prices to be used in the definition of the differences. These prices are represented by:

$$Rp = (rp_1, \ldots, rp_n) \tag{4}$$

where:

(i) Rp is the vector of reference prices (in €/MWh);
(ii) rp_k, $k=1,\ldots,n$, is the reference price associated with a specific block of a day.

With the formalization of these vectors, the differences between prices can be computed, and their multiplication by energy quantities gives the appropriate financial compensations. Specifically, when the strike prices are smaller than the reference prices, the seller agent will pay to the buyer. The total amount will be given by the following expression:

$$C_s = \sum_{k=1}^{n} (rp_k - sp_k) \times q_k \tag{5}$$

Conversely, it will be the buyer's turn to pay a financial compensation when the strike prices are higher than the reference prices. The total amount will be given by:

$$C_b = \sum_{k=1}^{n} (sp_k - rp_k) \times q_k \tag{6}$$

3 Bilateral Contracting and Risk Management

3.1 Risk Attitude and Utility

Agents can control their exposure to risk by adopting specific behaviors throughout negotiation. These behaviors depend on their attitude towards risk and the model presented below tries to formalize this dependency.

The expected utility theory states that agents are risk averse when they prefer a prospect with guaranteed outcomes to any other risky prospect that may have better outcomes [11]. Accordingly to this theory, the negotiating agents fit into one of the following categories:

1. *Risk-averse agents*: prefer a setting where they are guaranteed to profit a certain amount to another setting where that profit can be bigger but there is a chance of not getting anything;
2. *Risk-seeking agents*: prefer a setting where there is a chance of making bigger profits (although they are not guaranteed) to another setting where a smaller amount of profit is guaranteed;
3. *Risk-neutral agents*: generally, have no preference over the outcome of negotiation and takes an intermediate stance compared to the two described above.

Negotiation may end with either agreement or no agreement. Risk-averse agents show typically more flexibility to secure a deal, and therefore, concede more to avoid that negotiation ends prematurely without agreement. If an agreement is reached, these agents will probably buy (sell) energy at a higher (lower) price compared to agents that are not averse to risk. Risk-seeking agents

Table 1. Agent classification according to the attitude towards risk

Level of risk aversion	Value of $r(x)$	Interval for λ
Risk-averse	$r(x) > 0$	$\lambda \in \,]0, 1]$
Risk-neutral	$r(x) = 0$	$\lambda = 0$
Risk-seeker	$r(x) < 0$	$\lambda \in [-1, 0[$

tend to be more rigid and firm, typically conceding less than their opponent. By engaging in this behavior, negotiation may end without an agreement being in place. Despite this, if negotiation ends successfully with agreement, risk-seeking agents will probably benefit more than risk-averse agents in similar situations.

In economy, utility is often considered the price that agents are willing to pay for the fulfillment or satisfaction of their desires [11]. Their preferences can be represented using a utility function $u(x)$ with the following properties:

(1) $U(x) > U(x')$ if agents prefer x to x';
(2) $U(x) = U(x')$ if agents are indifferent between x and x'.

For each $x_1, x_2, \ldots, x_n$, there is a probability $\pi_1, \pi_2, \ldots, \pi_n$, of occurrence. Considering mutual exclusivity, the utility function can be written in the following way:

$$u(x) = \pi_1 \, u(x_1) + \pi_2 \, u(x_2) + \cdots + \pi_n \, u(x_n) \tag{7}$$

which is often referred to as expected utility function or von Neumann-Morgenstern utility function [12]. Typically, for risk-averse agents, the utility function is concave, meaning that the utility of the expected value is greater than the expected utility of wealth. Likewise, for risk-seeking agents, the utility function is convex. For the intermediate case (risk-neutral), the utility function is linear [13].

3.2 Measuring Agents' Risk Aversion

A typical approach to quantify agents' attitude toward risk is through the curvature of the utility function. Considering the second derivative $u(x)''$, it will be negative for a concave function, positive for a convex one, and zero for a linear function. John Pratt [14] proposed the following equation to measure agents' risk aversion:

$$r(x) = \frac{-u''(x)}{u'(x)} \tag{8}$$

The sign of $u''(x)$ equals the sign of $-r(x)$. A negative (positive) sign implies unwillingness (willingness) to accept risk. Also, a negative (positive) sign implies strict concavity (convexity) and, therefore, aversion (propensity) to accept risk. Pratt's work will be used as a basis to measure agents' risk aversion: let λ be a parameter correlated with $r(x)$, with $\lambda \in [-1, 1]$. Given λ, and using the sign stipulation of Pratt, agents can be classified according to table 1.

3.3 Negotiation Strategies and Risk Management

Negotiation strategies can reflect a wide range of behaviors and lead to different outcomes. In this paper, we focus on concession making strategies: negotiators reduce their aspirations to accommodate the opponent. Specifically, the measure of risk aversion (λ) will be used to develop a new group of concession strategies.

For a given price P, we adopt the formulae proposed in [5,9] (for seller and buyer, respectively):

$$P_{k_{new}} = P_{k_{prev}} - C_f \ (P_{k_{prev}} - lim), \ k = 1, \ldots, n \tag{9}$$

$$P_{k_{new}} = P_{k_{prev}} + C_f \ (lim - P_{k_{prev}}), \ k = 1, \ldots, n \tag{10}$$

where $P_{k_{new}}$ is the new price for period k, C_f is the concession factor, and lim is the price limit established by the agent. The concession factor C_f varies, in percentage, between 0 and 100. If C_f is null, then agents will not concede during the course of negotiation. If it is equal to 100, then agents make a complete concession on P and thus accept a price equal to their limit.

The concession factor can be simply a positive constant independent of any objective criteria. However, most often it is modelled as a function of a single criterion. Typical criteria include the total concession made on each issue throughout negotiation [5] and the time elapsed since the beginning of negotiation [15]. In this work, we model the concession factor as a function of the attitude towards risk: the bigger the flexibility in negotiation the bigger the concession factor will be. This implies that a risk-averse agent makes concessions at a bigger rate and, therefore, the concession factor will be bigger than the one of a risk-seeking agent that shows unwillingness to concede and less flexibility in negotiation.

The concession factor can be represented by considering either a polynomial or an exponential function. In this work, we consider an exponential function. To keep multi-agent negotiation as close as possible to real-world negotiations, functions that give values for C_f smaller than 5% and larger than 25% were not considered, as these values do not represent reasonable negotiation stances. The general form of the exponential function is as follows:

$$C_f = C_{fn} \ e^{c\,\lambda} \tag{11}$$

where λ is the value of the agent's risk aversion, C_{fn} is the concession factor for a risk-neutral agent ($\lambda = 0$), and c is a constant that shapes the function's curvature.

Equation 11 represents a family of tactics, one for each pair of values (C_{fn}, c). Accordingly, several simulations were made to define appropriate values for these

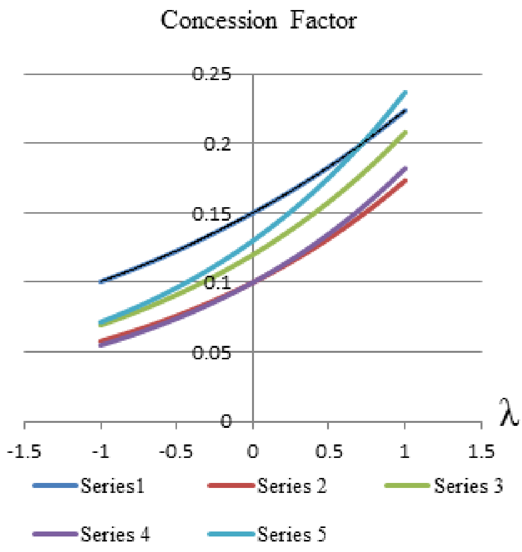

Fig. 1. Concession factor for a given measure of risk aversion

parameters. Table 2 shows the values considered and figure 1 the behavior of the resulting functions. After a detailed analysis, we chosen the following exponential function: $C_f = 0.1\ e^{0.55\,\lambda}$, which gives the following range of values for the concession factor: [0.057, 0.17].

Table 2. Tested exponential functions

Series	Function
1	$C_f = 0.15\ e^{0.40\,\lambda}$
2	$C_f = 0.10\ e^{0.55\,\lambda}$
3	$C_f = 0.12\ e^{0.55\,\lambda}$
4	$C_f = 0.10\ e^{0.60\,\lambda}$
5	$C_f = 0.13\ e^{0.60\,\lambda}$

4 Conclusion

This paper has presented the key features of a negotiation model for bilateral contracting in multi-agent electricity markets, placing emphasis on risk management and contracts for difference. Conceptually, the model incorporates a set of strategies and a set of tactics. The agents negotiate according to their attitude towards risk. Risk-averse agents show typically more flexibility to secure deals, and therefore, are willing to concede more to avoid that negotiation ends prematurely without agreement. Risk-seeking agents are more rigid and firm, typically conceding less than their opponent.

Negotiation tactics are functions that specify the individual moves to be made at each point of the negotiation. Typically, these tactics are modelled as functions of specific criteria (e.g., the time elapsed since the beginning of negotiation). In this paper, we focus on concession making tactics: negotiators reduce their aspirations to accommodate the opponent. They are modelled as exponential functions of the attitude towards risk: the bigger the flexibility in negotiation the bigger the concessions will be. In the future, we intend to perform a number of experiments to empirically evaluate the key component of the agents, notably the concession making strategies and their associated tactics.

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