PAY-AS-BID AUCTIONS FOR A FIRM BILATERAL STATUS

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Abstract – This paper presents a systematic auction mechanism carried our by the System Operator to allocate Firm Bilateral Status. This status guarantees scheduling priority of physical bilateral contracts, and is considered an obligation rather than an option. To compete for the purchase of this firm status, each participant submits an offer that specifies the amount it is willing to pay in the event it wins any portion of the requested firm status. Similarly, parties that have already obtained this status may submit bids to sell them. The auction is settled by solving an optimization problem that maximizes the combined revenues from the offers and bids, while respecting system constraints, such as the power balance at all buses, constraints on the generation and transmission flow limits.

In contrast to Financial Transmission Rights (FTRs) auction techniques, the method proposed here is based on pay-as-bid pricing, as payments for the firm status of winning offers are equal to the values that have been submitted to the auctioneer. Therefore, market participants who take part in the auction know exactly the price they will face if their offer is successful. Furthermore, this pay-as-bid approach is more transparent as the price for obtaining the firm status does not depend on system operating conditions that may change from one auction to another. The proposed procedure could also be used to allocate FTRs.

Keywords: Firm Bilateral Status, transmission rights allocation, auction mechanisms, pay-as-bid pricing, marginal pricing.

1 INTRODUCTION

To ensure and encourage competition, some electricity markets currently allow both centralized and bilateral trading. The first form is usually managed by a System Operator (SO), who decides on a system dispatch based on submitted generator bids and load offers, while respecting system constraints.

Bilateral trades, on the other hand, can be arranged either directly among interested parties or through facilitated forwards and futures markets. Depending on the market, these trades can be either physical obligations or financial instruments. While a majority of markets favors financial agreements, markets in California [1], Ontario [2], and the UK permit physical contracts.

Open access to the transmission network is a vital element for both centralized and bilateral trades. Transmission access rules have to ensure that all market participants have equal access to the transmission grid as denial of such services infringes on free market operation and distorts competition.

Because of losses and congestion, the ability to trade can however be very much affected by the transmission network. In particular, some markets participants may be denied access to the transmission network because for certain trades they would need to use congested lines, i.e. lines where the capacity has already been "consumed" by other participants.

While congestion in the network affects all market participants, those involved in bilateral trades are especially vulnerable for two reasons. First, in the case of physical contracts congestion may prevent some bilateral trades from being scheduled because there is not sufficient transmission capacity available to support the requested transfer of power. Second, bilateral contracts usually involve only an agreement for the delivery of energy. Their negotiated price does not include payments for transmission and ancillary services. When the transmission system is congested, these additional payments can be very high for both financial and physical contracts.

The aim of this paper is to address the first problem, that is, how to approve physical bilateral transactions ahead of time so that the parties involved can be sure that their contract will be honored. An auction mechanism that allows parties to obtain pre-approved point-to-point Firm Bilateral Status (FBS) is thus proposed. This pre-approved firm status guarantees that a bilateral transaction has priority in scheduling, and thus it amounts to a firm right. Note that the FBS also represent an obligation on the producer and the consumer to carry out the approved contract.

To ensure the security and optimal usage of the system, the allocation of firm rights must be done centrally by the System Operator. Furthermore, the process of allocating a firm status can either rely on a periodic sales or on a continuous auctions operated on a first-come-first-served basis. The former is being denoted *Purchased Firm Bilateral Status (PFBS)* and the latter *First-come-first-serve Firm Bilateral Status (FFBS).*

To compete for the purchase of this firm status, each participant submits an offer that specifies the amount of firm rights it is seeking and the amount that it is willing to pay for any portion of the requested firm status that it wins at the auction. Similarly, parties that have already obtained a firm status may submit bids to sell it. The auction is settled by solving an optimization problem that seeks to maximize the combined revenues from the offers and bids, while respecting system constraints, such as the power balance at all buses, constraints on generators and transmission flow limits. The SO also verifies that approved bilateral contracts can be delivered under certain contingencies.

A discriminatory *pay-as-bid* pricing mechanism has been adopted for this auction, so that payments for the firm rights of winning offers are equal to the offer submitted to the auctioneer. Thus, market participants who take part in the auction know exactly the price they will face if their offer is successful. We believe that the pay-as-bid approach is more transparent as the price for obtaining the firm status does not depend on system operating conditions that may change from one auction to another.

As shown below, the allocation based on the first-come-fist-served concept has a similar mathematical formulation as for the purchased auctions. The main difference is that all interested parties submit only values of the requested Firm Bilateral Status, while the offer price is the same for all transactions. Furthermore, there is no payment associated with obtaining these rights, as they are now allocated for free.

Note that this pay-as-bid auction mechanism for Firm Bilateral Status can also be applied to allocate Financial Transmission Rights. These financial rights are used to hedge against volatile transmission and congestion charges, since they enable their holders to collect congestion revenues. As discussed in the next section they significantly differ from Firm Bilateral Status of physical bilateral contracts.

2 FIRM BILATERAL STATUS VS. FINANCIAL TRANSMISSION RIGHTS

Recall that, generally, two types of bilateral contracts can be distinguished, that is *physical* and *financial*.

In this paper, we are mainly concerned with physical contracts. It is not our aim here to advocate in favor of any of these two types of contracts, but to address a problem of how to approve physical bilateral trades without violating system security limits. For bilateral parties involved in these trades it is necessary to confirm with a System Operator that their agreements can be scheduled, and this permission is typically obtained well ahead of time.

Physical bilateral trades specify the parties that generate and consume the power agreed to in the contract, the buses of injection and consumption, as well as the amount of traded power. A selling generator has the obligation to produce power to supply at least all of its physical bilateral contracts, while a load is expected to consume at least all of its physical bilateral contracts.

Financial contracts, on the other hand, are agreements that specify only the amount and the price of the traded power. The points of injection and consumption may or may not be defined. Even if known, these points are not binding. This means that a selling side of the contract is free to appoint any market participant willing to supply the energy, while a buyer can also resell the contract further, and find another party to consume the power. Financial contracts may be resold at the market several times before the expiration date.

From the operational point of view, physical contracts directly affect generation dispatch and transmission flows. Because of these influences on the overall system operation, the network usage resulting from each bilateral contract has to be approved by the System Operator before its actual scheduling.

Financial contracts on the other hand do not need to obtain any kind of advanced approval. A system operator does not even have to know about their existence. To implement the trades arranged through financial contracts it is, however, necessary to transform them into settlements that firmly define the points of consumption and to specify whether these loads are supplied bilaterally or through the pool.

As mentioned above both physical and financial contracts are vulnerable to congestion of a transmission network. Physical contracts are concerned both with the problem of available transmission capacity to transfer the requested power and with the problem of high congestion charges, while bilateral parties involved in financial contracts are only concerned with congestion payments.

2.1 Financial Transmission Rights (FTR)

In practice, the problem associated with the congestion charges has been often addressed by introducing Financial Transmission Rights (FTRs) [3] or using Flowgates [4].

Financial Transmission Rights are point-to-point rights that entitle their owners to collect a congestion charge. For example, if a market participant holds a FTR between point i and point j for the amount of power GD_{ij}, it will receive a corresponding congestion charge that is equal to the nodal price difference between these two buses, multiplied by the specified power GD_{ij}. By obtaining such FTR bilateral parties who trade this amount of power between specified points will receive a congestion rent that is equal to their congestion payment, and thus hedge against uncertain network conditions.

The FTRs are typically sold in auctions run by a System Operator who manages transmission access. So far, few models for auctions of Financial Transmission Rights have been developed and applied in practice [1]. Their main characteristic is that interested parties submit offers to purchase a portion of the available transmission capacity and the auctioneer allocates the rights by maximizing revenue collected from these sales.

All of these auctions are cleared at marginal prices, and most of them allow for point-to-point Financial Transmission Rights in the form of obligations, and sometimes options [5]. Furthermore, such auctions normally include a *Simultaneous feasibility* test that verifies whether a requested FTR satisfies power system constraints under various contingencies. This test should ensure revenue adequacy, which, as stated in [5], can be proved for lossless DC networks, but not for non-linear models that also include losses. If necessary, the revenue adequacy of the SO is preserved by scaling down the FTR payoffs. Except for the New York market, all auctions are based on linearized DC models.

Although Financial Transmission Rights have been accepted as a useful instrument to hedge against congestion rents, recent analyses of currently operating markets indicate that there is a significant difference between expected FTR payoffs and their clearing prices [6-7]. It is argued in [6] that inefficiencies in FTR auction are due to the simultaneous feasibility test. As clearing prices depend on the values of the bid quantities, it is very difficult to predict the actual value of a FTR. Similar results are found in [7], where empirical data from auctions held in New York market were evaluated.

In addition, a complex joint energy and transmission rights auction has been proposed in [8]. Their model includes both Financial Transmission Rights and Flowgates, with the possibility for the FTRs to take a form of either obligations or options. Although the method in [8] is also based on marginal pricing, the clearing price reflects a shadow price of the congested line. Thus, it may happen that the clearing price becomes zero in the case when lines are not congested.

2.2 Firm Bilateral Status (FBS)

In this paper, we propose the concept of a Firm Bilateral Status (FBS) that will address a problem associated with uncertainty with respect to the available transmission capacity so to execute a physical bilateral trade. When bilateral parties come to an agreement that they want to trade a specified amount of energy via a physical trade, they need to obtain a Firm Bilateral Status. This status will give them a right to access the network at specified points and transfer the pre-approved amount of power. Allocation of the FBS will be in the domain of a System Operator. Since it is already responsible to operate transmission network and maintain its security, it has all necessary information and tools to verify feasibility of physical bilateral trades.

In contrast to Financial Transmission Rights, FBS can only be in the form of obligations, as bilateral parties have to implement their trade for which a Firm Bilateral Status has been obtained. Furthermore, these rights may or may not encompass Financial Transmission Rights so to act as a hedge versus high congestion rents.

3 MECHANISMS FOR ACQUIRING FIRM BILATERAL STATUS

The rights associated with a firm bilateral agreement can be acquired in two ways, as *Purchased Firm Bilateral Status (PFBS)* and *First-come-first-serve Firm Bilateral Status (FFBS)*. Both of these rights will essentially guarantee firm bilateral status to the involved bilateral contract. The first method is through an auction where the highest bidder wins and essentially buys a Firm Bilateral Status. As shown below, the PFBS auction is defined systematically though an optimization procedure that accounts for all system constraints including losses and transmission congestion. The auction gives firm status to all bidders if there is enough capacity, and if not, it gives firm status to the sub-set of bidders who place the highest combined worth on their requested bilateral contracts. The contracts that are assigned firm status by the auction then pay to the SO an amount equal to the worth that they quoted. This is in contrast to auctions for Financial Transmission Rights, which are sold at marginal clearing prices.

So far, the marginal pricing has been the predominant pricing mechanism applied in electricity markets, especially for energy auctions. The argument for this has been that marginal prices send a correct economic signal regarding the availability of the adequate resources. Following these arguments, auctions for Financial Transmission Rights have been set in a similar manner, so that all FTRs are cleared at marginal prices. However, analyses of empirical data from some current markets indicate that it is difficult for market participants to guess the actual value of FTRs properly, and thus the economic signals that these prices should convey remain hidden.

Thus, the pay-as-bid pricing mechanism could be appropriate for both FTRs and Firm Bilateral Status. To obtain this status market participants still have to compete against each other, therefore the economic signals regarding the efficient usage of available transmission resources are preserved. Only, the prices that bilateral parties need to guess are more transparent, and easier to forecast.

Similarly to Financial Transmission Rights, the Purchased Firm Bilateral Status could be traded in a secondary market, with the restriction that its owners always retain responsibility for the allocated power transfer. This differs significantly from FTRs whose owners actually do not have to get involved in any physical power transaction. Note that market rules could be chosen in a way that for congested operation allows owners of the Purchased Firm Bilateral Status to trade it back to the SO through curtailment offers [9].

In the First-come-first-serve Firm Bilateral Status (FFBS) approach, the SO assigns firm status periodically and relatively frequently. The allocation is based on the transmission capacity available at the very moment when this procedure is performed. All bilateral contracts that have been previously awarded firm status remain intact, while the SO seeks to accommodate as much of the newly requested bilateral transactions sum as the current transmission capacity allows. In contrast to PFBS, under the FFBS all contracts are considered equal and typically do not pay anything for obtaining Firm Bilateral Status.

It is interesting to note here that one of the suggestions made in [6] is to allocate FTRs for free based on some historical data, and then leave it to the secondary market to determine the true value of FTRs. In practice, it may be difficult to justify allocation according to previous trading patterns because it will discriminate against new trading agreements. Thus, one of the solutions could be to use the allocation on the first-come-first-serve basis.

3.1 Purchased Firm Bilateral Status (PFBS)

The systematic auction mechanism carried out by the SO to allocate PFBS to bilateral contracts is presented below. To compete for firm status, each bilateral contract submits an offer to the SO representing the value that the contract parties jointly place on acquiring firm status. This value should normally be less than the negotiated price of the bilateral agreement. The SO then allocates firm status to the sub-set of bidders who place the highest combined worth on their requested bilateral contracts. The contracts that are assigned Firm Bilateral Status by the auction pay to the SO an amount equal to the value that they have quoted.

In this auction, the bid submitted by each bilateral contract specifies the points of injection, *i*, and consumption, *j*, and the price in $/MWh that the contract parties are willing to pay, bf_{ij}^{app}, for the eventual amount of firm power allocated, GDF_{ij}. This level of firm allocated power must be less than or equal to the amount requested, that is, $GDF_{ij} \le GDF_{ij}^{req}$.

The auction run by the SO is settled by solving an optimization that maximizes the combined revenue from all bids, while respecting the system constraints,

$$\max_{\mathbf{GDF}} \sum_{i,j=1}^{n_b} bf_{ij}^{app} GDF_{ij} \qquad (1)$$

$$\text{s.t.} \quad (\mathbf{P}_g, \mathbf{Q}_g, \mathbf{V}, \boldsymbol{\delta}) \in S$$

$$0 \le GDF_{ij} \le GDF_{ij}^{req}$$

$$\mathbf{P}_g \ge \mathbf{P}_g^b = \mathbf{GDF} \cdot \mathbf{e}$$

The ($n_b \times n_b$) matrix **GDF** in (1) describes the Firm Bilateral Status allocated to bilateral contracts whose requested values are defined by ($n_b \times n_b$) matrix $\mathbf{GDF}^{req}$. Therefore, each of the elements GDF_{ij} and GDF_{ij}^{req} represent allocated Firm Bilateral Status and requested bilateral contract values between generator i and load *j*, respectively. For the sake of simplicity, it is assumed that for a network of n_b buses, each bus has only one load and/or one generator.

In the above equations, the total of all bilateral agreements for each generator, $\sum_{j=1}^{n_b} GDF_{ij}$, define its bilateral generation component, P_{gi}^b, as described in [10] for the combined pool/bilateral market. These individual bilateral generation components now compose vector $\mathbf{P}_g^b$ of equation (1). Also, we have defined the n_b-dimensional vector $\mathbf{e}=[1 \ldots 1]^{\mathrm{T}}$.

Furthermore, the set S above denotes the security region of the power system in the space of generation levels and bus voltages, ($\mathbf{P}_g, \mathbf{Q}_g, \mathbf{V}, \boldsymbol{\delta}$). Such a region is defined by:

- the load flow equations,

$$\mathbf{P}_g = \mathbf{P}_d + \mathbf{P}(\mathbf{V}, \boldsymbol{\delta}) \quad \text{and} \quad \mathbf{Q}_g = \mathbf{Q}_d + \mathbf{Q}(\mathbf{V}, \boldsymbol{\delta}),$$

- the range of real and reactive generation,

$$\mathbf{P}_g^{\min} \le \mathbf{P}_g \le \mathbf{P}_g^{\max} \quad \text{and} \quad \mathbf{Q}_g^{\min} \le \mathbf{Q}_g \le \mathbf{Q}_g^{\max},$$

- the voltage magnitude limits,

$$\mathbf{V}^{\min} \le \mathbf{V} \le \mathbf{V}^{\max},$$

- and the transmission flow limits,

$$\left|\mathbf{P}_f(\mathbf{V}, \boldsymbol{\delta})\right| \le \mathbf{P}_f^{\max}.$$

Thus, the auction for firm bilateral status is carried out in a systematic fashion that accounts for both the network power balance at all buses and for transmission flow constraints. This is an important feature when compared to the allocation of Financial Transmission Rights, which in practice is usually based on simple transmission capacity models that may not accurately reflect the true transmission capacity.

As discussed before, once a firm contract is approved, the trading parties have both the right and the obligation to transfer the allocated amount of power.

The expenses associated with this Firm Bilateral Status for each contract is,

$$E_{ij}^{app} = b_{ij}^{app} GDF_{ij} \qquad (2)$$

On the other hand, the revenue of the SO from the above auctions is,

$$R_{SO}^{app} = \sum_{i,j=1}^{n} bf_{ij}^{app} \; GDF_{ij}, \qquad (3)$$

which becomes part of the SO merchandising surplus.

3.2 First-Come-First-Serve Firm Bilateral Status (FFBS)

The Firm Bilateral Status can also be acquired using a first-come-first-serve method. Here, the SO performs the allocation procedure periodically as new requests for bilateral firm status are received. Allocation of the remaining capacity is performed without modifying any of the firm bilateral contracts previously approved. Also, in a new batch, all requests for firm status have the same priority.

Since the goal of the SO is still to maximize the combined value of the approved firm bilateral contracts, the objective function as defined in (1) is used here with $bf_{ij}^{app} = 1$ for all new allocated bilateral agreements, GDF_{ij}. Moreover, the lower generation limit now also has to account for the already approved bilateral contracts, GDF_{ij}^{app}, that is, $\mathbf{P}_g \ge \mathbf{P}_g^b = (\mathbf{GDF}^{app} + \mathbf{GDF}) \cdot \mathbf{e}$. Note that in the above constraint previously approved contracts, GDF_{ij}^{app}, are imposed as hard limits, which normally cannot be modified in subsequent auctions. Therefore, there are no bids associated with already approved contracts, unless parties that already own firm rights wish to sell them.

Thus, in the sequential First-come-first-served approach, the SO allocates firm bilateral status by carrying out the following optimization procedure,

$$\max_{\mathbf{GDF}} \sum_{i,j=1}^{n} GDF_{ij} \tag{4}$$

$$\text{s.t.} \quad (\mathbf{P}_g, \mathbf{Q}_g, \mathbf{V}, \boldsymbol{\delta}) \in S$$

$$0 \le GDF_{ij} \le GDF_{ij}^{req}$$

$$\mathbf{P}_g \ge \mathbf{P}_g^b = (\mathbf{GDF}^{app} + \mathbf{GDF}) \cdot \mathbf{e}$$

As in the case of (1), the set S denotes the power system security region that includes the real and reactive bus power balance at each bus.

In the first-come-first-serve approach, the SO does not collect any revenue since the bilateral parties do not pay to acquire firm status. A difficulty with this approach is that when there is not sufficient transmission capacity the solution of (4) may not be unique if bilateral trades that are causing congestion have submitted their requests at the exactly same time.

It is interesting to note here that when the last inequality constraint of equation (1) that defines lower generation limits, $\mathbf{P}_g \ge \mathbf{P}_g^b = \mathbf{GDF} \cdot \mathbf{e}$, is replaced with the corresponding constraint of (4), $\mathbf{P}_g \ge \mathbf{P}_g^b = (\mathbf{GDF}^{app} + \mathbf{GDF}) \cdot \mathbf{e}$, the model for Purchased Firm Bilateral Status is enhanced so to allow for periodic auctions. In these periodic auctions, the SO operator may decide first to sell only a portion of the available capacity, while the remaining transmission capacity will then be allocated in few successive auctions that respect the already existing Firm Bilateral Status of the previous rounds.

Furthermore, pay-as-bid pricing mechanisms that are similar to above described auctions could also be applied to auctions for Financial Transmission Rights.

4 NUMERICAL EXAMPLES

The proposed pay-as-bid auction mechanism for the Firm Bilateral Status is illustrated on a 5-bus network, whose data are given in an Appendix. Requested values of the Firm Bilateral Status in MW are modeled by the following matrix,

$$\mathbf{GDF}^{req} = \rho \begin{bmatrix} 20 & 30 & 20 & 90 & 100 \\ 0 & 30 & 20 & 70 & 150 \\ 0 & 0 & 30 & 30 & 50 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} MW \tag{5}$$

By varying parameter ρ in the above equation, we will investigate how different levels of requested Firm Bilateral Status, $\mathbf{GDF^{req}}$, affect the final approved values, $\mathbf{GDF}$. For the Purchased Firm Bilateral Status these approved values also depend on the offers submitted by bilateral parties, which here have values (in \$/MWh) of,

$$\mathbf{bf}^{app} = \begin{bmatrix} 0.01 & 3.33 & 5.1 & 1.11 & 6.1 \\ - & 0.01 & 0.12 & 0.24 & 0.36 \\ - & - & 0.01 & 0.04 & 4.98 \\ - & - & - & - & - \\ - & - & - & - & - \end{bmatrix} \tag{6}$$

The unfilled positions in the above matrix indicate that there are no corresponding bilateral contracts and thus no offers. Furthermore, contracts between a generator and a load at the same bus do not generally need to buy this firm status. However, some of these contracts are defined as non-zero elements in matrix $\mathbf{GDF}^{req}$, as we wanted to illustrate that even when these contracts apply for the FBS, they will indeed be taken into consideration and approved. For example, a requested value of Firm Bilateral Status between generator 1 and load 1 is $GDF_{11}^{req} = 20$ MW. Because such contracts do not use the network, their offers could be equal to 0, but due to numerical considerations, we have set them to a small number of 0.01 \$/MWh. Note that we have also set low offer values, bf_{ij}^{app}, for some transactions that are between different buses and thus need to secure network access. The objective of such choice was to demonstrate that even low offers could acquire Firm Bilateral Status, but only when there was sufficient transmission capacity. This is not the case however if transmission network is heavily used.

First, we consider an instance when parameter $\rho = 1$. The solution of (1) allocates Firm Bilateral Status to all bilateral trades for the entire requested values, so that $\mathbf{GDF} = \mathbf{GDF}^{req}$. This result will not change even if we take into consideration line contingencies by simulating the outage of each line.

Note that even transactions between different buses that have low offer values, bf_{ij}^{app}, are fully allocated. For example, a Firm Bilateral Status for transaction between generator 3 and load 4 is equal to the requested value $GDF_{34} = GDF_{34}^{app} = 30$ MW, even though these participants have submitted offer of only $bf_{34}^{app} = 0.04$ \$/MWh. The similar is true for the transaction between generator 2 and load 3.

Corresponding expenses that bilateral trades have to pay to the SO for the allocation of the Firm Bilateral Status are calculated on a pay-as-bid basis as defined in (5), and are shown in Table 1. The revenue that the SO collects from these sales is equal to the sum of all of these payments, that is $R_{SO}^{app} = 1285.6$ \$/h.

		E_{ij}^{app} [$/h]				
		bus # of buying load				
		1	2	3	4	5
bus # of selling generator	1	0.2	99.9	102	99.9	610
	2	–	0.2	2.4	16.7	53.8
	3	–	–	0.3	1.13	298.8

Table 1: Pay-as-bid payments for Firm Bilateral Status when ρ=1

To investigate how an increase in requested values of Firm Bilateral Status will affect the actual allocated amounts we have raised the value of parameter ρ to 2. In this case, values of approved Firm Bilateral Status become,

$$\mathbf{GDF} = \begin{bmatrix} 40 & 60 & 40 & 180 & 200 \\ 0 & 60 & 40 & 140 & 300 \\ 0 & 0 & 60 & 2 & 100 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \text{ MW} \qquad (7)$$

Curtailed by 97 %

The above **GDF** matrix is valid for a network operating under normal conditions. If we consider line outages, then the following adjustments have to be made:

- due to a congestion on line 1-2 when line 1-4 is out, contract 1-4 has to decrease by 16.7%, to the value $GDF_{14} = 150$ MW. At the same time contract 2-5 is reduced by 82% to $GDF_{25} = 54.2$ MW, while contract 2-3 does not get allocated any amount of the requested Firm Bilateral Status;
- a failure of line 4-5 causes a congestion on line 3-5, which calls for a contract 2-5 to decrease by 45% to the value $GDF_{25} = 164.5$ MW. However, the limit on contract 2-5 set by the previous contingency is lower and thus binding.

These limitations are consistent with the values of bilateral contract offers as they are low for all of the above agreements. To obtain higher levels of Firm Bilateral Status these market participants need to reevaluate their bids and recognize that they have underestimated the value of the available transmission capacity.

It is also interesting to note that despite the fact that the offer of contract 3-4 was very low it was nevertheless able to secure the full value of its requested Firm Bilateral Status. This is due to the behavior of other participants as their requests put more stress on the system, which could have not be alleviated by curtailing transaction 3-4.

For this case, corresponding payments of bilateral contracts are given in Table 2, while revenue of the SO is $R_{SO}^{app} = 2444.8$ \$/h.

		E_{ij}^{app} [$/h]				
		bus # of buying load				
		1	2	3	4	5
bus # of selling generator	1	0.4	200	204	166.7	1220
	2	–	0.4	0	33.5	19.5
	3	–	–	0.6	2.7	597.6

Table 2: Pay-as-bid payments for Firm Bilateral Status when ρ=2

The above results show that pay-as-bid auctions can be successfully used for allocation of Firm Bilateral Status, as they assign these rights to the parties that value them the most. The calculation of winning bids is simple, yet it conveys correct economic signals with respect to the efficient usage of a transmission network. Although in some cases it may seem that bilateral contracts may obtain FBS for free, there is a risk of not being able to secure transmission if the network becomes congested.

5 CONCLUSION

The paper presents a systematic pay-as-bid auction mechanism for the allocation of a Firm Bilateral Status. For market participants who are involved in physical bilateral trades these rights are useful tools to address a question of how to secure transmission access and priority in scheduling of their bilateral agreements. As these trades directly affect system operation, the problem of their coordination is an important issue for both a System Operator and involved bilateral parties.

The proposed method allows bilateral partners either to compete for the purchase of the Firm Bilateral Status or obtain them on the first-come-first-served basis. The allocation of these rights is done via centrally controlled auctions, which are run by the SO. These auctions are usually performed periodically, so that the total transmission capacity is not distributed at once, but rather in a few successive steps. Every subsequent step respects the Firm Bilateral Status awarded in the previous auctions.

To compete in the PFBS auctions, each participant submits an offer that indicates the price it is willing to pay in the event it wins any portion of the requested Firm Bilateral Status. In addition, parties that already have this status but wish to sell it may submit bids to do so. The SO collects these offers and bids, and settles the auction by solving the optimization problem that maximizes the combined revenues from Firm Bilateral Status sales. To ensure secure system operation, the settlement procedure accounts for system constraints such as network power balance at all buses, constraints on the generation and transmission flow limits. This auction procedure that includes AC power flow constraints is solved once at each auction period.

Since the method proposed here is based on the pay-as-bid pricing, payments of winning offers are equal to the values that interested bilateral parties have submitted. Therefore, the price of the allocated Firm Bilateral Status is known in advance to each party participating in the trade. This is in contrast to typical settlement process of Financial Transmission Rights, which are sold at marginal clearing prices.

Proponents of marginal pricing usually argue that this method sends better economic signals regarding the availability of the available resources. However, the application of the proposed PFBS auction procedure is illustrated on examples whose results show that pay-as-bid pricing mechanism here properly reflects the lack of sufficient transmission resources, and sends adequate signals to involved bilateral parties. Its advantage is that it is more transparent and easier to use, as market participants decide in advance on the price they will pay for any portion of the allocated Firm Bilateral Status. Although guessing the behavior of others is not a trivial task, it may be less complicated to estimate correctly adequate beneficial offers in pay-as-bid then in marginal auctions. As mentioned, a research on FTR auctions in some US markets has showed that under marginal pricing market participants tend to overpay for obtaining this right.

The paper also shows that a similar optimization procedure can be used to allocate a Firm Bilateral Status on first-come-first-serve basis. Since now all competing bilateral trades have the same price, bilateral parties that wish to participate in FFBS auctions submit only values of requested FBS. Typically, this type of FBS is allocated for free.

Finally, we conclude that the presented pay-as-bid auction technique can also be extended to formulate similar mechanisms for allocation of Financial Transmission Rights.

6 APPENDIX

Table 3 shows the data for a five-bus illustrative network used in these studies.

From	To	r (p.u.)	x (p.u.)	b (p.u.)	P_f^{max} (MW)
1	2	0.0147	0.11	0.138	300
1	4	0.0108	0.12	0.102	355
2	3	0.0185	0.12	0.185	300
3	4	0.0294	0.14	0.296	300
3	5	0.0221	0.12	0.213	300
4	5	0.0108	0.135	0.104	450
2	4	0.0105	0.101	0.100	360

Table 3: Network line data

The bus voltages are assumed fixed at one per unit by sufficient VAr sources. The line resistances, series impedances and shunt reactances are in per unit on a basis of 100 MVA and 200 kV. The column, P_f^{max}, denotes the absolute line flow limits in MW. This limit is used for a network under normal operating conditions, while emergency limits applied in contingency analysis are considered 50% higher.

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