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AgentUDE: The Success Story of the Power TAC 2014's Champion

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Abstract. The future smart grid will bring new actors and features such as local producers, storage units and interruptible consumers to the current electricity grid along with the challenge of sustainability. The Power Trading Agent Competition (Power TAC) provides a comprehensive simulation platform to enable and verify various smart grid studies from the perspective of sustainability as well as an annual competition in which autonomous agents trade in energy markets and make profits. AgentUDE won the Power TAC 2014 Final as the youngest agent of the competition utilizing an adaptive and reactive agent. This paper details the basic strategies of AgentUDE and tournament results.

Keywords: Power trading, broker, wholesale market, energy, multi-agent.

1 Introduction

Smart grid has become a stimulating topic for researchers and entrepreneurs while new energy actors are being involved in the grid that make possible to store electricity in a distributed way. In the meantime, fossil fuel based electricity production is likely to be replaced with renewable energy production, which have fitful energy production trend [5]. At this point, data, money and power flow between these power actors have to be experienced and verified within a realistic smart grid simulation platform in order to fill the gap between theory and practice. Power TAC[1] provides an open source, smart grid simulation with the aim of addressing a solution to this problem through letting autonomous brokers to trade in a smart grid environment. The platform enables various smart grid studies based on the power models such as customer models and energy markets and simulates typical energy markets such as wholesale market, retail and balancing markets where the details are explained in Section 3 [1].

Power TAC 2014 Final games were held in AMEC / TADA workshop co-located with AAMAS 2014 in Paris. Here, 72 games were played in 3-player, 5-player and 8-player game sizes. All in all, AgentUDE won the Power TAC 2014 Final competition as the newest participant among seven brokers by means of having the most profit. After AgentUDE, cwiBroker and CrocodileAgent took the second and third places respectively.

[1] Power TAC, http://www.powertac.org.

This paper describes the wholesale, retail market and balancing activities of AgentUDE as well as a detailed performance comparison. In the meantime, the main focus of this paper is the aggressive tariff strategy of AgentUDE, which brings the first place in Power TAC 2014 Final games. The organization of the paper is as follows. Related work is given in Section 2. Afterwards, 2014 Final games are detailed in Section 3 in addition to tournament results. Section 4 is dedicated to AgentUDE that details retail, wholesale and balancing activities. Future work is given in Section 5. Finally, paper is concluded in Section 6 with a projection to Power TAC 2015 final games.

2 Related Work

Unfortunately, there are very few publications available from the brokers' side. One of them is TacTex which is the winner of the Power TAC 2013 final games. As mentioned in the paper, TacTex uses "Markov Decision Process" to minimize the energy costs in the wholesale market. On the other side, it optimizes the future demands, prices and predicted energy costs in order to pick an appropriate tariff among precreated, fixed-rate candidate tariffs [3].

Another broker publication from AstonTAC team focuses to the wholesale market trading using "Markov Decision Process" for price optimization and "Non-Homogeneous Hidden Markov Models" for future predictions [4].

The last broker paper is written by cwiBroker team, which was very successful in 2013 and 2014 Final games. They took the second places in both tournaments utilizing a trading technique using equilibrium in continuous markets and a strategy inspired by Tit-for-Tat in the Iterated Prisoner's Dilemma [8].

Another review paper, published by Jurica Babic and Vedran Podobnik, analyses the 2014 Final games deeply. In this paper, brokers are compared to each other based on pre-defined key performance indicators (KPI). Besides, retail and wholesale market activities are discussed here, including market shares and proximities of the future, trade-enabled time slots [7].

Compared to the approaches above, AgentUDE implements a reinforcement learning method in wholesale market. On the retailer market side, it uses empirical strategies, which is called "aggressive tariff strategy" in the paper. These methods and strategies are detailed in Section 4.

3 The Power Trading Agent Competition

The Power Trading Agent Competition (Power TAC) is an open source smart grid simulation platform which consists of a wholesale market, a tariff market, a number of costumer and producer models, a distribution utility and brokers. The balancing market keeps track of supply and demand, and charges brokers for their imbalanced energy. The wholesale market is a typical day-ahead market where the large generator companies, renewable production farms and brokers put their bids and asks for the future time slots. The retail market allows brokers to build their customer portfolio by

means of offering multiple tariffs to local producers and loads. Customers are simulated as independent consumer and producer models such as electric vehicles, households, storage units and solar panels. The interaction between customers and brokers takes place in the retail market through subscriptions. Figure 1 illustrates the schematic landscape of the Power TAC environment.

Fig. 1. Power TAC components.

Brokers represent the business entities in the simulation platform. They offer tariffs through the tariff market and try to increase the number of their subscribed customers. With this intention, they have to trade in the wholesale market in order to avoid imbalance between supply and demand of customers. In all game sizes, games start with monopoly conditions with a built-in broker called default broker. After a certain amount of time, which is called bootstrap period, brokers are allowed to join the games. Timing does not perform a contiguous form in the simulation platform. Instead, simulation time proceeds as discrete time blocks which are called time slots. Each time slot is equal to five seconds in the real world and one hour in the simulation world [1].

3.1 The Power TAC 2014 Final Games

In the Power TAC 2014 Final games, 72 games were played in total. From those, 16 games were in 8-player size, 35 games were in 5-player games and 21 games were in 3-player game size. Note that Power TAC's built-in broker, default broker, is always included in all game sizes. For this reason, for instance, there are 2 competing brokers in game size 3. In the meantime, all the statistics and graphs that are included in the paper are obtained through the analysis of game logs.

Table 1. Official game results of Power TAC 2014 Final.

Broker	Game Size 3	Game Size 5	Game Size 8	Total
AgentUDE	0.279	1.499	1.976	3.754
cwiBroker	1.557	1.026	0.600	3.183
CrocodileAgent	0.952	-0.893	-0.560	-0.501
Maxon	-0.921	0.142	-0.643	-1.423
Mertacor	-0.945	-0.492	-0.865	-2.302
coldbroker	-0.922	-1.281	-0.509	-2.712

Table 1 shows the official results of 2014 Final games. 7 brokers competed in the tournament. Unfortunately, TacTex is not included in the official result since TacTex team decided to withdraw from the tournament due to some problems. At first sight, it can be clearly seen that AgentUDE and cwiBroker dominated the games by having the best scores among other brokers. AgentUDE took the first place in game size 5 and game size 8, and third place in game size 3.

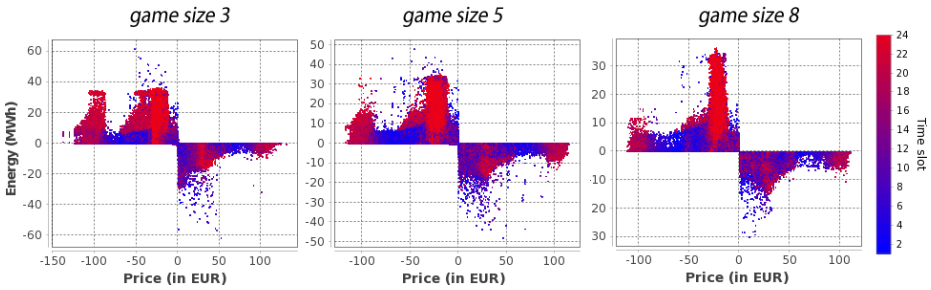

Fig. 2. Wholesale market cleared prices of brokers.

Figure 2 illustrates the wholesale market trading patterns of the brokers in which generator companies (GenCos) and other wholesale actors are excluded. Here, a negative price indicates the payment from brokers for a certain amount of bought energy. Similarly, a positive price refers to a received payment for a certain amount of sold energy. Red color represents the far future in the simulation time in which contracted energy will be delivered roughly 24 hours later. Similarly, blue color indicates the near future for a sooner delivery. Although there are minor differences between game sizes, main characteristics of the market can be understood easily. As expected, the cheapest energy is usually available at the last enabled time slot. Afterwards, the most expensive interval starts after this period. It means, wholesale energy is sold immediately whenever it is available.

The right side of the origin illustrates the selling averages of the brokers. This area is not active as much as the left side since the priorities of the brokers are to meet their demand and supply. Very few brokers, such as Maxon, preferred to make brokerage in the market. Individual performances are detailed in Section 4.

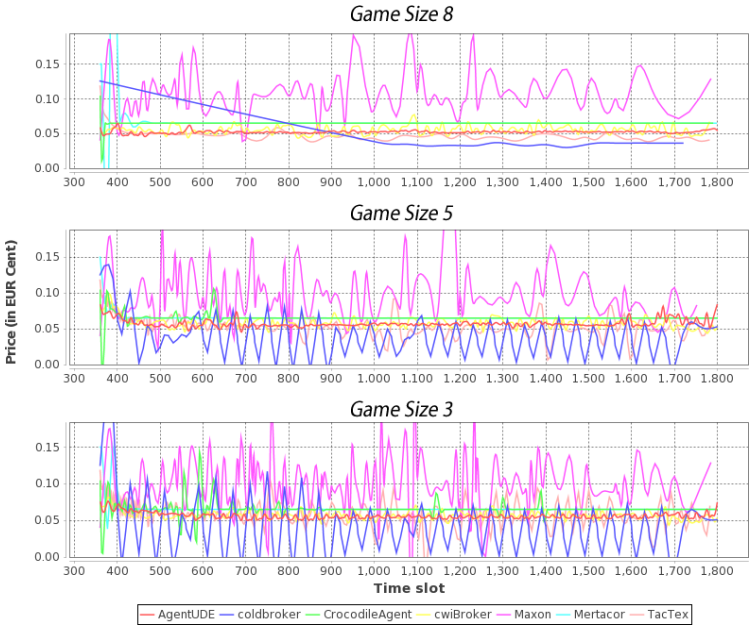

Fig. 3. Tariff minimum values of competing brokers.

Figure 3 presents the pricing trends of the brokers in the retail market. Apparently, brokers have their own price regimes depending on their tariff strategies. What can be easily seen here is, the hard competition takes place around 0.06 ₵/kWh. Further analysis can be found in the next section.

A detailed game review is already available in the literature that is written by Jurica Babic and Vedran Podobnik [7]. This paper reviews and compares the brokers in detail as well as some game statistics.

4 AgentUDE at a Glance

The broker abilities of AgentUDE can be divided into three groups: wholesale, retail and balancing market activities. As seen in Figure 4 below, AgentUDE evaluates and completes its basic facilities in a time slot. For this reason, this section has three subsections to detail these activity groups.

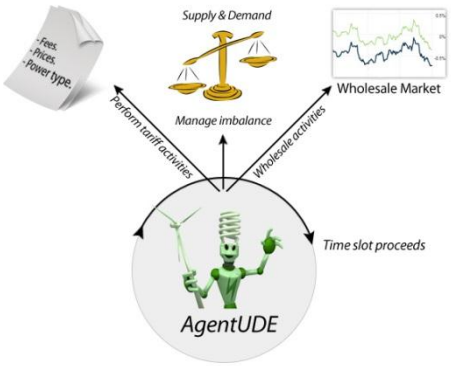

Fig. 4. AgentUDE activities in a time slot.

The scope of this paper is mainly reserved to retail market activities. The wholesale activities are given in brief, since the wholesale market costs of brokers are very close to each other (See Table 2). Retail market activities of AgentUDE are detailed more in respect to tariff parameters such as contract length, bonus payment and early withdrawal payment.

In summary, the wholesale trading module of AgentUDE uses an adaptive Q-learning method which tracks the past market data. Thanks to this method, the broker is able to catch the market trends regardless of weather conditions, hour of the day and day of the week. On the other side, AgentUDE uses an aggressive tariff strategy by means of offering the cheapest tariff as well as manipulating tariff parameters such as contract length, early withdrawal penalty and bonus payments. There are two main goals in the retail strategy: To provoke other brokers to publish cheaper tariffs and force customers to change their tariff in order to trigger their tariff penalties. The results of this strategy are given in the next sub-sections.

Before jumping to the wholesale market activities, an indicator used by AgentUDE has to be introduced here. Basically, it indicates the profit achievement acceleration of the broker where a higher value means better profit performance. The idea behind it is to improve decisions in tariff creations and wholesale market activities. Following Formula 1 evaluates the rhythm at time slot *t*:

$$R_t = R_{t-1} + \omega * \left(\frac{\left(C_t - \sum_{n=0}^{5} \left(\frac{C_{t-n}}{5} \right) \right)}{C_t} \right) \quad (1)$$

Where R is the rhythm at given time slot, C is cash balance and ω is weight. Consequently, the formula above returns a value based on the cash positions. This rhythm is smoothed with a weight value to avoid bouncing during the game. Roughly, AgentUDE behaves more generously in case of a positive rhythm. Otherwise, it limits the expenses such as publishing less tariffs.

4.1 Wholesale Market Activities

Wholesale trading is a vital issue for all brokers since they have to minimize their imbalanced energy. Additionally, brokers are challenged to buy the cheapest possible energy in order to be flexible against their competitors. In the end, customers would like to subscribe to the cheapest tariff available.

AgentUDE uses an adaptive way to create its wholesale market orders. Each market order is calculated using the Q - learning method. Price evaluation takes place in two steps: Base and the final price determined.

The base price is a mean value that is calculated by utilizing the past data. The Final price determination differentiates the base price in order to create bids and asks to be submitted. Following formula gives the base price at current time slot *t* for the energy that will be delivered at future time slot *T*.

$$B_{t,T} = (B_{t-1,T} + C_{t-1,T}) * \varphi \; + \; (F_{t,T} + \max_{t} C\,(t,T) - \min_{t} C\,(t,T) + R(t,T)) * \omega \qquad (2)$$

Where *B* is a base price for the given current time slot *t* and future time slot *T*. *C* stands for the market equilibrium price for *t* and *T*. *R* is risk function: Simply, it makes the order price cheaper for a far future time slot. *F* indicates the constants such as market mean and averages. Weights, ω and φ are managed using rhythm value which is given in Formula 1.

AgentUDE assesses the prices depending on the game's state. These dependencies can be listed as needed kWh, current time slot, urgency and game rhythm. Needed energy is predicted using the consumption patterns of subscribed customers. Urgency is a discount factor and it is derived from searching the number of unsuccessful market orders. Thus, the orders are adjusted accordingly based on the unsuccessful attempts.

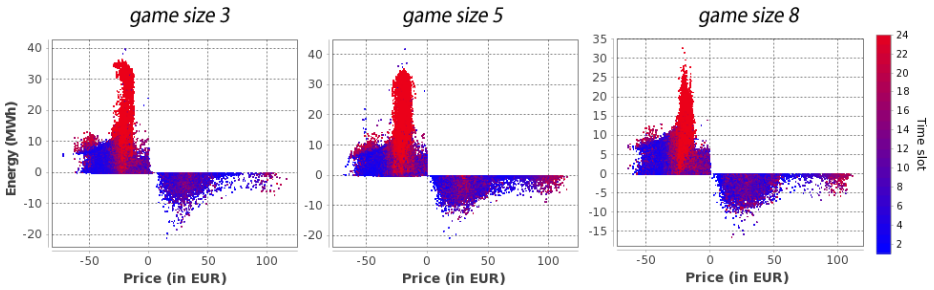

Fig. 5. Cleared bids and asks of AgentUDE.

Figure 5 shows the cleared bids and asks of AgentUDE in all game sizes. Altogether, bidding density of AgentUDE is narrowed to 25-15 EUR/MWh. Compared to Figure 2, AgentUDE takes a profitable position in both bidding and asking areas. Thus, the average buying price is 22.7 EUR/MWh and selling price 28.9 EUR/MWh (See Table 2).

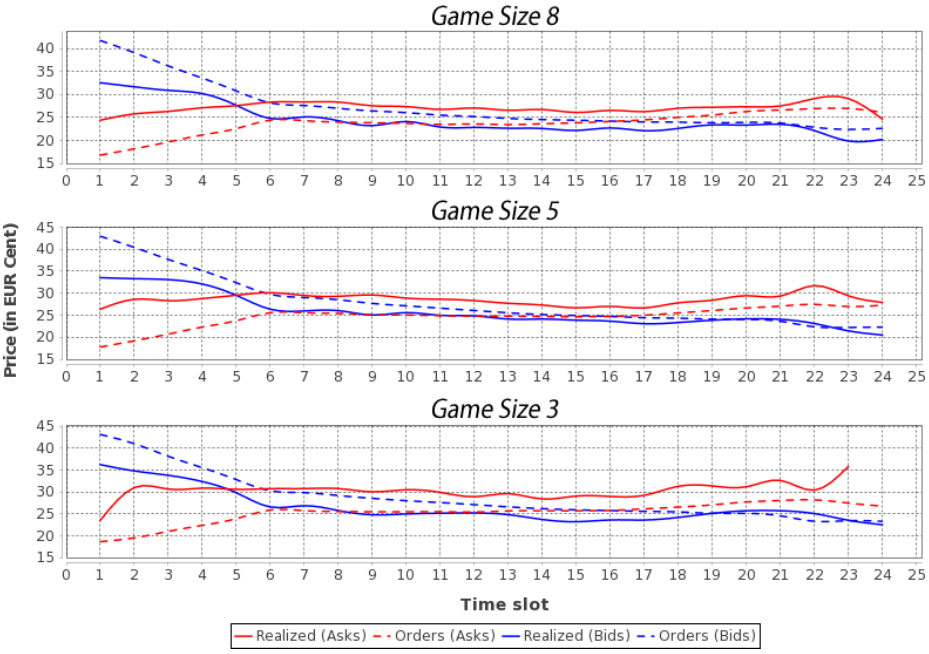

Fig. 6. Average cleared wholesale prices and trading performance of AgentUDE.

Figure 6 illustrates the prediction performance of AgentUDE in different game sizes. In game size 8, success rate is higher than other game sizes since the market is more stable due to the large number of participants. Before fifth future time slot, selling prices are always less than buying prices. Therefore, this area is regarded as a risk area due to approaching delivery time. For this reason, brokers may submit extraordinary prices in this area to avoid imbalance penalties. These panic prices can easily be seen in Figure 2 as blue colored prices that are close to 100 EUR/MWh.

Table 2. Wholesale market averages of the brokers.

Broker	P_{bids} *(€/MWh)*	P_{asks} *(€/MWh)*
AgentUDE	22.70	28.90
cwiBroker	22.49	27.60
CrocodileAgent	43.11	13.08
Maxon	23.15	53.30
Mertacor	26.36	-
coldbroker	27.87	27.49
default broker	29.10	26.49
TacTex	22.94	19.81

Table 2 lists the wholesale bidding and selling costs of brokers. P_{bids} and P_{asks} indicate the average bidding and asking prices. AgentUDE has a market cost around 22.7

EUR/MWh and asking performance of 28.9 EUR/MWh where the consumption share is around 23% of the total energy distribution. In this landscape, AgentUDE is the second best broker after cwiBroker in terms of the lowest market cost. However, these values are very close to each other and do not have a serious contribution to the overall profits of the brokers. In the next section, retail activities are given, which makes AgentUDE special among other brokers.

4.2 Retail Market Activities

AgentUDE applied a new strategy in the retail market, which has not used by another broker sofar: Publishing aggressive tariffs, comparatively with the lowest tariff values and customer binding tariff fees such as early withdrawal penalties and bonus payments. During the course of the competition, this strategy provoked other brokers to publish cheaper tariffs which triggered early withdrawal penalties of AgentUDE tariffs. All in all, AgentUDE forced its customers to change their tariffs. In the end, this strategy provided about 20% contribution to overall cash balance (See Figure 7).

Table 3. Tariff activities of the brokers in Power TAC 2014 Final.

Broker	$N_{tariffs}$	Frequency	M_{cons} (€/kWh)	M_{prod} (€/kWh)	S_{cons} (€/kWh)	S_{prod} (€/kWh)
AgentUDE	3791	27	6.0	1.52	6.3	1.52
cwiBroker	1071	97	7.8	-	7.8	-
CrocodileAgent	1106	94	7.1	1.58	9.7	1.58
Maxon	1426	73	522	-	7.7	-
Mertacor	2732	38	7.3	-	6.7	-
coldbroker	607	171	5.3	-	5.4	-
default broker	144	725	50	1.50	50	1.50
TacTex	1670	62	7.3	-	5.6	-

Table 3 shows the tariff statistics of the brokers. $N_{tariffs}$ is the number of total published tariffs. Frequency indicates the publication cycle in terms of time slot. M_{cons} is the mean of consumption tariffs. Similarly, M_{prod} is the mean of production tariffs. S_{cons} is the average price of energy that is sold to customers. Finally, S_{prod} means price of energy that is bought from customers.

As seen in Table 3, publication cycle of AgentUDE is 27 which is the largest number of tariffs submitted to the retail market. After AgentUDE, Mertacor and TacTex have the most tariffs. On the other side, only AgentUDE, CrocodileAgent and default broker published production tariffs. However, AgentUDE publishes a new producer tariff if the sum of minimum production tariff value and distribution fee is less than wholesale market cost. Otherwise, production tariffs are not published.

In a competitive environment, tariffs are the primary weapons of brokers to earn profit. AgentUDE uses multiple parameters to create competitive tariffs. These parameters are the number of subscribed consumers, cash position, market cost, number

of active brokers, competitors' tariffs, current time slot and rhythm value which is introduced in the previous section.

A well optimized broker has to consider all the costs (operational, distribution and market costs) in order to make profit. Before creating a tariff, AgentUDE has to take its costs and tariffs of competitors into account. Therefore, it watches the wholesale market prices and adjusts its red lines, boundaries for tariff values. This limit price, in other words, the minimum tariff value is obtained as follows:

$$Cost_t = \frac{(\sum_{n=0}^{60} \sum_{m=1}^{24} P_{m,n})}{(\sum_{n=0}^{60} \sum_{m=1}^{24} E_{m,n})} + (\theta * \varphi) + (t * \omega) \quad (3)$$

Where t and θ represents the current time slot and distribution fee, respectively. Note that simulation proceeds as discrete time blocks called time slots which are integer values starting from one. Therefore these integer values are included in the formula above as a parameter. On the right part of the formula, φ and ω indicate the weights that are determined empirically. P and E refers to total money and energy transactions and the formula above runs up to the most recent 60 hours and 24 enabled future auctions of the wholesale market. Consequently, the division yields an average price by means of dividing the total payment to the total energy.

The number of subscribed customers has an impact on the determination of the bonus payment and early withdrawal penalty fee. These fees are derived through taking total customers and subscribed customers into account with the aid of pre-defined weights and critical rate value. Note that the critical rate is an internal parameter of AgentUDE that depends on the number of competing brokers and subscribed customers. Generally speaking, the critical rate points to a threshold with respect to the number of subscribed customers that the broker has to reach. Henceforth, if the number of subscribed customers increases, the bonus payment should decrease or withdrawal payment should increase. After all, the calculation of withdrawal penalty fee can be formulated as *(C * T * φ) - (S * ω)* where *C* is critical rate, *T* is the number of total customers in the competition environment, and *S* is the number of subscribed customers. Weights φ and ω differ based on the tariff type.

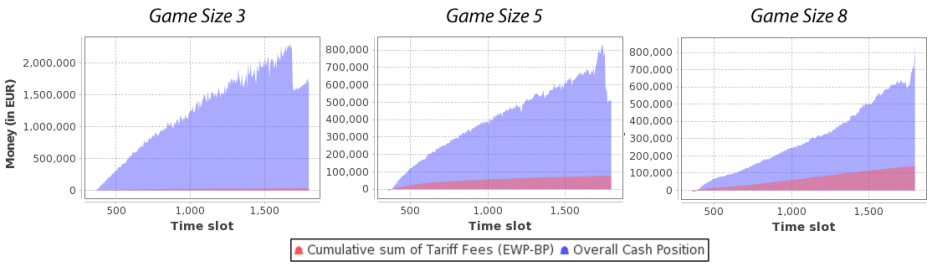

Fig. 7. Total cash position and cumulative contribution of early withdrawal payments (EWP) and bonus payments (BP) of AgentUDE.

Figure 7 shows the collected money from tariff fees. As a result, serious amount of cash position was collected from tariff fees. This rate increases in game size 8 due to hard competition.

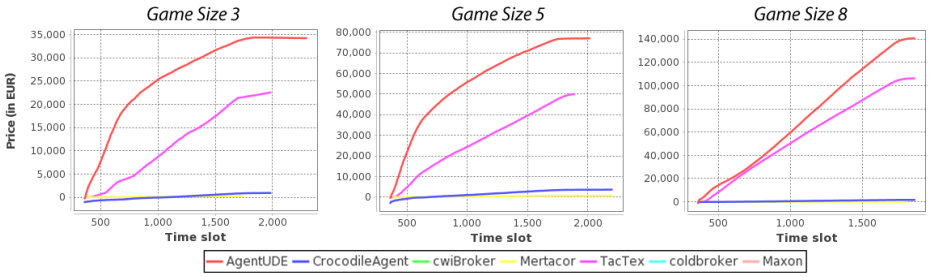

Fig. 8. Average cumulative profits that are collected from early withdrawal penalty payments and bonus payments.

Figure 8 compares the tariff fee performances of all the brokers. Surprisingly, only AgentUDE and TacTex benefitted from tariff fees. Maximum profit achieved from game size 8 due to hard competition.

In order to have more profit from this strategy, some requirements have to be met: Active customer and a good competitor. Customers have to have some reasonable and profitable tariffs to make a transfer decision. If not, customers tend to ignore them and resume their tariff. In this case, the aggressive tariff strategy of AgentUDE does not work well. The second condition is also related to first one: Another broker has to offer competitive tariffs so that customers can evaluate their position and change their tariffs if needed. Following Figure 10 proves the active customer and broker claim.

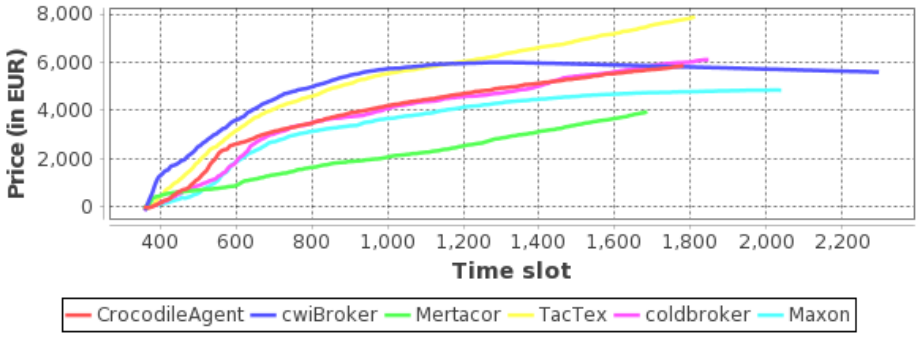

Fig. 9. Cumulative tariff fee earnings of AgentUDE that are collected through 3-sized games.

Figure 9 shows the tariff fee earnings of AgentUDE and only includes the games between AgentUDE and respected broker. Apparently, TacTex, Croco and cwi gave the most profit to AgentUDE while Mertacor, Maxon and cold gave less. In the same fashion, this symbiotic relationship is proportional to the official results given in previous sections. The conclusion is, TacTex, cwiBroker and AgentUDE offer the most profitable tariffs to the customers and convince them to change their tariffs.

4.3 Balancing Activities

Brokers have to meet their demand and supply. If they cannot, they lose their serious portion of profits by paying huge imbalance fees. The most challenging issue at this point is to predict future consumptions. AgentUDE uses the consumption data of customers to make predictions. However, this method does not always give the best result due to changing conditions such as weather. Balancing market sends signals to brokers regarding their imbalance status. Consequently, needed energy is calculated as the sum of predicted consumption and imbalance signal. Final amount of needed energy is smoothed and submitted to the market.

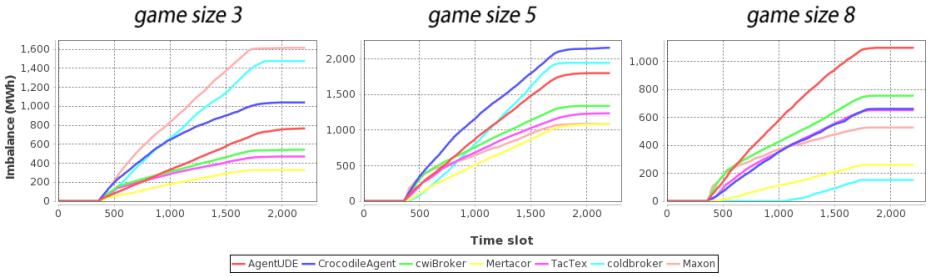

Fig. 10. Cumulative volume of negative and positive imbalances.

Figure 10 illustrates the cumulative imbalance volumes. In this figure, negative and positive volumes are regarded as absolute values. Game size 3 gives the best result for AgentUDE. However game size 8 carries out a poor picture. Since the figure illustrates the volumes, increasing number of participants make AgentUDE trouble to adjust its imbalance due to changing customer usages. Besides, customers have more tariff options in game size 8 in comparison to game size 3. Therefore, withdrawal or sign-up activities of customers eventually result in last-minute imbalances.

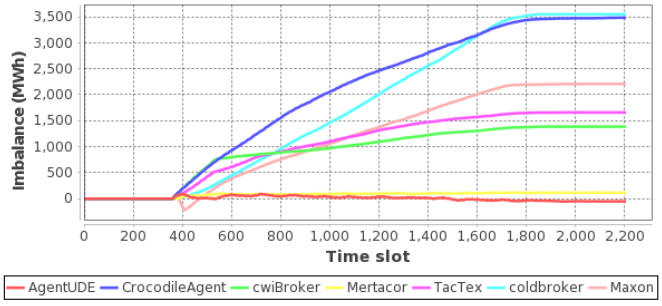

Fig. 11. Cumulative sum of positive and negative imbalances in all game sizes.

Figure 11 shows the average imbalances where negative and positive values are summed. AgentUDE draws a flat line due to wave-style imbalance activity. In other words, positive and negative values are almost same.

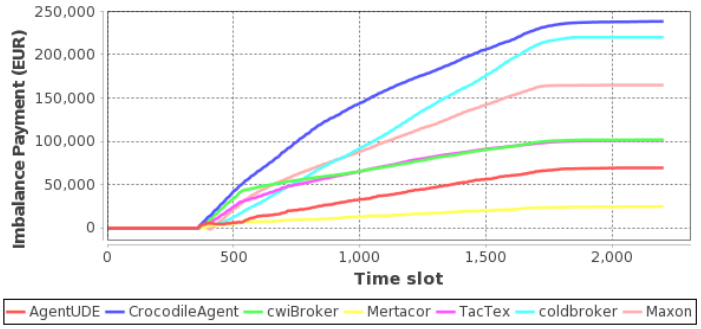

Fig. 12. Total imbalance payments from brokers to distribution utility (all game sizes).

Figure 12 illustrates the overall imbalance payments from brokers to distribution utility. AgentUDE is the second best broker who pays less money to distribution utility. However this payment only consists of imbalance penalties since the total imbalance energy is close to zero line, as shown in Figure 12. For a typical negative imbalance, brokers have to pay price of imbalanced energy in addition to penalty fee. TacTex and cwiBroker paid 100k EUR for their 1700 MWh and 1450 MWh imbalanced energy, respectively. If a comparison is needed at 70k EUR, where the imbalanced energy of AgentUDE was almost 0, TacTex and cwiBroker paid this 70k EUR plus 17.6 EUR/MWh and 20.6 EUR/MWh for their negative imbalance. In respect to wholesale market costs shown in Table 2, TacTex and cwiBroker had a good deal on the balancing market over AgentUDE.

5 Future Work

AgentUDE seems to be a promising broker. However, there are still waiting issues to be improved. Following points are the most important topics that are expected to be solved in Power TAC 2015 games.

One of these outstanding issues is wholesale trading. AgentUDE still loses serious amount of money with its relatively inefficient bids and asks. Therefore, price predictions in the wholesale market ought to take future weather forecasts into consideration in order to catch future trends.

Second improvement is the utilization of unused power figures. In the Power TAC environment, there are many new generation power actors such as storage units, controllable customers. However, most of the brokers do not use them. No doubt, utilizing these components improves the efficiency of the broker.

Another issue is capability of surviving in a longer game period. As planned for the future competitions, AgentUDE has to be compatible for longer games.

6 Conclusion

As a result, this paper includes the basic strategies of AgentUDE and results from the business perspective as a winning agent in Power TAC 2014 Final. However, success is a relative term, especially in such dynamic and progressive platforms. The participated teams are getting stronger year by year, and changing their strategies. As a result, the competitiveness of the game is raised aggressively. For this reason, comparisons are valid for the specific release versions of brokers.

This paper details the trading designs and approaches of AgentUDE from the business perspective. As has been noted in the wholesale market section, the gaps between the market performances of brokers are very close to each other. It is clearly seen that all the brokers have a decent market performance based on their customer profiles and risk levels. What makes AgentUDE one step ahead is its competitive and aggressive tariff strategies. On the other hand, the results showed that AgentUDE earned the serious portion of its profit through tariff fee manipulation. This strategy was never used before by another broker and, no doubt, this ability made AgentUDE more competitive and flexible against other brokers. Lastly, Power TAC 2014 Final showed that it has an enormous benchmark capacity for smart grid studies. Therefore, we kindly invite new teams to be a part of this platform.

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