BU MET ABA Program to Quantitative Trading in Energy Market

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Abstract. This paper presents a study conducted by the author during his enrollment in the Applied Business Analytics program at BU Metropolitan College from September 2019 to January 2021. Equipped with the acquired techniques and skills, the author subsequently joined a high-tech energy company and engaged in quantitative trading to capitalize on the financial opportunities presented by the DART spread. The paper provides an overview of the New England wholesale energy market, including an explanation of how the DALMP and RTLMP are settled, highlights extreme market events, and discusses the market's chaotic nature. The author further describes the qualitative and quantitative approaches employed, such as machine learning, statistical analysis, and data mining, which enabled him to achieve an impressive annual rate of return of 25.52% and a peak daily rate of return of 334.87% (translating to net earnings of $100,462.36 within a single day) through quant trading.

Keywords: Quantitative Trading · Wholesale Energy Market · DALMP · RTLMP · DART spread · volatility · rate of return

1 Bridging the Gap: The Intersection of BU's MET Applied Behavior Analysis Program and Quantitative Trading

The author was admitted to Metropolitan College's Applied Business Analytics program at Boston University (hereinafter referred to as BU MET ABA Program) in September 2019. After one year and a half's study, the author graduated in January 2021, subsequently joined a high-tech renewable energy company, and started to work as an energy market analyst and quantitative trader. The author mainly focused on the wholesale energy market in New England, studied the market rules, conducted extensive data analytics using the techniques and skills he obtained from the BU MET ABA program, and exceeded his annual revenue goal of 3.39 million by 34.31%. This paper mainly introduces how the wholesale energy market in New England works, DALMP and RTLMP, and how the author conducted quantitative trading to obtain financial benefits from DART spread.

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2 New England Wholesale Energy Market Overview

2.1 Introduction to the Wholesale Energy Market, DALMP, and RTLMP

The energy market in New England (Massachusetts, Connecticut, Rhode Island, New Hampshire, Maine, and Vermont, six states in total) area is operated and monitored by the Independent System Operator New England (hereinafter referred to as ISO-NE).

In the ISO-NE wholesale energy market, electricity is bought and sold in two different markets: the day-ahead market and the real-time market. The day-ahead market is used to plan and schedule electricity generation and consumption for the next day, while the real-time market is used to balance supply and demand in real time based on actual consumption.

The energy market in New England is a clearing energy market, and ISO-NE uses economic dispatch to balance demand and supply[1]. ISO-NE dispatches all generation resources in an economic merit order, i.e., resources that submit the lowest price will be dispatched first, and when demand (load) increases, higher-priced supplies (generators) will be dispatched next, and highest-priced supplies (peak facilities) will be dispatched last.

Under this mechanism, supplies are stacked up incrementally from the lowest price to the highest price with different supply quantities. When the demand meets the supply, the market will clear, some supplies with low prices will clear the market, some supplies with high prices will not clear the market, and some supplies with certain prices will partially clear the market, as shown in Fig. 1.

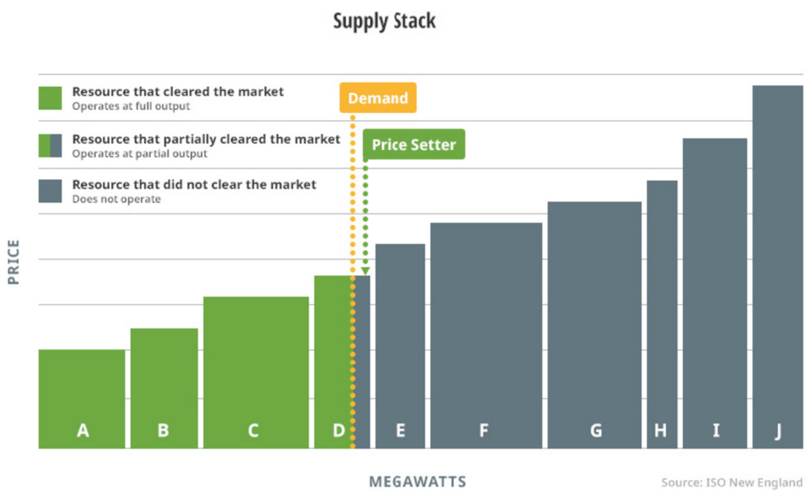

Fig. 1. How do prices clear in a clearing market?

Since there will be a supply stack that is "on the margin", the energy clearing price in New England is called Locational Marginal Price. This clearing mechanism is the same across the day-ahead market and real-time market, therefore, there are two prices in the wholesale energy market, one is Day-Ahead Locational Marginal Price (hereinafter referred to as DALMP), and the other is Real-Time Locational Marginal Price (hereinafter referred to as RTLMP).

The DALMP will be a fixed price for the specific hour, for example, between 1 pm and 2 pm on a certain day (hour ending 14), DALMP is \$17.26/MWh. The RTLMP may change every 5 min based on real-time supply and demand, and after each hour, an hourly-average RTLMP will be calculated for settlement purposes. This hourly-average RTLMP may be higher or lower than the hourly DALMP, and for over 99.9961% of the time (there is only 1 h in recent 3 years that the DALMP and RTLMP are the same for the same hour), RTLMP and DALMP will be different for the same hour.

The difference between the DALMP and RTLMP is called the Day-Ahead-Real-Time spread (hereinafter referred to as the DART spread). Since most times the DART spread is not 0, it is possible to financially gain the benefit from the DART spread.

2.2 Attributes of DALMP and RTLMP

The wholesale energy market in New England is free, however, ISO-NE has its own market rules. Some may think that generators can bid whatever price they want, on the contrary, they cannot simply do that. All generation resources must bid with their variable costs[2]. Generators that use different fuels will have different variable costs, for example, for some renewable fuel generators, their variable costs can be low or even zero (PV, hydro, and wind); nuclear units usually have relatively low variable costs as well; natural gas units have higher variables costs, and coal and oil units can have even higher variable costs.

For most times, the marginal supply stack is the natural gas units, which settles the DALMP. Different units have different heat rates, and the variable costs of natural gas units will be:

*Bidding Price = Gas price*heat rate + some fixed costs*

Therefore, the DALMP is mainly driven by natural gas price and demand level and will not be negative in most regions/areas/interconnection nodes, unless in some certain areas/interconnection nodes, renewable resources are the marginal supply stack.

On the other hand, RTLMP is balancing the demand and supply in real-time, and when real-time demand is lower than day-ahead demand and real-time supply is higher than day-ahead supply, RTLMP will be lower than DALMP.

On the other hand, if real-time demand is above day-ahead demand and real-time supply is below day-ahead supply, RTLMP will be higher than DALMP. This may last very shortly, as ISO-NE will try to dispatch available resources to offset this supply shortage and keep the whole power grid system stable, however, this may last long enough if the supply is not offset, even to 48 h.

Sometimes, RTLMP can be as low as \$0/MWh, or even negative. This usually happens in the spring and fall months, such as late April, early May, late September, and early October, when solar irradiation is strong and PV output significantly reduces the system demand.

RTLMP can also be as high as \$900/MWh. Historically the highest RTLMP record within the last 5 years was \$2632/MWh, which occurred on December 24th, 2022, between 6 and 7 pm. The negative RTLMP and extremely high RTLMP are usually relevant to extreme events of the system, known as Minimum Generation situation, and Capacity Scarcity condition.

2.3 Extreme Events: Min Gen and OP-4 Event

The wholesale energy market in New England can be volatile, and ISO-NE's top priority is to balance the electricity supply (generation) and demand (load). The Day-Ahead market is relatively more stable than the Real-Time market since things can change fast in real-time, e.g., some generators that have Day-Ahead generation obligations but did not show up due to unit trip/malfunction, some Day-Ahead demand did not show up due to unexpected sunny and warmer weather, some Real-Time demand emerged due to sudden temperature drops or raises, etc. Although ISO-NE was trying its best to maintain stability, every participant in the market, no matter supply or demand and how small they are, can be a snowflake that contributes to an avalanche.

ISO-NE has a considerable amount of capacity reserve: they usually have an approximate 28,000 MW capacity reserve2 while the annual highest demand for the last 5 years was 25,559 MW which occurred on August 29, 2018, between 4 pm and 5 pm[3]. When supply is below demand, ISO-NE will dispatch some fast-start generators to meet the demand; and when supply is above demand, ISO-NE will dispatch some generators to back down to shed some supply.

This operation strategy worked fine most times, however, there are some certain times that ISO-NE cannot shed enough supply to match the demand, then the supply will be above demand for several hours until demand increases to match the supply level. When that happens, it will trigger an extreme event named "Minimum Generation Emergency", hereinafter referred to as Min Gen, which means that the Minimum must-run Generation/Supply is significantly higher than the Demand/Load. When a Min Gen is triggered, the system-wide RTLMP will drop to 0 or negative, until demand raises, and Min Gen is canceled. The main cause of a Min Gen is usually an operation strategy named "Posturing".

When ISO-NE is foreseeing extreme weather to occur in 2 or 3 days, they will try to dispatch all generators to meet the potential demand. Since not all generators are fast-start, it will take 24 or even 48 h to get some generators to ramp up, and these generators cannot back down until the extreme weather passes. Other generators cannot back down such as Nuclear Reactors, combined with winds or hydro that have a production tax credit that makes sure the owners of the generators get paid no matter what the RTLMP is, supply will exceed demand significantly, and a Min Gen may be triggered.

Table 1 below is an example of how ISO-NE postures supply to counter extreme weather:

Assume that Day 3 ISO-NE is seeing a 20,500 MW demand/load, then ISO-NE will start dispatching all slow start generators from Day 1. As time flows, the Must Run MWs will continue increasing as these slow-start generators ramp up to their maximum capacity. By Day 3, when the extreme weather comes in, ISO-NE will have enough supply to meet the demand and keep all lights on across the New England area.

However, in the middle of Day 2, between 10 am and 4 pm, the system load can be only 10,000 MWs or even lower, when temperatures are mild, PV outputs are high,

Table 1. How ISO-NE postures supply to counter extreme weather

Date	Must Run MWs	Fast Start MWs	Total Available Supply
Day 1	8,000	8,000	16,000
Day 2	11,000	8,000	19,000
Day 3 (Extreme weather day)	13,000	8,000	21,000

and decent wind and hydro outputs. This will trigger the Min Gen situation since the Must Rum MWs are at least 1,000 MWs higher than the system demand. RTLMP will drop to 0, and even negative, while DALMP will stay positive. This will bring a great opportunity to get DART spread.

Another extreme event is the contrary of Min Gen. It is named the Capacity Scarcity Event and will happen when ISO-NE cannot provide sufficient supply to meet system demand. This is a rare event compared to Min Gen and will cause serious problems such as electricity outages in several regions, blackouts, and even casualties when combined with extreme weather.

When a capacity scarcity event occurs, ISO-NE will trigger Operation Procedure (OP)-4, which is trying its best to offset this capacity shortage, including raising the RTLMP via real-time generation auctions. RTLMP will be much higher than DALMP and can last several hours. Usually, peaking facilities (also known as peakers) which are usually natural gas units and have extremely high heat rates will be picked up, and push RTLMP to around $800/MWh, and even to over $2000/MWh.

Min Gen occurred more than OP-4 in the last 5 years. There is only one scarcity event that triggered OP-4 in the last 5 years, and it happened on December 24th, 2022. A cruel cold snap hit New England, including New York State, Quebec, and New Brunswick in Canada. A huge chunk of generation tripped offline due to extremely cold weather, and they could not come back online fast since most operation and maintenance workers were not working since it was Christmas Eve. A similar thing happened to New York State which has its independent system operator known as NYISO, and NYISO, Quebec, and New Brunswick also cut their exports to New England to reserve their energy. Suddenly, energy is short in the whole northeastern area of North America, ISO-NE could not borrow or purchase any extra energy from outside, or inside. The situation worsened during the evening peak hours, from 6 pm to 8 pm when system demand kept climbing and supply was in severe shortage. ISO-NE implemented OP-4 to raise RTLMP to encourage suppliers to offer enough generation to meet the demand, RTLMP went to $2,632/MWh and was historically highest in the last 5 years while DALMP was around $320/MWh. This situation was finally resolved the next day, and luckily, this capacity scarcity event did not cause any casualties and all lights were on during Christmas.

On the other hand, Min Gen occurred 4 times from 2023 until May[4]. Predicting these extreme events is one of the key components to obtaining the financial benefit of DART spread, and it is also very important to understand what caused these extreme events.

2.4 Financial Transactions to Get DART Spread, INC and DEC

ISO-NE provides official ways to obtain the DART spread through Financial Transactions/Trading. However, conducting the financial trading will require certain Financial Assurances since there can be potential losses and collaterals must be withheld for hedging. If the financial transactions exceed the financial assurance limit, ISO-NE will cancel all transactions.

ISO-NE provides two types of financial transactions: Incremental (hereinafter referred to as INC), and Decremental (hereinafter referred to as DEC). INC allows traders to sell energy with DALMP and buy back with RTLMP, and DEC allows traders to buy in energy with DALMP and sell with RTLMP. INC and DEC do not require physical dispatches of energy, since these transactions are selling some amount of energy during some hour and buying back the same amount of energy during the same hour, no actual generation/consumption of energy will occur. For example, there is one INC transaction for 8 MWs for Hour Ending (hereinafter referred to as HE) 8, and DALMP is $23 and RTLMP is $22, this transaction is selling/generating 8 MWh energy with $23 and buying/consuming 8 MWh energy with $22, no net generation or consumption will occur.

The equations of the financial benefit of INC and DEC are below:

For INC:

$$Net\ Earning = MWs * (DALMP\text{-}RTLMP)$$

For DEC:

$$Net\ Earning = MWs * (RTLMP\text{-}DALMP)$$

If some INC transactions are cleared and DALMP is above RTLMP for the same hour, some net earnings will be realized; however, if RTLMP is above DALMP, some losses will be realized. Similarly, if some DEC transactions are cleared and DALMP is below RTLMP for the same hour, some net earnings will be realized; however, if RTLMP is below DALMP, some losses will be realized. The losses will result in negative net earnings.

Financial transactions can be profitable, but also risky. All financial transactions must be made before 10:30 am on the prior day, i.e., if a trader is going to make some INC/DEC for Day 3, all bids/offers/transactions must be submitted before 10:30 am on Day 2, and no real-time adjustments or cancellations will be available during Day 3. Therefore, although INC/DEC does not dispatch real energy, a physical or financial hedge will be helpful.

2.5 Chaotic Nature of the Wholesale Energy Market, and Information Asymmetry

Figure 1 is a good resemblance of how the wholesale energy market works. The Day-Ahead energy market makes good plans to balance supply and demand, nonetheless, the supply and demand can change in real-time. Some supplies that have day-ahead obligations can malfunction and trip offline, some external imports can be cut off due to some system problems such as a Quebec Hydro transmission line broken or under unplanned maintenance, some nuclear plants can have some emergent technical issues, some PV panels are performing less than expected due to unexpected overcast weather, etc. Demands are similar, some extra demand can show up due to unexpected hot or cold weather, or some demand facility decides to consume a huge amount of energy when they see low RTLMP. Demand can also be severely below forecast due to a warm, windy, and sunny day, when PV outputs are strong, just like what happened on April 16th, 2023, in California, system net demand hit zero and even negative due to strong PV and wind output while forecasted system demand was around 7,000 MWs[5].

A lot of events can happen without any forebode, and this reveals the chaotic nature of the wholesale energy market. Some generation outages are planned or scheduled, and ISO-NE will release this information for transparency purposes; some outages cannot even be predicted. Every participant's bidding behavior may affect the whole energy market, for example, as small as 10 MWs extra generation may set RTLMP to $0 from $18, and 10 MWs extra demand may set RTLMP to $200 from $40.

No participant in the energy market can have all the information. Some participants/traders will have more information, and some will have less. This will cause an information asymmetry[6], and participants/traders who possess more information will be likely to make better decisions. To obtain the financial benefit of DART spread, more information will be helpful for traders to achieve their goals.

3 The Author's Approach to DART Spread Analysis

As a quantitative trader, the author utilizes different methods some of which he obtained from the BU MET ABA program and some of which he learned by himself to analyze DALMP and RTLMP. There are over 1,200 grid nodes that can settle DALMP and RTLMP in New England, most nodes will have similar DALMP and RTLMP for the same hour, while some nodes' DALMP and RTLMP will clear differently due to renewable energy impacts such as solar, wind, and hydro, or system conditions such as transmission line outage, transmission constraint, etc. The author collected DALMP and RTLMP for the last five years for the New England Hub node (near Boston), and some nodes that have higher volatility in northern Vermont and Maine. The author then conducted the statistical analysis and found that the annual average DALMP was above the annual average RTLMP for the last 5 years, except for one day that had the capacity scarcity event, December 24th of 2022. A naïve rule that just bid in INC without any other analysis will make a small amount of financial benefit each year, though taking a lot of ups and downs in the process.

However, if that day of scarcity event was counted, RTLMP will be above DALMP for the fiscal year of 2022, and that will result in severe financial loss for that year. The naïve rule is not optimal, since one scarcity event will wipe out the whole year's net earnings, and simply applying it is against scientific thinking and will not be accepted by most organizations.

Although the naïve rule does not work well, it does provide the insight that DALMP is likely to be higher than RTLMP. The author then switches to supervised machine learning to get a better forecast of DALMP and RTLMP and uses that forecast to make trading decisions.

Since the wholesale energy market is a clearing market, demand plays a crucial role in the DALMP and RTLMP. The fortunate part is that ISO-NE does provide an hourly demand forecast for the next three days, and it is the guideline of how DALMP is cleared in each node; the unfortunate part is that ISO-NE admits, its demand forecast is not accurate enough[7], and may cause volatilities in the wholesale energy market. When demand gets lower, it gets more likely that RTLMP goes negative since Min Gen may be triggered; when demand gets higher, it is more likely that RTLMP goes above DALMP, and even several times higher since an OP-4 may be triggered. The author is using ISO-NE's official real-time demand as an input for the supervised machine learning model and using ISO-NE's official demand forecast as an input for DALMP and RTLMP forecast.

Another important input variable is the Pipeline Natural Gas Price at Algonquin City Gate of Boston. Since most times Natural Gas units are marginal units, and all natural-gas units must bid with their variable costs, higher gas prices will result in higher DALMP and RTLMP, and the higher the natural gas price is, it is more likely that RTLMP is also much higher than DALMP. The author uses historical Algonquin City Gate natural gas prices as an input and uses estimations of future natural gas prices from the ICE platform for forecast purposes.

Different hours, weekdays, and wintertime shifts are also valuable input variables. For example, 8,000 MW demand for HE 18 is usually the lowest point of the year, while 8,000 MWs for HE 13 can happen 40 times across the whole year. Weekdays usually have higher demand, and weekends and holidays usually have lower demand. The wintertime shift also plays a critical role since this will shift the hour.

With all these necessary inputs, and public nodal DALMP and RTLMP gathered the author went through the process of model selection. The author tried different supervised machine learning models, such as Multiple Linear Regression, Polynomial Regression, Lasso and Ridge regression, K Nearest Neighbor regression, Random Forest, Gradient Boosting regression, Artificial Neural Network (Tensorflow), etc., and utilized cross-validation methods to minimize the loss. After hyper tuning all those parameters for those models, the author noticed that the Gradient Boosting regression model has the lowest cross-validation mean-absolute-error (hereinafter referred to as MAE) of 3.43 for DALMP and MAE of 9.36 for RTLMP. The higher MAE of RTLMP proves the chaotic nature of the energy market since RTLMP can be more volatile.

4 Quantitative Trading Performance

The author started quantitative trading to get DART spread in May 2022, after extensive analysis and market rule studies. At first, the author was acting conservatively, bidding small MWs of INC/DEC, such as 2 MWs for an hour and 4 h for a trading day. Then after some successes, the author started to increase the bidding amount, to 8 MWs for each hour, and up to 24 h maximum per day.

The rate of return is a key performance indicator of trading success. The usual calculation of the rate of return is:

ROR = (Revenue-Cost)/Cost

However, when some INC transactions were cleared and RTLMP went to 0 or negative, the cost can be 0 or negative, and ROR will be an error or negative, which does not make a good sense of how the performance was. Therefore, the author was using a different approach to calculate the rate of return.

For INC transactions, the ROR will be:

ROR = (DALMP-RTLMP)/DALMP

For DEC transactions, the ROR will be:

ROR = (RTLMP-DALMP)/DALMP

And for the year 2022, the author obtained a 25.52% rate of return for quantitative trading. This ROR is a year-flat rate, and cannot be compounded intra-year, however, for future years, this ROR can be compounding since net earnings are going into bidding costs for future transactions.

The author's highlight spot was December 24th, 2022, when the capacity scarcity event occurred. The author saw a cold snap attacking New York State, New England, Quebec, and New Brunswick and deemed that there may be a huge chunk of generation outages occurring and they could not come back online soon enough since it was Christmas. The author then submitted big amounts of DEC transactions with a $30,000 bidding cost; the market proved the author's decision correct, and even better, a capacity scarcity event occurred and RTLMP went off the charts. The author made a $100,036.24 net profit within one day, and the Rate of Return of that day was 334.87%.

5 Conclusions and Next Steps

The author was successful in quantitative trading, with a compounding annual rate of return of 25.52%. The techniques he obtained from the BU MET ABA program played a key role in his success, and it proves that the BU MET ABA program is competitive, helpful, and can create new opportunities when combined with domain knowledge in other areas.

The author is not satisfied with ISO-NE's official demand forecast since it is not accurate enough which is admitted by ISO-NE and is a crucial input for supervised machine learning models. The author is trying to build his own ISO-NE demand forecast model and aims to have better forecasts for DALMP and RTLMP. The author is also considering using techniques such as deep learning, reinforcement learning, etc. to decrease the losses of machine learning models to get better forecasts.

The author is also aiming to study the New York State energy market managed by NYISO, the California energy market managed by CAISO, and the Texas energy market managed by ERCOT. These markets have higher volatilities compared to ISO-NE yet have similar market rules, and can achieve a higher rate of return if the right decisions are made.

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