Automated Transactive Energy (TeMIX)

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Abstract

Automation of electric energy transactions enables a more efficient and customer friendly electric grid. Transaction automation also supports increased variable renewables on the grid with fast response. Transactive Energy Market Information Exchange (TeMIX) is a methodology to support automated energy transactions and decentralized management of energy use and supply on a smart electric grid [1]. Using TeMIX, customer devices such as air conditioners, plug-in vehicles, distributed generation and storage automatically interact with distribution grids, transmission networks, and central generation and storage.

TeMIX is a subset or profile of the Organization for Advancement of Structured Information Standards (OASIS) eMIX information model [3] and the OASIS Energy Interop services [2] for *Transactive Energy*. The core concept of TeMIX is pairwise interactions among parties using simple tenders and transactions. Automation of TeMIX is straightforward because of the simplicity and standardization of TeMIX.

This paper focuses on the automation of Transactive Energy using the TeMIX information model and services.

1. TRANSACTIVE ENERGY AND TEMIX

1.1. Introduction

Transactive Energy is a business process for energy transactions. A Transaction is an exchange among parties of a product for a price. Transactive Energy is most useful in decentralized competitive electric energy markets, but it has applications in centralized dispatch and vertically integrated electric utilities. Transactive Energy is a term with increasing usage in the smart grid community [5] [6].

TeMIX is a profile (subset) of Transactive Energy standards as specified by OASIS [2] [3]. In its *ideal* implementation, TeMIX uses frequent communication of small tenders (price for a quantity) and transactions for products. TeMIX has just two products; energy and energy transport, and call and put options on these. Parties to transactions may be (1) owners of end-use devices, generation, and storage with interval meters, (2) financial parties providing risk management with no intention of delivery, (3) suppliers and consumers of physical energy transport services, or (4) suppliers and consumers of financial transport hedges. A party may take the buy or sell side of a transaction. A consumer can sell by reducing a purchased position or by self-generating. A supplier can buy back from a sold position.

TeMIX needs no hierarchy. Where regulations permit, any party can transact with any other willing party, or with willing intermediaries. No information is required from a counterparty except for information discovered by issued tenders and responses to tenders. No control over another party is implied except as mutually agreed in an option transaction. Options may be transacted for risk management or reliability reasons.

1.2. TeMIX Market Structure

The exchange of TeMIX tenders and transactions among parties is illustrated by the two-way arrows in Figure 1.

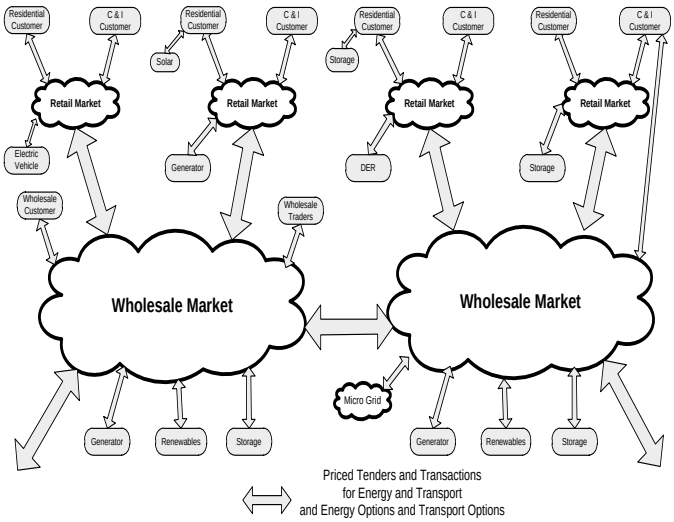

FIGURE 1 : TEMIX MARKET STRUCTURE

TeMIX tenders and transactions are for current and forward delivery intervals, each with a start date/time and duration.

For example, forward tenders may be a sequence of hourly sell tenders over the next 24 hours. Tenders are typically accepted as a transaction before delivery. Tenders may be issued and accepted after delivery for delivery balances.

Subject to regulatory policy, two parties with collateral or other assurances acceptable to the other party can accept a TeMIX tender. The standardization and simplicity of TeMIX transactions supports effective risk management and regulatory oversight.

TeMIX information exchanges are the same for generators, distributed energy resources (DER), variable energy resources such as wind or solar, commercial and industrial customers, homes, electric vehicles, microgrids, energy traders, brokers, exchanges, aggregators, and market operators. Transactions can occur between parties in retail and wholesale markets and between parties in different wholesale markets.

Current wholesale system operator markets and integrated utilities use a more centralized dispatch of generation and transmission. TeMIX can coexist with such markets.

TeMIX Energy transactions occur at locations or nodes on the grid. TeMIX Transport transactions allow buyers to pay for transport or hedge the price difference between an injection and a takeout node. A transport transaction may be for high voltage transmission or lower voltage distribution services.

TeMIX Transport and Energy transactions work together to balance supply and demand across the grid while accounting for losses and grid constraints. Either, a party can purchase energy from another party at a given delivery location at a price that includes transport; or the party can purchase energy at another location and also purchase transport from that location to the delivery location. The price of TeMIX Transport is an all-in, point-to-point price that covers marginal losses, congestion costs and other fixed and variable costs between two grid locations. Transport products also apply to cost-based transmission and distribution services.

2. TEMIX INFORMATION MODEL AND SERVICES

2.1. TeMIX Parties and Sides

Instances of a TeMIX Party include: a metered retail customer, an aggregator of metered customers, a retail or wholesale customer owning a separately metered device (such as an electric vehicle or a generator), the owner of a metered generator or storage device, a retail or wholesale market operator (including a system operator), an exchange, a broker, a power marketer, a distribution system operator, or a transmission system operator.

Parties or their automated systems transact at locations that are at customer or supplier meters or trading hubs.

A Party takes one of two sides in a TeMIX interaction: Buy or Sell.

TeMIX Parties interact with tenders for transactions as illustrated in Figure 2.

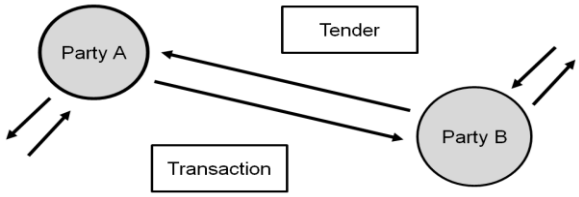

FIGURE 2: PARTIES INTERACT WITH TENDERS AND TRANSACTIONS

A Party may asynchronously interact with several parties taking a different side in each interaction. All TeMIX Interactions are pairwise: if a Buy tender by Party B to Party A is accepted by A, A takes the Sell side and B the Buy side with respect to the new transaction.

At any moment, each Party has a position in the market for a given delivery interval and location. A Party's position can be with more than one counter party. A Party selling energy relative to its current position takes the Sell side. A Party buying energy relative to its current position takes Buy side. A generator typically takes the Sell side, but can also take the Buy side to reduce generation. An end-use customer typically takes the Buy side, but if tendered an attractive price may curtail usage and thereby take the Sell side.

A distributed generator can take a Buy or a Sell side. For example, if a distributed generator sells 2 MW for a future hour (2 MWh of energy), it may later decide to buy back all or a portion of the 2 MW for the hour if the price is low enough. A distributed storage device will also take the buy or sell side in different transactions in different intervals.

2.2. TeMIX Option Tenders and Transactions

Two parties can also engage in an Option Transaction. An option is a promise granted by one party (Option Writer) to a second party (Option Holder) for a premium payment. The Option Holder is granted a right to invoke specific transactions for energy that the Option Writer promises to deliver. Any party may take the buy or sell side of a tender for an Option Transaction.

Demand response and some ancillary services are embedded options. TeMIX provides for explicit options such as price caps and floors and put and call options for energy that can provide demand response and ancillary service-like capabilities.

2.3. TeMIX Products

TeMIX products are a profile of the EMIX Power Products [3]. TeMIX Products are based on blocks of Power/Energy and Transport with a constant rate of delivery of energy over an Interval. The terms Power and Energy are used interchangeably in TeMIX. Each transaction imposes an obligation on the buy side to purchase and the sell side to deliver a physical TeMIX Power Product or for the two sides to cash out a financial Product at delivery.

The four TeMIX Products are:

1. TeMIX Power Product
2. TeMIX Transport Product
3. TeMIX Option Power Product
4. TeMIX Option Transport Product

2.4. TeMIX Delivery Interval

A TeMIX Delivery Interval is specified by Start Date/Time and Duration. TeMIX Products for each TeMIX Delivery Interval are tendered and transacted independently of the other intervals. Delivery intervals are nested so that shorter duration intervals fit within longer duration intervals. A typical set of nested durations might be a calendar year, calendar month, day, hour, 5-minute, or 4-second interval. For example, a position in a 5-minute interval that is nested within hourly or monthly intervals can include positions in those intervals.

2.5. TeMIX Rate of Delivery

The quantity of a TeMIX energy product is specified by the rate of delivery (kW or MW, for example) over an interval. The amount of energy (kWh or MWh) delivered over the interval is the average rate of delivery over the interval times the duration of the interval measured in hours.

TeMIX deems that every transaction is at a constant rate of delivery over an interval[1]. A constant rate of delivery defines the rate of delivery in each subinterval of the interval, a necessary requirement to determine the position after subsequent transactions on the subintervals.

A transaction to deliver at a rate of 1 kW (1 kWh/hour) over a 24-hour day is a transaction for 1 kWh in each of the 24 hours of the day (a total of 24 kWh) and 1/12 kWh in each 5-minute interval of the day. A short daylight savings day of 23 hours delivers 23 kWh. However, in every hour of the day the rate of delivery (power) is the same 1 kW.

By assembling a set of transactions, a party can shape the total energy delivery as desired. For each interval, the sum of the rates of delivery for all transactions (sells less buys) is the party's position for the period. Note that a position for a party could include transactions with several counterparties and positions can be physical or financial.

2.6. TeMIX Network Architecture

Figure 3 illustrates a network of parties that may transact with each other using TeMIX. The parties illustrated include generators and customers, intermediate parties such as exchanges, traders, brokers, aggregators, retail energy providers (REP) and transmission and distribution operators. This list is not exhaustive.

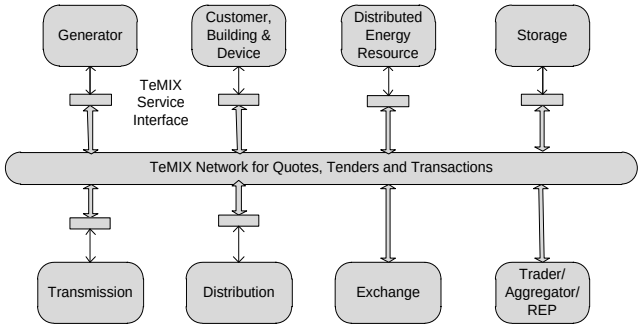

FIGURE 3: ILLUSTRATIVE TEMIX NETWORK

2.7. EMIX Interface

TeMIX and EMIX transactions occur at EMIX Interfaces [3] where the beneficial rights of a product are transferred between parties. An EMIX Interface is at node or meter as defined in Table 1 or an aggregation of nodes or meters, a pair of nodes, or a geographic area as described in Table 2. The elements of the interface allow interface with standard grid domain locations and customer domain locations.

TABLE 1: TYPES OF EMIX INTERFACES

Elemental Type	Description
MRID	As defined in IEC-TC57 [13] identifies a physical device (Customer Meter or other End Devices).
Node	As defined in IEC TC57, a place on the grid. Many, but not all nodes are associated with meters.

TABLE 2: EMIX POWER INTERFACE

EMIX Power Interface	Description
Service Area	Locations or regions relevant to power transactions.
End Device Asset	Physical Device (MRID).
Meter Asset	Physical device or devices that perform the role of the meter (MRID).
Pricing Node (PNode)	Location in an ISO / RTO where participants submit bids and the ISO / RTO publishes locational prices.
Aggregated Pricing Node	Specialized type of Pricing Node for zone, control area, or aggregated generation, load, or trading hub.
Service Location	Location where ownership of service changes hands. Potentially has many Service Delivery Points.
Service Delivery Point	Logical point where ownership of service changes.
Transport Interface	Delineates edges at ends of a transport segment. Names two nodes: point of receipt and point of delivery.

[1] An exception to the constant rate of delivery is for variation within the metered delivery interval. For example, if the metered delivery interval is one hour only the total energy or average power for the hour matter.

2.8. **TeMIX Service Interface and Management**

The TeMIX Service Interface illustrated in Figure 4 is based on the EMIX Power Interface. TeMIX Service Interfaces may be associated with a device or many devices or no devices as in the case of intermediaries such as aggregators, traders, retail energy providers and exchanges.

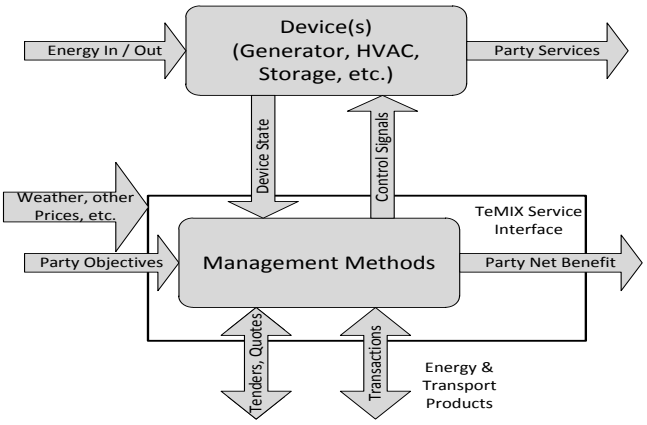

FIGURE 4: END DEVICE AND TEMIX SERVICE INTERFACE

A TeMIX Service Interface to one or more devices may reside at the device, at the facility, or in a network or cloud application.

Typically a device has local control loops tightly integrated in the device for safety, device sequencing and protection. The control signals described here are higher level control signals such as temperature and generator set points.

An end device produces or consumes energy and may store energy. Large generators, distributed generation, variable wind and solar renewables, and battery storage are end devices. Residential, commercial and industrial customer air conditioning, heating, pump, lighting, and electronic equipment are also end devices.

End devices may be passive or active (with on / off, or variable control). Some devices respond to control nearly instantly while others require notification lead and ramp time. Some devices may be integral to a building or process.

Figure 4 illustrates the TeMIX operation of end devices. At the top of the figure the device is illustrated. At the bottom of the figure the TeMIX Service Interface is illustrated.

Power input and output and services to the devices are determined by control signals and the physics of each device. A generator outputs energy. A consuming device inputs energy and produces services to the party such as heating and cooling. Storage both inputs and outputs energy. Except for co-generators, generators and storage typically do not provide services to the party other than the net value of energy output or input.

The TeMIX Service Interface has three functions: (1) determine the devices' target current and forward operating levels, (2) receive and issue forward tenders and (3) execute transactions with other parties based on their tenders. TeMIX Service Interfaces may also employ transport products to transact at other locations and pay for delivery of the energy to or from another location.

The Management Methods for devices can be as simple as turning a device on when the price tendered is lower than a threshold price and turning it off when the price is higher than the threshold price. Or Management of a device may be based on optimal control, forward tenders and quotes, and automated forecasting and learning.

The objective is to maximize Party Net Benefits based on party objectives, current state and characteristics of the devices, and external variables such as weather and fuel prices. Many devices will use simple rules for operation but optimization is now feasible and economic for many devices.

Importantly, there is no communication of device state or characteristics outside and no control signals from outside of the TeMIX Service Interface.

2.9. **TeMIX Market Processes**

TeMIX supports decentralized decisions and coordination using near-continuous, asynchronous communication of TeMIX tenders among parties. Many different market processes to reach agreements on transactions may use the TeMIX model. Different parts of the energy market may employ different market processes.

TeMIX market processes are characterized by Transactive States. TeMIX uses the five Transactive States in Figure 5 to qualify the TeMIX information model for each state.

FIGURE 5: TEMIX TRANSACTIVE STATES

An Indication of Interest is non-binding and non-actionable. It is (1) a request for a Tender, (2) a forecast of usage or supply, or (3) a forecast of price. A priced Indication of Interest is also called a Quote.

A Tender is a price and quantity for a Transaction with an expiration date time. A Transaction is formed by accepting a Tender. Delivery is the metered quantity delivered usually offset by a position resulting from several transactions. Publication communicates transacted prices, quantities, costs, or revenues.

2.10. TeMIX Forward Transactions and Positions

Forward TeMIX transactions accumulate in forward physical and financial positions. Financial, hedge positions are cash-settled, perhaps based on an index of market clearing prices. Forward physical positions are compared to metered delivery and any differences are settled by real-time transactions. Figure 6 illustrates such a sequence of forward transactions and positions for delivery. In some markets, forward transactions by a party may be with several counterparties. The TeMIX concepts are similar to concepts used in continuously traded bid/ask markets such as commodity and stock exchanges, and energy bilateral transactions.

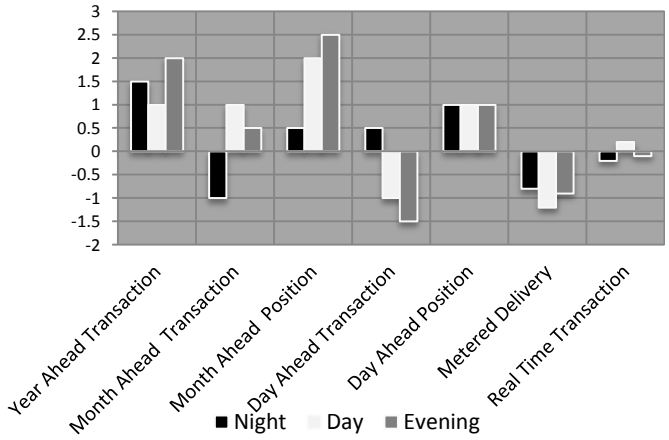

FIGURE 6: SEQUENCE OF FORWARD &REAL TIME TRANSACTIONS

2.11. TeMIX Product Information Model

Elements of the four TeMIX Products are shown in Table 3.

TABLE 3: TEMIX PRODUCT DESCRIPTION

TeMIX Element	Description
Power Product	Power, Transport, Power Option and Transport Option
EMIX Interface	One Node for Power and two Nodes for Transport
Start Date Time	When the Interval begins.
Duration	Extent of time of the Interval.
Price	Unit Energy Price for the Interval
Energy Item	Real Energy (Power * Time) delivered over the Interval
Power Quantity	Rate of Delivery of Energy over the Interval.
Transactive State	Indication of Interest, Tender, Transaction, Delivery, or Publish.
Side	Side the information originator is on: Buy or Sell.
Expires Date	Date Time Tender expires.
Power Item	Units for the Rate of Delivery of Energy for the Interval.
Currency	Currency for the exchange.

The price of a TeMIX Product is expressed in energy units. At a price of $80 per MWh of energy, the extended price (cost) of 1 MW of Power (2 MWh of Energy) for two hours between 3 and 5 PM is $160; the extended price for 1 MW of Power in each 15-minute Interval of the two hours is $20.

A TeMIX Transport Product provides transmission or distribution service for a TeMIX Power Product from the Injection Node to a Takeout Node of an EMIX Interface. A Transport product is financial or physical. The energy required by a transport operator to compensate for transport losses is assumed to be paid for in the transport price.

For TeMIX Options the additional elements in Table 4 apply:

TABLE 4: TEMIX POWER OPTION PRODUCT DESCRIPTION

TeMIX Element	Description
Option Holder Side	Side which may exercise Option. Other side is Writer.
Option Strike Price	Price the Option Holder pays Option Writer to deliver.
Exercise Lead Time	The Minimum Notification Duration.
Option Exercise	The Availability Schedule expressed as an EMIX Term.
Temporal Granularity	A 15 Minute Granularity one hour option starting at 10:00 can be called for 10:00, 10:15, 10:30, or 10:45.

A TeMIX Option Product provides the Option Holder the right to instruct the Option Writer to deliver (call) or take (put) a TeMIX Power or Transport Product up to the transacted quantity (rate of delivery) of the Option at a Strike Price. The Option can be exercised during the Delivery Interval of the Option for any sub-Interval not smaller than the Temporal Granularity.

For example, a TeMIX Option for 10 MW for a Day with an Option Interval Granularly of 1-hour and an Option Lead Time of 30 minutes allows the Holder to exercise the option for any or all hours of the Day at the Strike Price by giving 30 minutes notice before each hour.

2.12. TeMIX Market Context

EMIX provides for communication of a Market Context [3]. Each Market Context has a Uniform Resource Identifier (URI) A TeMIX Market Context will typically hold the Energy Item, Power Item and Currency from Table 3 and it may also hold the EMIX Interface, Duration and Power Product. The reduced TeMIX Product Description or Payload for a tender, quote, or a transaction is shown in Table 5.

TABLE 5: TEMIX TENDER, QUOTE OR TRANSACTION PAYLOAD

TeMIX Element	Description
Market Context	Market Context URI
Start Date Time	When the Interval begins.
Price	The Unit Energy Price for the Interval
Power Quantity	Rate of Delivery of Energy over the Interval.
Transactive State	Indication, Tender or Transaction.
Side	Side the information originator is on. Buy or Sell.
Expires Date	Date Time Tender expires (tender only)

2.13. TeMIX Web Services

TeMIX Services are defined in OASIS Energy Interop [2]. The services and operations are consistent with the OASIS Reference Model Service Oriented Architecture [7].

A TeMIX Service conveys a TeMIX Payload (Table 5) from a Party to a CounterParty.

The TeMIX Tender Services are ***EiCreateTender, EiDistributeTender, EiCancelTender*** and ***EiRequestTender***. The "Ei" prefix designates the OASIS Energy Interop services.

EiCreateTender communicates a Tender from a Party to a Counter Party. EiDistributeTender communicates Tenders from a Party to each of a set of CounterParties identified by a geo-location or group. EiRequestTender allows a Party to request a payload of standing Tenders already created.

The TeMIX Quote Services are the same as the Tender Services except the Transactive State is "Indication" and the Quotes are not actionable whereas a Tender is actionable.

The TeMIX Transaction Services are ***EiCreateTransaction*** and ***EiRequestTransaction***. A Transaction is created between two parties when a Party accepts a Tender using EiCreateTransaction. EiRequestTransaction allows a party to request a payload of previously executed transactions.

Similar services and payloads are provided for the other Transactive States: Indication of Interest, Delivery and Publication and for communication of Market Context.

TeMIX services are composed with standard secure and reliable messaging protocols [2] as required.

3. RETAIL DYNAMIC PRICE EXAMPLE

3.1. The Case for Retail Dynamic Prices

It is beyond the scope of this paper to make the case for retail dynamic prices for electricity; especially as many others have done so, very effectively. Science, real-world experiments and implementation have proven the cost effectiveness, customer acceptance and fairness of dynamic prices [8] [9] [10]. These studies clearly show that retail dynamic prices are a far better alternative than flat or time-of-use prices, direct load control, or event-based demand response. The purpose of this example is to illustrate how the TeMIX products and services are used to implement dynamic price tariffs.

3.2. Structure of the Example

The example describes one or more Retail Energy Providers (REPs) serving retail customers (residential, commercial, industrial, or distributed generation or storage customers). The example applies to both competitive and regulated REPs. The method of determining price is out of scope for this paper. However, the REP price to the customer is an all-in delivered price for energy, transmission, distribution and fixed charges. The structure of the example is illustrated by Figure 7. As shown, retail customers respond to tenders from REPs with forward transactions cumulating in forward positions in each delivery interval and a final balancing transaction as was described in Figure 6.

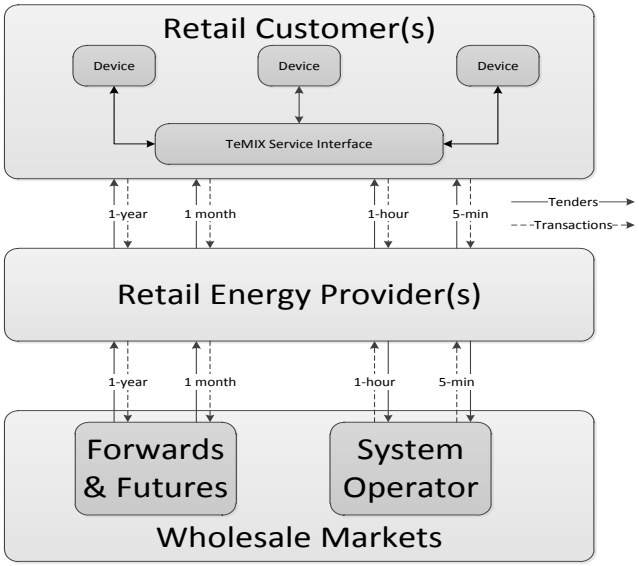

FIGURE 7: TEMIX RETAIL PRICING MARKET STRUCTURE

3.3. Retail Energy Provider TeMIX Tenders

A REP Tender is for the sale or purchase of a specific quantity of energy by a customer for a specific delivery interval and location. The price and quantity may differ for the buy and sell side tenders. Figure 7 shows customers only responding to REP buy and sell tenders but they may also submit tenders to the REP. In competitive markets a customer may interact with more than one REP. REPs will typically offer a set of forward tenders such as hourly tenders for the next day, month or year at each opportunity.

3.4. REP Transactions with Wholesale Markets

Figure 7 also illustrates the transactions between REPs and the system operator markets and parties in other wholesale markets. Such transactions may or may not be based on TeMIX. Transactions with System Operators are based on tenders initiated by the REP because the Operator's bid-based auction clearing methods typically do not post tenders. Generally the REP will strive to hold a balanced portfolio of positions with retail customers and wholesale markets.

3.5. Sequence of Transactions

The sequence of transactions in Figure 6 also applies to this example. The sequence may begin with REP tenders for night, day, and evening blocks (intervals for delivery within

prescribed times of the day, for example) of power for a year. The tenders may be made one or more years ahead of delivery and a tender may be withdrawn by a REP before customer acceptance and a new tender made at any time. The customer or a customer's automated devices decide the transacted quantity in each block and the customer is obligated to pay the transacted price and quantity.

Monthly and daily, a REP also may tender blocks of power at current prices. The customer or the customer's device may transact to adjust his position as indicated in Figure 6. Assuming one REP provides balancing 5-minute energy, the customer incurs default 5-minute transactions with that REP for any difference between the 5-minute position in each interval and the measured delivery at a real-time price posted by the REP before or after the close of the interval. Forward transactions are called subscriptions [9] and the process is sometimes called "buying your own baseline" [8].

If the forward transactions are financial, the forward positions are cashed out at the 5-minute real-time prices and the proceeds used to offset the full cost of energy delivered at the 5-minute prices.

A REP, also using automation, may issue forward tenders at any time. For example, ahead of each 5-minute interval a REP may tender energy in each 5-minute interval for each of the 5-minute intervals in the next two hours. Customers or their automated devices may then forward buy and sell 5-minute energy at forward tendered prices.

3.6. Customer TeMIX Transactions

Customer TeMIX transactions may be automated using devices acting on the behalf of the customer and based on customer preferences and not a REP's preferences as described in Section 2.8.

3.7. TeMIX Options as Real-Time Price Caps

TeMIX Call Options can be offered by a REP to customer as the Option Holder. The call option effectively caps the price a customer pays for the Option Quantity at real-time prices. The REP would charge a premium for this "price insurance" and the customer would decide how much price cap insurance to purchase as an alternative to or in addition to forward energy transactions.

3.8. Interface with the Rest of the Grid

REP Tenders typically reflect the REP's marginal short and long-run costs for wholesale energy, ancillary services, transmission congestion, transmission access, T&D losses, distribution congestion and other fixed items. Theoretically, all such costs may vary by interval and be reflected in a varying price in each interval. The tendered price can vary because of variable demand, plant outages, transmission outages, variable wind or solar or high levels of electric vehicle charging. The tendered prices for each interval location and resulting customer price response help to bring supply and demand into balance at each location on the grid. Tenders and transactions can occur on intervals as short as necessary (5-minutes, 1-minute, or 4-seconds, for example).

3.9. Frequent, Small TeMIX Tenders

TeMIX tenders ideally are for small quantities offered frequently by an automated REP TeMIX Service Interface to an automated retail customer TeMIX Service Interface at tendered prices. If more or less is needed by the customer, then the customer's automated interface can access additional tenders automatically posted by the REP, perhaps at different prices. The response of the automated customer interface to tenders provides information on customer price sensitivity that helps guide the REP's tenders in system operator and forward wholesale markets and subsequent tenders to customers.

Sequences of small tenders and transactions protect the stability of the grid from sudden, large price and position changes. Frequent, small tenders and transactions avoid the need for random or arbitrary smoothing of the customer response to large price changes from the REP. Frequent tenders provide for quick response to grid changes and the size of the tenders can be adjusted to the need.

3.10. Real Time Prices

Real Time Prices (RTP) are tenders for real-time energy. The forward transactions and positions in the example provide risk management for the customer and REP and forward information for forward wholesale transactions by a REP. TeMIX forward positions reduce the risks of RTP without reducing customer response to RTP volatility.

Where forward tenders are not provided, TeMIX can convey forward indications of RTP (Quotes) to help the customer manage use based on RTP indications.

4. SUMMARY

TeMIX is most useful for smart meter enabled customers with smart HVAC controls and appliances, smart PEV chargers, building or process automation and other such devices. TeMIX provides transacted baselines (positions) for each delivery interval so that the response of customers to price is discovered without verification and statistical estimation of baselines as is the case with conventional demand response programs. TeMIX can considerably simplify settlement and billing. The same system can apply to regulated or competitive REPs, all customer classes, and distributed energy resources. An advantage of TeMIX for retail dynamic prices is that customers and their automated devices respond with giving control of their devices to a REP and without providing forecasts or response curves.

TeMIX has applications in all grid domains. The dynamic processes of TeMIX can enable the coordinated, decentralized operation of variable renewables, distributed generation, customer appliances, industrial processes, electric vehicles, storage, and peak load management with distribution, transmission and centralized generation which is an important goal of the smart grid [11][12].

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Biography

Dr. Cazalet is a leader in the design and implementation of markets for electricity, the development of smart grid standards, and the analysis of transmission, generation, storage and demand management investments. Dr. Cazalet has decades of electric power and related experience as an executive, board member, consultant, and entrepreneur.

He is a former Governor of the California Independent System Operator (http://www.caiso.com) and founder of TeMIX Inc. (http://www.temix.net), MegaWatt Storage Farms Inc. (http://www.megawattsf.com), The Cazalet Group (http://www.cazalet.com), Automated Power Exchange, Inc. (APX) (http://www.apx.com), and Decision Focus, Inc.

Dr. Cazalet has successfully promoted storage legislation and policy both in California and at the Federal level. He has advocated new electricity market designs to promote the integration of renewables and the use of price responsive demand as well as storage to support high penetration of variable renewables and efficient grid operation and investment by the grid participants including customers.

Dr. Cazalet is co-chair of the OASIS Energy Market Information Exchange (EMIX) Technical Committee and a member of the OASIS Technical Committees on Energy Interoperation and Scheduling.

Dr. Cazalet holds a PhD from Stanford University in economics, decision analysis and power system planning and engineering degrees from the University of Washington.