Transactive Device Architecture and Opportunities

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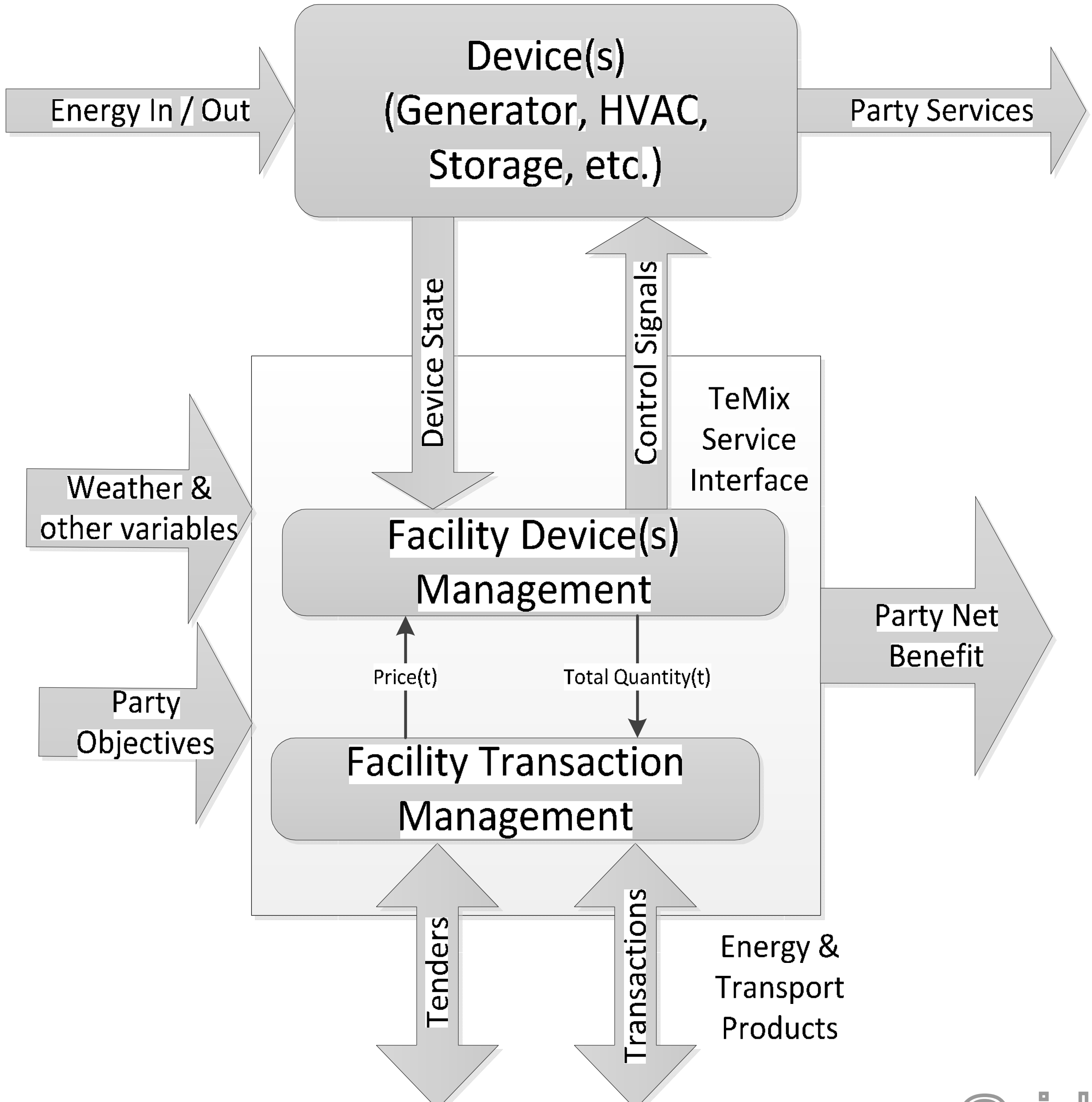
Devices & TeMix† Service Interface



† "Automated Transactive Energy (TeMix)",Grid-Interop Forum 2011, temix.com/images/GI11-Paper-Cazalet.pdf.

Device Management Approaches

- Instantaneous Device Management
  - Example : lighting
  - Manage based on cost per hour = kWh * Price/kWh
- Dynamic Device Management
  - Device may have storage and services may be time shifted.
  - Examples: pumping, HVAC, refrigeration and battery charging.
  - Manage with heuristics or Optimization of Net Benefits (Benefit – Cost) based on forward prices over a planning horizon.

Model Predictive Control (MPC)

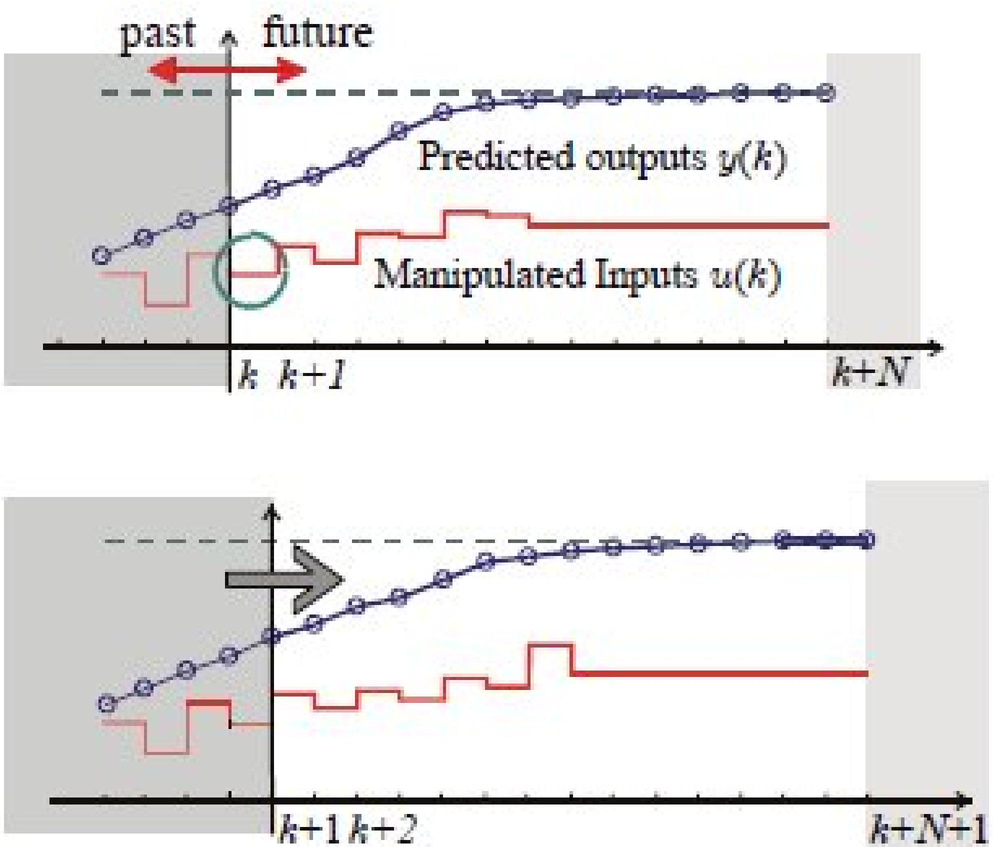
MPC is

1. Explicit use of a model to predict the output of a system being controlled along a sequence of time steps up to a future time horizon.
2. Calculation of a control sequence to optimize net costs or net benefits.
3. A receding horizon strategy, so that at each time step, the horizon is moved towards the future, which involves the application of the first control signal of the sequence calculated at each time step as in 2.
4. Repeat steps 2 and 3.

Model Predictive Control (MPC)

Model Predictive Control
Receding Horizon Policy

Define optimal control problem with finite prediction horizon



- Optimize at time k with measurements x(k)
- Apply only the first few optimal moves u(k)
- Repeat the whole optimization at time k+1

Source: Manfred Morari, ETH

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Optimal Device Management

$$\text{Net Benefit}(\tau) = \max_{z} \sum_{t=\tau}^{H(\tau)} f[z_t, t] - p(t) * x[z_t, t]$$

- τ is the current time interval.
- **H(τ)** is the current horizon.
- ***t*** is the index to the time intervals in the moving time horizon.
- **z(*t*)** is the control level for the device in each interval of the moving time horizon.
- z_t is the vector of control levels z(*t*) for the current and prior intervals t.
- The function **f[z_t,*t*]** encodes the device operational benefits and device physics and constraints given current and previous control levels.
- The function **x[z_t,*t*]** gives the power quantity used in interval t as a function of the control levels z_t in current and prior intervals of the moving time horizon. Power production is a negative quantity for x.
- **p[*t*]** is the forward energy price in each forward interval. **p(*t*) depends on forward tender prices.**
- $x^*(t)$ is the current optimal power quantity in each forward interval.

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Facility Transaction Management

- Total net power used or produced by the devices in a facility should be procured or sold (Transacted) at the same prices used for device management.
- The real-time price may not be known before the devices are operated.
- Forward buy and sell transactions at forward tendered prices support
  - Forward prices for device optimization,
  - Forward device operation commitment,
  - Forward hedging, and
  - Forward information to suppliers and grid operators.

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Basic Business Transaction Process

- You make an offer or tender of a product to me at a price, I choose to accept.
- You deliver the product, I deliver money.
- Each of us makes transactions we consider beneficial.
- And each is obligated to meet the needs of the other — reliably.

Market neutral: works for regulated retail dynamic tariffs, competitive retail dynamic rates, peer-to-peer retail transactions and wholesale transactions.

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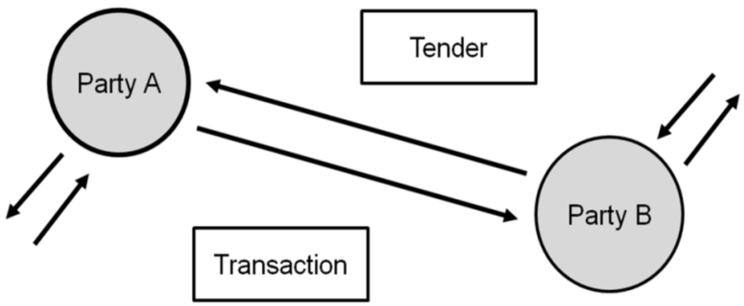
TeMix Energy Business Process

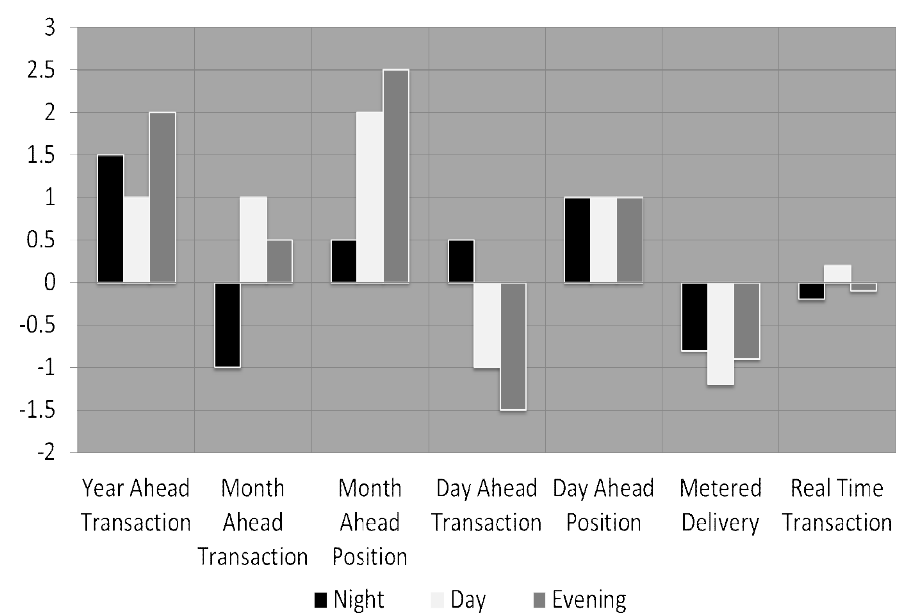
Typical Transaction Durations: year, month, day, hour, 15-min,5-min,1-min,4-sec



Parties

- Residential, Commercial, Industrial, Electric Vehicle Customers
- Generation, Storage, DER Owners
- Distribution & Transmission Operators
- Retail Energy Providers
- Traders and Marketers
- Exchange Operators
- System Operators
- Balancing Operators
- *Grid Custodians*

Forward Transactions, Positions and Delivery
(actual transactions and positions may be continuous)



Facility Transaction Management

- The incremental buy quantity (sell, if negative) is

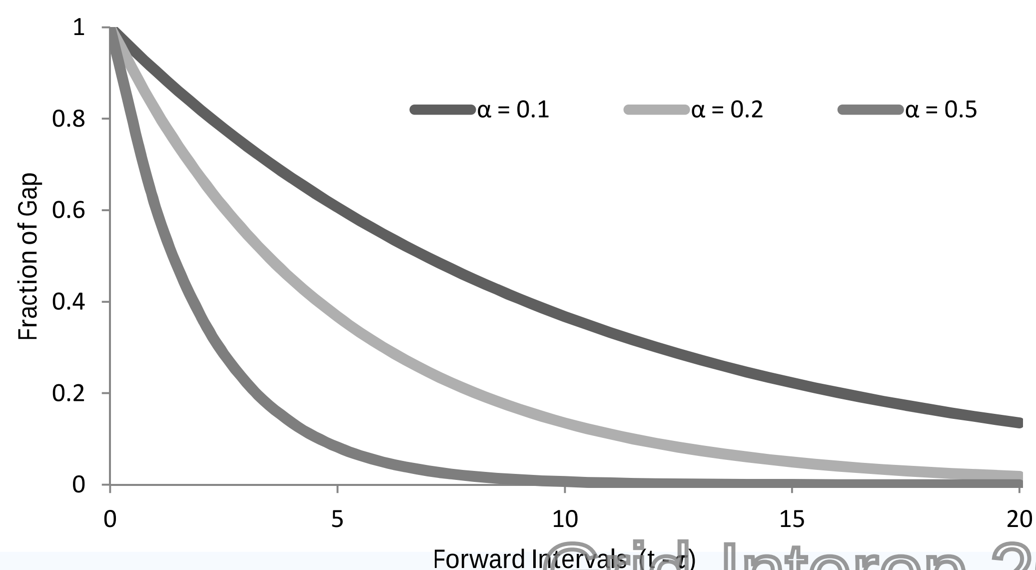
  $w(t) = X^*(t) - Y(t)$,

  – $X^*(t)$ is the total power for the committed and planned operation of all devices at a facility.

  – $Y(\mathrm{t})$ is the power previously contracted.

- The quantity of the best buy or sell tender accepted is

  $W(\mathrm{t}) = w(\mathrm{t})\ e^{-\alpha(t-\tau)}$



Example: Commercial Refrigeration

- Multi-zone refrigeration system
  - Several cooling units sharing a common compressor
  - Control cooling capacity to each unit (control variables)
  - Minimize energy costs using forward energy prices p(t) (input variables)
  - Satisfy min and max temperature limits in each zone (constraints)
- MPC solutions are fast and repeated often.
- Savings of 30% versus standard thermostat.
- Sophisticated response to price variability.

ref: T. Hovgaard, L. Larsen, J. Jørgensen and S. Boyd, “Nonconvex Model Predictive Control for Commercial Refrigeration”, http://www.stanford.edu/~boyd/papers/noncvx_mpc_refr.html

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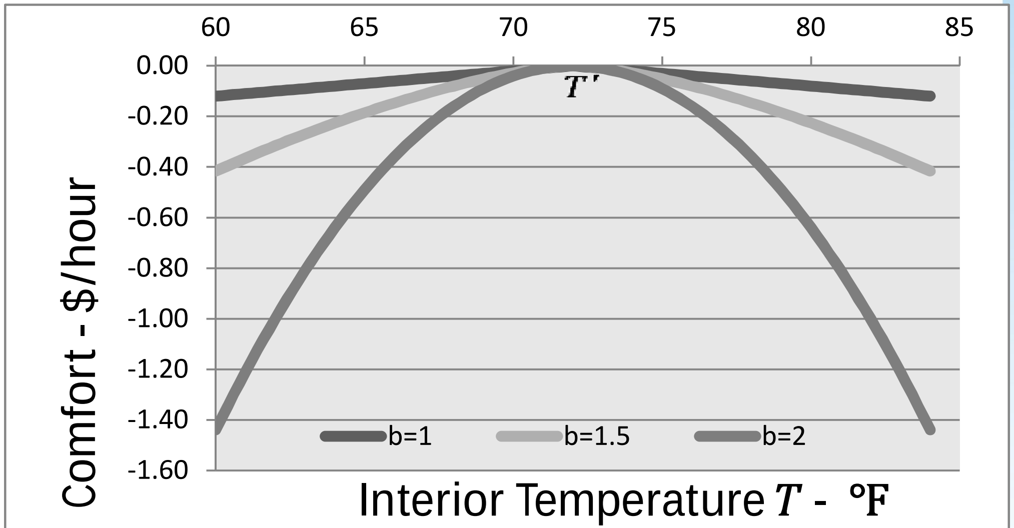
Example: Residential Air Conditioning

- $\text{Net Benefit}(\tau) = \max_{z} \sum_{t=\tau}^{H(\tau)} f[z_t, t] - p(t) \; * \; x[z_t, t]$
  - $z(t)$ temperature set point in each interval
  - z_t temperature set points $z(t)$ for current and prior intervals
- $f[z_t, {}_t] = comfort[\,T[z(t), t], t\,]$
- $comfort[T, t] = -\,abs[\,a * (T - T')^{\,b}\,]$
  - T actual temperature
  - T' desired temperature
  - a benefit sensitivity
  - b benefit sensitivity shape



Retail Provider Forward Tenders Example

Priced Buy and Sell Tenders for blocks (subscriptions) at a KW rate for:

- each of next 10 calendar years
- each of next 24 calendar months
- each day of the next calendar month
- each hour of the next 24 hours at a price
- each 5-minutes of the next 12 5-minute intervals
- after each 5-minute interval, the balance between the facility net forward position and the metered quantity.

Transactive Energy & TeMix

- Contrary to often expressed misconceptions, Transactive Energy is *not* prices-to-devices broadcasting of price signals.
- Such price broadcasting has many problems including risks of grid instability, abuse of market power, and volatile costs and revenues.

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Summary

We have illustrated

1. The TeMix facility transactions process combined with optimal device or rules operation
2. A device architecture for device and controls suppliers
3. TeMix retail tariffs