Home Energy Demand Manager

Load and Supply Optimization to Replace Demand Response and Anticipation

The problem defined: Energy loads and energy supplies (primarily on the electrical grid) are not synchronized. The current solution is to over-supply the grid to meet the occasional coincident loads and to aggregate buildings on branches of the grid to average out their load profiles (and reduce the surplus requirement.) Added to this are initiatives like California's "Flex Alert" as demand management efforts. Commercial customers pay demand charges that provide rough feedback, but residential customers have no easy way to automatically interact with the grid to modulate their demand. Clearly these measures are insufficient. The grid infrastructure needs some additional information exchanges to address both our increased electrification and the opportunities and problems of distributed generation.

Managing demand today is presented as a form of "virtuous self-privation" wherein you turn off/down excess appliances to avoid power outages. Alternatively, one can ignore the call to conserve as a demonstration of economic independence/wealth. This is a sort of Spinach vs *Pâté de Foie Gras* conflict (with all the moralizing and political baggage that implies.) Energy use is, however, not the real goal of any consumer. It is the services the energy provides that consumers desire. But the current tools (information, technical and economic/cultural) cannot extend much further into the future. Going forward, an alternative, positively framed, approach is needed. One such approach is presented here, in outline.

A recent study funded by the California Solar Initiative[1], addressed the shape of loads for a neighborhood of net-zero houses with solar arrays (and some with battery arrays.) To make the study comprehensive, they electrified heating loads that would conventionally in California be served by natural gas. This made monitoring of the homes' various peaks and valleys of consumption and production possible and easily comparable at the cost of exaggerating the swings in the loads. With distributed generation, the incentives, for a home owner, of what loads to serve electrically will naturally shift and evolve. While the study artificially inflated the electric loads, the drift in that direction is underway due to the continuing drop in panel prices. This will create an incentive to serve local (in the home) loads rather than make sacrificial sales to the grid at wholesale prices just to buy them back at retail prices. Of interest in the resulting data were the spikes that came when domestic hot water and air conditioning loads, or air conditioning and clothes drying, or oven use, coincided. These brief periods were not under control and, for service to be reliable, required significant "over-capacity and over-supply" to be built into the grid that served these (exceptionally efficient) houses. This standby capacity is a considerable unnecessary expense. The elimination of that excess would mutually benefit both the consumer and the grid operator but can only be accomplished by cooperative, *forward-looking* load planning and deployment.

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[1] CSI RD&D Webinar - PV Integrated Storage: Demonstrating Mutually Beneficial Utility-Customer Business Partnerships http://calsolarresearch.ca.gov/funded-projects/109

The solution summarized: The Home Energy Demand Manager (HEDM) is an automated energy broker that automatically negotiates and executes an optimized plan for flows of energy in, around, and from the home. To generate the daily use plan, the HEDM monitors and a wireless mesh network of smart appliances to address both anticipated and ad hoc loads. Via this network, each participating appliance can periodically announce their energy haves and wants (to the extent they know them), allowing the HEDM to coordinate and optimize the sequence of smart appliance load, storage and generation cycles. The "bids" from the appliances, batteries, solar arrays, and cogeneration systems would include information like the desired time of initiation and completion, duration, wattage range/profile, urgency and likelihood, etc. The HEDM takes each bid for energy services and brokers them so they fit into the home's ideal load profile. Once an appliance has an approved bid, it stops bidding for the day, assuming there are no changes needed – if there are, it submits a new bid and the process resumes.)

Just as the consuming appliances submit bids for time and placement in the load queue, the distributed generation facilities (i.e. solar PV arrays/inverters, heat pumps, solar thermal arrays, and cogeneration plants) forecast their production and offer up resources to the HEDM. This allows the HEDM to match to local loads. Finally, any storage equipment would offer up data on available energy and available storage (including the rate of standing losses/decay). Importantly, the electric grid, when available, is figured in as a virtual storage battery and as a source at the prices (in both directions) currently on offer. This communication with the grid could be static (a pricing table), dynamic (broadcasts of electricity availability and prices), or some mix of the two. The key is a standardized bid/contract format for the HEDM to read and then authorize/schedule. All this is to be trafficked on a decentralized wireless network. (c.f. https://en.wikipedia.org/wiki/LPWAN.)

HEDM versus existing "home automation" and "smart home" approaches: Nest (now a Google offering) and HomeKit (from Apple) or the Eco Dot (Amazon) and X10 have concentrated on opening sightlines into the current physical state of the home and then offering the operator some controls for a growing number of appliances. But without information about the loads to come during the day (as well as other energy events), these systems are essentially just fancy remote controls for appliances. HEDM's chief virtue is the forward look into the loads of the day and the opportunities to optimize them. Unfortunately for the home automation venders currently in the market, home appliances already come with a full set of very familiar controls that work serviceably well... So there is no natural pain-point that will drive customers to add a second layer of novel controls. There are many serious barriers to adoption of home automation as it is now offered: from the expense of re-kitting one's house, to the "one more interface to learn" hassle: home automation is waiting to grow up from a "gadget maven's toy set" to a "home appliance."

Even if the "home of the future" enthusiasts are great enough in number to drive the prices down, the fundamental risk to grid operators and planners is that these systems remain essentially command-and-control centers and *not* constructive demand managers and grid cooperation agents. As a result, while they might become successful on their own terms, they would still not address the load management needs of a truly smart grid because they are top-down remote control mechanisms at their heart. What is needed is a planning and learning system for optimizing power management and grid participation.

HEDM evolves from, rather than revolts against, "home automation": Demand management in the style of HEDM does not fundamentally contradict the "smart home agenda." Instead, it folds in vital, missing parameters. Namely, price signals and load margins as well as forward-looking time considerations. HEDM brings together
1) The occupant's desires (expressed in plans, habits, behaviors and behavior patterns)
2) Pricing information/signals (both sides of the meter, in both directions)
3) The "availability of energy" forecasts (both sides of the meter)
4) All the particulars of the home's array of
  a) Loads - by type and time and priority etc.
  b) Storage - thermal, electric and "service in advance"
  c) Production - thermal and electric generation
  d) Losses - thermal, from insulation limits
  e) Losses - electric, from conversion and battery standing losses, etc.

This comprehensive perspective allows HEDM to address real pain-points for both the consumer and the grid operator. For the consumer, the pain point is energy costs and working to make efficient use of their own generation and storage assets. For the grid operator, we address and suppress the unpredictability of the loads. Also of interest to the grid operator is the ability to send and receive fine-grained pricing signals to both consumer-side generation assets (DG) and energy storage assets (DS) to help address supply issues: both shortages and surpluses.

Since it obtains pricing information, the HEDM can provide documentable, auditable return on investment (ROI) data for both the consumer and the grid operator. Importantly, the HEDM can periodically inform the user of their actual savings yield and possibly offer additional, concrete options on how to achieve further savings. Appliances that interact on the HEDM mesh network(s) to lower operating costs can likewise "remarket" themselves to the users via savings reports. This will increase brand awareness in a "good news" context. They can develop a positive brand mind-share by showing how they help keep the home's energy economy under control. Consumers would be naturally interested in expanding their fleet of HEDM-capable appliances when they are informed about the savings they've achieved. This further induces the manufacturers to participate in producing appliances with the fullest set of HEDM mesh network features.

The method of operation: The HEDM continually receives bids regarding current and future energy loads, as well as local and imported (grid) energy supplies and the various storage opportunities available. The HEDM uses this information to build schedules that are optimized to stay within the grid- and customer-defined bounds and to meet the cost goals. The HEDM, having composed an optimized plan for the coming hours, releases "approved bids" (or contracts) back along the mesh network in order to implement the cost/income and service optimizing goals. Contracts can be rescinded and a call for new bids made if conditions warrant. For instance, emergencies or an override might pull the contracts already issued - depending upon the status of the load in question. Simulation of the energy flows forecast for the day to come will allow the HEDM to pick a lowest-cost, highest-value permutation for the day's energy uses. This plan for collection, delivery, use, and storage merges the comfort and service levels required by the home owner, with a rational use of time-shifting and turn-taking by the fleet of appliances, batteries, and generation devices, etc.

The HEDM is a rational and persistent representative of the consumer and their home in the domestic and grid mediated energy market. It provides and consumes transparent real-time pricing and tireless recalculating of advantages to deliver optimal yields.

The parts of the system: The HEDM is a combination of a mesh network base station, and a lightweight CPU with software to track the bids, optimize the plan, publish/broadcast the results, and store and offer up logged data for analysis. Additionally, Internet capability is desirable for receiving grid information and for software updating. This might be accomplished as a one-way reception of broadcast radio as well. The physical elements could be housed in a TV cable set-top box or in a home internet router, be a standalone device using a computer or phone for the physical user interface, or it could join the feature set of one of the incumbent products (listed earlier) as an enhancement.

Existing simulation engines to power this analysis are already available as a starting point: principally TRNSYS. The novel components would be the interface for both the user and for the mesh network of participants and the plan propagation (broadcasting the winning bids as contracts and, where necessary, orchestrating the synchronization of loads).

The mesh-networked appliances would require new, additional control circuitry and product development/integration. Providing an open standard (as outlined here) for this hardware would mean the device controllers, communications and user interface elements could be developed and produced as modular commodities for fast reductions in cost. In order to get network effects (the more you use, the greater the advantage to the user), we would need to start with big appliances (for greatest benefits at the start) and flow down to smaller ones. Adoption would probably go in the following order: solar inverters, air conditioners, battery arrays, water heaters, and lighting. But having a universal standard for the hardware and the communications protocols at the outset is the best means for broad and quick adoption. And only broad adoption is of use to the grid operator.

The motivation to produce the HEDM controller hardware is not to gain control of the market for that hardware itself but to foster its quick adoption. Thereby, we'd populate the grid with better, more cooperative nodes. This will increase productive bidirectional exchanges of distributed generation and distributed storage (DG and DS) services.

Upstream of the HEDM (at the grid operator level) is a counterpart system that similarly issues bi-directional pricing information for the day. It also approves bids to establish the regional energy sourcing and delivery needs.

Further implications of HEDM and mesh network approach: The California Solar Initiative study cited above showed some important implications for "load planning" and storage on the grid.

1) Overlapping loads
2) Over-electrification of thermal loads as a hazard
3) Thermal services as storage/load-shifting opportunities
4) Air conditioning as the primary surging load

These problems are, in large part, the consequence of un-integrated systems more than over electrification. Integration will organically influence the technical development of appliances over and above the addition of a mesh network interface. To get better yields in this cooperative context of an HEDM network, novel features will evolve such as:

a) Fractional cycles (to share load headroom)
b) Drip cycle air conditioning (to flatten the load profile)
c) Rightsizing of air conditioning (over-sized installations are a problem today)
d) Solar thermal collection getting a second look
e) Dual drive for pumping loads becomes feasible (allowing flexible choice of AC or DC drive on a per-work cycle basis, depending on the price and availability of the watts on a local DC bus vs that on the AC bus)
f) Optional work cycles (price driven)
g) Time shifting of non criticial services
h) Grid support services beyond "driving meters backward" (for example voltage support, emergency islanding, power conditioning, etc.)

There is a risk to grid operators in this reformulation of the equipment on the customer side of the meter. A more rational consumption and delivery of energy services to and from the grid will place more emphasis on pricing signals than do the current rate structures. Time Of Use rates (a requirement for HEDM to work) will enable fine-grained responses from the customers and will induce right-sizing, right-timing and self-service (meaning in-home energy routes bypassing the grid – and thus bypassing the grid's tolls.) For that reason, differences between the wholesale prices and the retail prices will have to be carefully shaped to incentivize participation in the grid-based exchange of services. Too big a difference in the costs will result in more customer-side self-reliance. This could starve the grid of the surpluses (until the price signals draw them back in.) The good news is the grid and grid operator can charge rational prices for the service and be a good market partner and the HEDM will allow the customer to answer in kind with no extra effort.

Appendix 1

A simulation of the HEDM and mesh network traffic in pseudo code:

Format of the pseudo code packets:

Packet Parts "Actor Name" "type {i.e. need;information;have}" "Details of packet" "Bid ID" or "Notice ID"

//Explanatory notes

Begin DAY:

Information Grid Operator Daily Price Grid: Standard Day Today + Feed-In-Tariff at contract +$.01 Kwhr 6PM-9PM on bid, +.0075 off bid.

//This is the daily notice from the grid operator trying to drum up supply from the distributed generators to meet demand without firing up the grid operators' peaking generators. In effect, this is contracting for a "virtual peaking generator" rather than waiting to see what happens with supply and over-generating to insure supply. This offer anticipates a need in the 6 to 9 PM range and gives an extra above standard premium offer for prebooking the power, less if you deliver it unscheduled.

Dishwasher, Need 15min @.2kWh, 30 min @.5 kWh, 15min @.2kWh ending by 4PM (Bid ID D2321)

//This "need" by the Dishwasher is from being filled with dirty dishes and the user selecting "Start when best ECO" option and a "deadline time".

Hot Water Heater, Need net 500Whr starting 15 min prior to Bid ID D2321 &
Hot Water Heater, Need net 500Whr starting anytime after 4AM, ending 6AM (bid ID1234)

// Hot water heater knows the family schedule and added the dishwasher load's requirement and figured the ramp up time to serve the dishwasher. If dishwasher heats its own water sufficiently, then the hot water heater (or the HEDMI) would know this and ignore that bid.

Hot Water Heater, Have net capacity as storage 3000Whr after 6AM until 8PM (bid ID1235)

Weather Forecast:

Information: Ambient 1AM 54°, 2AM 54°, 3AM 52°, 4AM 51°, 5AM 52°, 6AM 52°, 7AM 58°, 8AM 60°, 9AM 63°, 10AM 70°, 11AM 75°, 12PM 60°, 1PM 60°, 2PM 60°, 3PM 60°, 4PM 80°, 5PM 88°, 6PM 90°, 7PM 90°, 8PM 84°, 9PM 80°, 10PM 75°, 11PM 70°, 12PM 68°

Information: Solar Irradiance South Facing Inclined Plane 6AM .1kWh, 7AM .2kWh, 8AM .3kWh, 9AM .8kWh, 10AM 1kWh, 11AM 1kWh, 12PM 1kWh, 1PM 1kWh, 2PM, .7kWh, 3PM .7kWh, 4PM .7kWh, 5PM .7kWh, 6PM .6kWh, 7PM .5kWh, 8PM .1kWh (Bid IDA2315)

//Note cloudy in the mid day then hot and sunny later (Wh/Wm2)

//Note the house's air conditioning and (hot water) standing-loss factors are known to HEDM, as are the battery's features and performance specifications (possibly learned anew everyday in notices of the bid type. They are subject to change and the HEDM is not irritated by verbosity or repetitiveness.

Air Conditioner [having listened to Weather Forecast], Need 1AM-2AM 0kWh, 2AM-3AM 0kWh, 3AM-4AM 0kWh, 4AM-5AM 0kWh 5AM-6AM 0kWh, 6AM-7AM 0kWh, 7AM-8AM 0kWh, 8AM-9AM 0kWh, 9AM-10AM 0kWh, 10AM-11AM .5kWh, 11AM-12PM 0kWh, 12PM-1PM 0kWh, 1PM-2PM 0kWh, 2PM-3PM 0kWh, 3PM-4PM 0kWh, 4PM-5PM .75kWh, 5PM-6PM 1kWh, 6PM-7PM 1.2kWh, 7PM-8PM 1.3kWh, 8PM-9PM .75kWh, 9PM-10PM .4kWh, 10PM-11PM 0.3kWh 11PM-12PM 0kWh, 12PM-1AM 0kWh (Bid ID C1239)

//Note: an air conditioner without mesh network node could be driven via thermostat signal path from the HEDM to similar effect.

Air Conditioner, Have Storage Potential 1AM-2AM 0kWh, 2AM-3AM 0kWh, 3AM-4AM 0kWh, 4AM-5AM 0kWh 5AM-6AM 0kWh, 6AM-7AM 0kWh, 7AM-8AM 0kWh, 8AM-9AM 0kWh, 9AM-10AM 0kWh, 10AM-11AM .5kWh, 11AM-12PM 0kWh, 12PM-1PM 0kWh, 1PM-2PM 0kWh, 2PM-3PM 1kWh, 3PM-4PM 2kWh, 4PM-5PM 1kWh, 5PM-6PM 1kWh, 6PM-7PM 1.5kWh, 7PM-8PM 1kWh, 8PM-9PM 1kWh, 9PM-10PM 1kWh, 10PM-11PM .5kWh 11PM-12PM 1kWh, 12PM-1AM 0kWh (Bid ID A3456)
//Note: The air conditioner is stating its ability to sink excess power by cooling beyond the minimum requirement, in advance of the need, if desirable. For instance an oversupply from the solar array that fetches a too low price from the grid operator can instead be used locally to pre-chill ahead of the heat of the day rather than sell too cheaply. This can migrate the demand to earlier, so now it is an anticipated AND known load rather than a reactive load surprising a non-smart, standard thermostat.

Solar Array Have: 6AM 1kWh, 7AM 2kWh, 8AM 3kWh, 9AM 8kWh, 10AM 10kWh, 11AM 10kWh, 12PM 10kWh, 1PM 10kWh, 2PM, 7kWh, 3PM 7kWh, 4PM 7kWh, 5PM 7kWh, 6PM 6kWh, 7PM 5kWh, 8PM 1kWh (Bid ID34521k)
//The Inverter controller read the weather report, figured de-ratings, string losses and multiples for the array, as installed and generated this bid.

HEDM Bid ID D2321 Approved for end 3PM
HEDM Bid ID A3456 2PM-3PM 1kWh, 3PM-4PM 2kWh, 4PM-5PM 1kWh, 5PM-6PM 1kWh Accepted
//The rest of the Air Conditioning energy sink/storage capacity will not be called upon)

HEDM outbound offer - 6PM-7PM 1.2kWh, 7PM-8PM 1.3kWh, 8PM-9PM .75kWh at Contract + $.02 (BID ID AK34598)
// This is a cheeky counter-offer from the HEDM to the grid operator. If they need the electricity they'll answer the bid with an approval If not, the HDEM has a plan for the electricity that is worth that much so it does not leave the value unexploited.
ETC...[END PSEUDO CODE SAMPLE TRAFFIC for HEDM network]