Utilization of Histogram in Control of Aggregated Loads with Innate Storage

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Demand response (DR) and energy storage could play important roles as new sources of flexibility and in accommodating larger penetration of renewable in emerging power systems. DR programs are being deployed in several North-American and European jurisdictions to reduce market and power system stress [1-4]. DR programs are currently providing energy, capacity, reserve and regulation in several wholesale markets [3]. However, even though the potential is significant, the contribution from the residential sector is still limited [5].

Buildings and appliances with thermal mass as well as batteries in electric vehicles can store energy. Hence, thermal loads and EV batteries can act as energy buffers [5-6] and could be used to balance renewable [3], reduce peak demand [14] and provide operating reserve [7-8]. While current programs are successful at attracting emergency or reliability-based programs, there is significantly more untapped potential. There is a need for DR technologies that will increase customer participation in everyday life scenarios with the right trigger to activate demand-side participation every time it is required, while keeping privacy and being fast enough [9-13].

When targeting advanced DR services, several challenges can be faced, including: (1) need for efficient aggregation (which include data mining and dispatch), (2) need to maintain privacy, (3) need for fast, end-to-end communication channel [12-13], (4) estimation for the dynamics of the aggregated loads, and (5) need to deal with different customer preferences.

To address the above mentioned issues, in this paper, a histogram based state observation, storage estimation and control technique will be presented. Throughout the paper, several advantages of this approach will be demonstrated.

The histogram is formed with each loads’ current status (within its controllable range) while loads do not need to disclose their identity. We claim that, with an overlay IP network, it is possible to accomplish this for millions of nodes in less than a minute, as being tested in our laboratory. The cumulative load states can be observed over any period of time through the evolution of the histogram. To characterize the flexible energy storage of a load community, some key indicators (along with their estimation techniques) will be presented, such as the energy status, energy drawn by users, minimum energy needed to maintain customer comfort, etc. These enable the computation for the state of charge of aggregated loads, the flexible en-
ergy stored in a load community and the availability of maximum ramp limits as a function of different time durations for various grid services.

![Diagram](image1)

**Figure 1:** Overview of the system architecture and temperature histogram with controllable temperature range and possible dispatch scheme.

![Graphs](image2)

**Figure 2:** (a) Diversified load profile of 10000 electric water heaters (EWHs) under control (operator’s requests were superimposed on the no control profile); (b) Temperature histogram for 24 hours; (c) Operator’s bidirectional control requests over 24 hours; (d) Hourly aggregated energy storage status against energy draw from hot water usage and energy loss.

Load dispatch schemes that can directly utilize the aggregated histogram will be presented. This also opens up the possibility for the loads to self-dispatch.

Case studies of a large number of simulated water heaters will demonstrate their storage potential, ramp characteristics and ability to provide operating reserves. Depending on the customer preferences, heaters allow a temperature range for control. For example, a group of heaters may allow $T_{min} = 55$ and $T_{max} = 65$ (degree Celsius), while another group could prefer a narrower range. The suitability of these resources to respond to one time dispatch events (levels must be achieved within five minutes) will also be demonstrated. With NRCAN’s research facilities, results can be verified by hardware-in-the-loop simulation.
The methodology presented in this paper can be utilized by aggregators for better managing their resources and by system operators or vertically integrated utilities to improve their energy management systems. This approach can also be extended to other types of distributed energy resources.

Selected References