Vision Statement

Development of the “Smart Grid”, a modernized power infrastructure, is a key sustainability challenge facing the United States. According to the Department of Energy, the Smart Grid should: (1) Enable active participation by consumers by providing choices and incentives to modify electricity purchasing patterns and behavior; (2) Accommodate all generation and storage options, including wind and solar power. (3) Enable new products, services, and markets through a flexible market providing cost-benefit trade-offs to consumers and market participants; (4) Provide reliable power that is relatively interruption-free; (5) Optimize asset utilization and maximize operational efficiency; (6) Provide the ability to self-heal by anticipating and responding to system disturbances; (7) Resist attacks on physical infrastructure by natural disasters and attacks on cyber-structure by malware and hackers [1].

The very first goal, enable active participation by consumers, involves a fundamental paradigm shift. Electrical utilities traditionally focus on achieving the opposite goal: enabling *passive* consumers whose participation is limited to plugging in appliances and paying a monthly bill. The historical success of utilities at reliably providing high quality power at low cost has led to multiple generations of consumers who need to know almost nothing about how their homes and workplaces are powered.

Initial efforts to enable active participation have focused on providing consumers with new forms of data regarding their energy consumption, and have achieved only moderate success. Feedback on consumption does facilitate one-time positive behaviors, such as installing new insulation or purchasing energy efficient appliances. While helpful, such behaviors do not constitute active participation. Time-of-use pricing is another approach to active participation, but the typical result is installation of controllers and a “set it and forget it” behavior. Unfortunately, feedback on consumption can even facilitate negative behaviors, such as when consumers install grid-tied solar panels and then consume more electricity because it now appears to be “free”. In all of these approaches, consumer behavior is individual and independent of others.

We propose a different path to active participation by consumers in the Smart Grid. Based upon our experiences as consumers and energy researchers in Hawaii, we have found that high penetration of distributed, intermittent renewables such as rooftop photovoltaics has the potential for negative impact on power quality and overall grid stability, and that this potential negative impact has created significant technical, economic, and social problems. On a technical level, we have observed power quality events at a weekly frequency in one of our households over the past year. On social and economic levels, our electrical utility has sought rate increases to improve infrastructure and limitations on the penetration of residential PV at the circuit level. Both of these actions have produced significant negative reactions from consumers, the media, and the government.

One possible solution for Hawaii involves a much deeper level of active participation by consumers, in which we as a community take more direct interest in the state of our grid and more political and economic responsibility for its stability. This is a tall order: how do we get there?

Over the past year, we have been designing and implementing a combination of low-cost hardware and cloud-based software that enables consumers to monitor the quality (voltage and frequency) of power in their household and upload that data to our Internet service in order to produce a crowdsourced perspective on grid health. If effectively deployed, the data could enable consumers to learn for themselves whether their household is experiencing degraded power quality, whether this problem is isolated to their own house or widespread in their community, whether the problem is intermittent or frequent, and whether the problem is unpredictable or regularly occurring. Our approach also has potential to support limited forms of prediction (such as whether certain forms of cloud cover create local instabilities) along with limited forms of diagnosis (such as whether an instability was a result of malfunction within a house or due to interactions between multiple houses). In contrast to consumption-based approaches with their individually-oriented, one-off results, our quality-based approach has the potential to produce community-level engagement and policy-level activism.

To test whether these potential benefits of crowdsourced power quality data can be achieved in practice, we propose a two year project to gather evidence regarding the following research questions:

1. *Can crowdsourced power quality data enable active participation in the Smart Grid?*

2. *What are the hardware, software, and analytic requirements for crowdsourced data that make it effective for prediction and diagnosis of Smart Grid power quality issues?*

To investigate the first question, we will manufacture and distribute approximately 300 power quality monitoring devices to volunteer households in three Oahu neighborhoods (selected to study low, moderate, and high penetration of distributed renewables). Through pre and post test questionnaires augmented with selected face-to-face interviews, we will assess the extent to which crowdsourced power quality data influenced their attitudes toward the electrical utility and public policy regarding the Smart Grid, as well as behaviors including interaction with neighbors regarding power quality and installation of appliance or whole house battery systems to improve household power quality.

To investigate the second question, we will augment the power quality data collected above with environmental data (temperature, humidity, wind speed and direction, and insolation), household consumption data (as available through an opt-in procedure), and household generation through photovoltaics (again, as available through an opt-in procedure). We will perform exploratory analytics on the resulting dataset in an attempt to determine the necessary sampling rates, granularity, and history for local power quality, consumption, generation, and environment necessary to support prediction and/or diagnosis of power quality and grid stability.

To be successful, our approach requires a combination of engineering, human-computer interaction, data analytics, and social science experimentation. Our research team combines expertise from all of these disciplines.

Our project is designed to yield insight not only into the use of crowdsourced power quality data, but to provide a basis for research into the application of crowdsourced data to address other sustainability-related resources. For example, water quality and air quality could be investigated using the same basic paradigm.

In the remainder of this proposal we will review research related to this effort, present our project plan, and summarize its intellectual merit and broader impacts.

References

[1] National Energy Technology Laboratory. The modern grid strategy: Characteristics of the modern grid. http://www.netl.doe.gov/moderngrid/opportunity/vision_characteristics.html, 2008.