The Case for a Collaborative Energy Sharing Network for Small Scale Community Microgrids

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Mina Rahimian
Pennsylvania State University

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Mina Rahimian, Lisa Domenica Iulo, Daniel Cardoso Llach

Department of Architecture, the Pennsylvania State University, Stuckeman School, PA, USA;
Email: {mxr446, ldi1, dzc10}@psu.edu

ABSTRACT Energy production is typically a regional enterprise, with the majority of energy produced far from the main areas of demand causing tremendous problems in terms of lack of resiliency and flexibility in handling the ever changing demands at the user's end. On the other hand, microgrids as local energy infrastructures have offered resiliency by allowing neighborhoods to exercise greater control over the production of the energy they consume. As a system, the flexibility and resiliency that embodies the microgrid has to reside across all of its components and functions. Although microgrids integrate various techniques of automation, optimization, pervasive control and computation in its system, but equally important is addressing the human factors. Users, as an undeniable part of microgrid's operational system, are thus required to act with respect to being resilient and flexible. By making all the information of every grid component accessible to the demand side via energy metering systems and feedback loops, microgrids play an important role in filling the gap of energy illiteracy, increasing user's awareness and understanding about how energy is consumed in their homes and thus helping them to make informed energy consumption decisions.

Research on delivering high quality energy-related information on user's activities and consumption rates signify the effectiveness of such information for inspiring and motivating users to change their behavior towards more energy saving ones but however the issue of making these behavior changes durable and integrated to one's lifestyle, is still remaining a topic for further investigation. Accordingly this research attempts to encourage new ways of thinking about user's engagement in the resiliency of their microgrid in terms of a collective process by combining computational means of feedback delivery with a collaboration incentive structure, requiring user's self-organized participation in a shared-energy community endeavor.

KEYWORDS: Microgrid, User Participation, Collective Intelligence, Resiliency, Energy Management.

Introduction: Energy Crisis and the Creation of Smart Grids

The static electrical power grid is a significant dilemma of the 21st century and threat to resiliency. The extant grid was designed and engineered to generate electricity by localized power generators built around communities with clear boundaries between subsystems (generation, transmission and distribution) (Villareal, et al., 2014). The arising issue is embedded in the one-way flow of delivering power from central generators to a large number of users handling only very stable outputs, without really considering the ever changing demands and fluctuations at the user's end. Limitations of the grid in response to continuous changes of the dynamic environment, such as climate change and natural disasters, in addition to lack of engagement with users demand patterns has led to serious problems in terms of resiliency and flexibility (Kang, et al., 2014).

Along these lines, challenges as unprecedented rise for electrical power at the demand side and outdated investments in the power infrastructure, coupled with network congestions and atypical power flows across the distribution network, threatened to overwhelm the system and cause catastrophic blackouts (Amin & Wollenberg, 2005) (Farhangi, 2010). The need for resolving power grid issues attracted national attention by an announcement made by the IEEE Power Engineering Society in the 90's (Werbos, 2011). The power industry recognized some mundane needs for upgrading the existing grid by placing a layer of computation over the infrastructure in order to solve the problem of lack of resiliency by deploying pervasive control and monitoring systems, data management, and communications among its different components (Folke, et al., 2002 - Farhangi, 2010). These basic ingredients accelerated utilities to benefit from various technologies as energy metering and feedback systems, simple sensors and communication networks ascribed at the power distribution and operation scale (Werbos, 2011). The context of these new technologies advanced the outdated electrical grid to a "smarter" grid capable of substituting energy and information among its components. The introduced "Smart Grid" is not known as a replacement of the existing electrical grid but a complement to it, coexisting with it and adding to its functionalities and capacities (Farhangi, 2010). Smart grids are known as the collection of innovative technologies allowing the fully integrated networking and communications of all generation, transmission and distribution subsystems and thus supporting the needs of its stakeholders by an efficient exchange of data, services and transactions (Farhangi, 2010).

Microgrids and Resiliency

Smart grids could be viewed as an ad-hoc integration of small groups of interconnected loads and distributed energy resources (Villareal, et al., 2014). In this view, loads are known as any device or mechanical system at the user's end, requiring electricity for operation and are controlled via costumer's demand. Distributed energy resources (DERs) refer to decentralized energy generators which are typically constituted of renewable energy resources (including but not limited to solar panels, wind turbines, fuel cells, biomass and etc.) and distributed energy storage systems which are unique to each microgrid costumed by specific spatial and climatic constraints, utility regulations and incentives, and costumer's demand (Sherman, 2007). These small blocks of DERs delivering energy to a network of users in a spatially defined area with clearly outlined electrical boundaries, are known as microgrids.

While energy production is typically a regional enterprise with the majority of energy produced far from the main areas of demand, microgrids as local community-scale energy infrastructures, allow neighborhoods to exercise greater control over energy production by generating energy close to the point of its consumption. Moreover, microgrids technically and simultaneously support the utilization of different renewable energy resources, providing security, reliability and resiliency under unexpected conditions of resource depletion or a rise on energy expenses, in addition to enabling the development of low-carbon energy technologies (Sherman, 2007).

Microgrids offer resiliency at the supply side by being able to operate autonomously while disconnected from the smart grid in "island" mode. On the other hand, if the consumption rate of a microgrid community is higher than its harvesting rate, the infrastructure could retreat its "island" mode and reconnect to the smart grid or other microgrids, and create a collection of networked microgrids by the existing transmissions lines and distribution systems in order to back up each other in certain situations. Additionally, by using information technologies microgrids are capable of predicting looming failures, taking corrective actions to avoid or mitigate system problems, and continually optimize the use of its capital assets while minimizing operational and maintenance costs (Farhangi, 2010).

On the demand side, by making all information of the grid components accessible to the users via energy metering systems, microgrids tend to engage users in the energy management of their system and promote sustainable and resilient lifestyles. That is, by empowering the users they set at ease optimal decision making relative to market, so users could adjust their consumption based on the time-of-day pricing of energy and reduce their consumption rate during the most expensive peak hours (Farhangi, 2010). Overall, microgrids are consistent with qualities of resilient communities - including diversity, redundancy, connectivity, modularity and adaptability (The Hurricane Sandy Rebuilding Task Force, 2013).

Human Factors in Constructing Resiliency in Microgrids

The embedded resilience and flexibility in the operation of microgrids has led to a substantial quality in tolerating the constant changes emerging in the electricity network area. The flexibility and resiliency that embodies the microgrid has to reside across all components and functions of the system (Farhangi, 2010). Microgrids have the capacity to integrate various techniques of automation, optimization, pervasive control and computation in its system, but equally important is addressing the human factor. Microgrids attempt to offer resiliency at the users' end, as an undeniable component of the system, via two-way communication technologies between the user and the grid. This communication is presented in the format of energy management by deploying advanced energy metering systems and the mere display of energy user's consumption feedback information, giving users the ability to control their consumption pattern based on the energy pricing rates throughout the day (Ipakchi & Albuyeh, 2009 - Kang, et al., 2014).

Energy feedback technologies are based on the hypothesis that most people lack awareness and understanding about how their everyday behaviour affects the environment and therefore limits the consumer's capacity to decide on taking conservation (Lutzenhiser, 1993 - Froehlich, et al., 2010). In microgrids, it is assumed that displaying energy feedback information at the demand side will increase the users' knowledge on consumption which consequently leads to managing energy usage by adopting long lasting conservation behaviors; but studies have observed a nonlinear process of adopting greener habits while feedback delivery alone is not going to make people change their consumption behaviors (Hargreaves, et al., 2010).

Research on delivering high quality energy-related information on user's activities and consumption rates signify the effectiveness of such information for inspiring and motivating users to change their behaviour towards more energy saving ones (Yu, et al., 2011). However, the issue of making these behaviour changes durable and integrated to one's lifestyle remains a topic for further investigation. Researchers' analysis on human behaviour in this context have shown that although displaying energy consumption information via visualizations is necessary and valuable in increasing awareness and helping consumers control their consumption, it is not enough in making long-lasting changes in behaviour unless it accounts for broader psychological, social and cultural patterns of household energy use[1] (Aune, 2007 - Hargreaves, et al., 2010). That is because this information provisions are neutral through meters since they only display information, and they acquire meaning after going through each household's interpretive and discursive lens, point of view and cultural practices. After information is processed by each individual, it brings in the ability of persuading people and solving the gap of "energy illiteracy", but it doesn't inspire them to adopt long-lasting behaviour change. In this regard, studies have emphasized the complexities of human behaviour by centering attention on environmental psychology literature for techniques and inspiration on pro-environmental behaviours and behaviour change strategies (Froehlich, et al., 2010).

Discussion

Researchers have approached the problem of promoting durable behavior change with feedback technologies mostly from a technological and psychological point of view.

Environmental psychologists argue that data can persuade people but it doesn't inspire them to act. This means in the context of provoking conservation behaviour and nudging users towards more energy responsive habits, giving feedback on consumption behaviour is not enough in promoting long-lasting behaviour change and is more effective when it is combined with other strategies like goal settings, incentive programs, economic penalties and etc. (Costanzo, et al., 1986 - Fischer, 2008 - Froehlich, et al., 2010 - Hargreaves, et al., 2010).

On the other hand, HCI researchers describe that users believe computerized devices are making lives more complex and frustrating rather than easier and more relaxing while they vary of the aesthetics, financial, and cognitive challenges that come with each new technologies. Studies in this category strongly recommend that the exploited technologies should not undermine people in their own home, and they need to be designed in a way to require human effort in ways to keep life mentally and physically challenging (Davidoff, et al., 2006). Requiring users to adapt to technology is very likely to fail quickly (Blumendorf, 2013).

One of the best references on the design of feedback delivery technologies or smart meters is conducted by Froehlich et al which documents the need for designing feedback technologies at the intersection of two fields of environmental psychology and human-computer-interaction (HCI). In order to resolve the issue of behaviour change in metering systems and feedback technologies, authors strongly suggest that the two disciplines of HCI and environmental psychology learn from each other; feedback researchers and practitioners in HCI base their designs on the fundamental principles of longitudinal behaviour studies explored by environmental psychologists, and then apply the unique methodologies and approaches found in HCI to advance the design of feedback technologies (Froehlich, et al., 2010).

Conclusion and Next Steps

The literature review explored in this study shows that for increasing the possibility of a resilient community to be energy responsive by its users, interpersonal psychology and HCI must be integrated. Toward this end, an energy exchange system – a collaborative energy sharing network for small-scale community microgrids - with a diversity of intense energy users, structured on a collaborative incentive program with interactive and comprehensive energy feedback information is proposed as a possible solution.

In this system, HCI and energy feedback technologies work together for information and communication facilitation in the community. The focus of this system is on the users as the smartest component of the system rather than any so-called smart technological device. The coupling of feedback technologies with a collaborative incentive structure aims to help users perceive the personal and group benefits of making better energy consumption decisions. While users more or less consciously choose their activities and consumption patterns, they are the main influence and last instance for any decisions. Thus the operation of the energy exchange is designed to depend on user's tacit knowledge for a self-sustaining change in their consumption behaviour.

Further developments on this conceptual prototype requires defining the basis of the system as the first step and plan its principles and fundamentals. Consequently, the interface design takes place based on the outlined propositions, the incentives structure and characteristics of effective interactive feedback technologies. Delineating system's operation requires laying out the system's operational regulations as a policy framework to nudge users towards conservation behaviour by participating in a community-based energy exchange system, in addition to describing the system's architecture.

As a result of this energy exchange system, it's expected that new patterns of energy responsive collaboration and participation result in the community microgrid from user's themselves, suggesting resiliency in form of participants' collective intelligence.

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Notes

[1] A very good qualitative field study done by Hargreaves and his fellow researchers in the UK have grounded this fact by studying how householders interact with feedback systems from different types of smart energy metering systems. The early assumption was that increasing feedback will increase awareness in household members and thus result in a change in behaviour. After analyzing behaviour and interviewing with the participants their observations show that almost all participants and family members got excited about the devices in the first place and started to change their energy behaviour towards conservation by adjusting their consumption based on hourly energy price. People got obsessed with their gadgets and monitoring devices when they first got it but after some time they just got used to it and their usage just fell off to almost nothing (Hargreaves, Nye, & Burgess, 2010).