Chapter 7
A Simulation Gaming Approach to Micro-grid Design and Planning: Participatory Design and Capacity Building

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Abstract Existing micro-grid design and planning approaches tend to emphasize techno-economic assessments and lack community engagement, necessary for effective planning and implementation. New approaches must be employed to not only include significant social impacts of micro-grids beyond technical components, but prioritize human development objectives, participation and capacity building. A newly proposed simulation gaming approach to micro-grid design provides an innovative, participatory tool and process that incorporates social, organizational, technical and financial factors for improved design and planning. Additionally, the approach represents an experiential learning and capacity building exercise that teaches shared resource management and collaborative decision-making.

Keywords Energy design · Micro-grid planning · Participatory design · Simulation game · Capacity building

Introduction

Recent advances in distributed generation technologies have intensified interest in decentralized electricity delivery models, particularly in its potential to meet rural users' energy and development needs through greater flexibility in technology options and organizational structures. However the design and planning of a micro-grid system for comprehensive development purposes requires careful and further

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consideration. With a wide range of possible technologies and delivery models, micro-grid design and planning is highly dependent on available resources, local social context, markets, institutional structures and users' energy requirements.

Planning a community-level, micro-grid system generally consists of a needs assessment, a resource assessment, technical design, and economic and financial analyses. Energy needs assessments for rural electrification are commonly conducted using participatory methods such as surveys, questionnaires and focused group discussions (FGDs) in order to assess electricity demand and ability to pay (Howells et al. 2002). Data from these methods are then used as a baseline for techno-economic assessments, employing energy design tools such as HOMER, LEAP, and RETScreen (Connolly et al. 2010) to design a sufficiently reliable technical system at minimal cost. Tariff schemes are then designed around cost recovery and end users' financial abilities.

The majority of energy design and planning approaches are largely focused on the technical system, or on techno-economic assessments that do not enable sufficient or effective community participation beyond initial base-lining. Techno-economic assessment tools are typically operated by non-community members, who may not have a thorough understanding of local energy needs and the system's impacts on the community. Additionally, rural community members with limited technical skills and understanding of micro-grid operations (or rural electrification in general) are unable to use these tools to fully participate in the design process, which restricts community engagement and does not leverage nor build their capacities.

Conventional techno-economic assessment tools and methods also tend to exclude critical, social micro-grid success factors such as organizational or institutional considerations, demand side management and community participation, all of which affect uptake and operational sustainability. A narrow system boundary also inadvertently limits the micro-grid's scope for human development impact, as systems are installed to mainly deliver electricity rather than support energy use for facilitating development. Furthermore, systems that do not account for social dynamics and local complexities may cause unanticipated and unintended outcomes (e.g. electricity or equipment theft) that consequently limit and hinder energy access for development. In order for rural electrification to enable development, system design and planning must reprioritize human development objectives over electricity delivery, and encompass an expanded system boundary to account for broader social and financial considerations targeted at development-related outcomes.

Meanwhile, participatory methods used to collect data for energy planning are challenging to conduct and may provide limited useful information. Inaccurate demand forecasts directly affect system size and capacity, which in turn produces higher installation costs for an oversized system, or inadequate electricity supply if undersized.

Surveys and questionnaires on household energy use elicit information through a mainly one-way transfer, and do not induce learning or capacity building. Obtaining useful responses depends on participants' understanding of the questions (which also means the interviewer has to ask participants meaningful questions) (Cross and

Gaunt 2003; Howells et al. 2002) and on the power dynamic between interviewer and respondent, which may further affect accuracy of responses. Additionally, communities with limited exposure to electrification may have difficulty in predicting their own electricity consumption and behavior. To account for this, surveys and questionnaires are used to forecast electricity demand based on the community's existing energy use (including traditional energy use). This creates uncertainty and inaccuracies as past energy use does not necessarily translate directly into electricity use, and moreover cannot predict new uses with electrification.

We propose a novel participatory design approach that merges the technical aspects of a techno-economic assessment tool with the emphasis on the social system from participatory processes. We utilize a simulation game to address the aforementioned shortcomings by building capacities in decision-making and resource management. This process expands the system boundary beyond a techno-economic assessment by including organizational considerations, participation and social interaction. It provides a simulation gaming environment in which community members have equal opportunity for participation (Chua 2005) and induces dynamic learning so they can contribute informed decisions and input into the design process (Brandt 2006).

This new approach can be used to both enhance the design process (i.e. build a sustainable micro-grid that delivers adequate, reliant and affordable electricity supply for enhancing human capabilities) and serve the more fundamental objective of building technical and governance capacity of the community.

Research Objectives

The main objective of this work is to create a useful participatory tool and process that can be used to elicit a rural community's energy needs and system design parameters, in order to facilitate design and planning. Meanwhile, the participatory process is also aimed at empowering and building community members' capacities by enabling a greater understanding of household and system load profiles, technical limitations of a micro-grid, the importance of system cost recovery and managing the micro-grid as a shared resource.

Methods

The Simulation Game as a Tool and Artifact

The participatory game is a simplified representation of an operating micro-grid, with individual players representing households (or other load center forms) and a facilitator acting as a system operator. The game may be used to explore both planning and operational decisions. The facilitator prompts the players to choose their end-use loads (e.g., appliances), as well as to play out their periods of operation. Players are networked so individual and aggregate behavior can be visualized real-time.

In the current version, the simulation has been implemented using the multimethod simulation software, AnyLogic. A game-round is initialized with system capacity, number of households and levelized cost of energy (LCOE), which may be calculated using HOMER or similar tools. System cost may be updated in later rounds if the community is allowed to change system capacity. The example shown here has reference data from a Malaysian case study (Abdullah 2013). The game shows two windows that represent individual household consumption and system-wide consumption. The game has a graphical user interface where players can choose household appliances from a pre-defined set or a customized “other”. The current choice of appliances and power ratings are also based on the Malaysian case study. Depending on the focus of given game play, a facilitator could choose to distribute appliances “for free”, or to price the appliances and provide players with an initial budget. The latter case would allow the community to explore the financial trade-offs of different appliances (e.g., incandescent vs. LED lighting).

Once the simulation clock starts, players explore consumption patterns by individually switching loads on or off. The main system window shows real-time total load and revenue collected. Currently, household energy costs are based on a minimum energy-based tariff set by the LCOE. Alternative tariff models, such as capacity-based payments or even dynamic pricing can be easily implemented (in future versions).

The current version allows the facilitator to set a varying generation output, but does not explicitly model the power generation process or include distribution losses or other network features. Warnings appear when total load is near capacity (90–100 %), at peak capacity, and over capacity (the system shuts down within a given duration).

The Simulation Gaming Process for Participatory Design

This participatory design process elicits system design parameters by alternating between simulation game playing and facilitated discussions. During discussion rounds, facilitators pose a set of questions aimed at obtaining the following system design parameters (Fig. 7.1):

- System capacity
- Demand side management options
- Organizational model
- Tariffs
- System policies and regulations

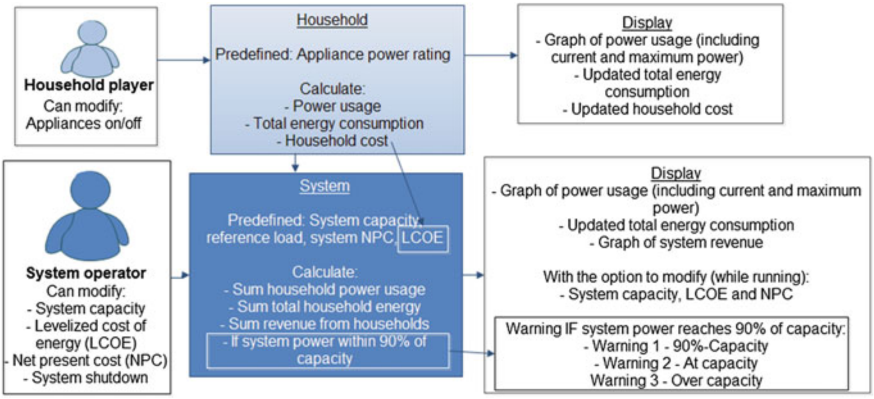

Fig. 7.1 Diagram explaining the simulation game methodology (Abdullah 2013)

The questions that lead to the above parameters are meant to represent an improved participatory design process over traditional planning methods such as surveys, questionnaires and techno-economic assessment tools. A representative set of questions is as follows:

- Identifying a reference load profile.
  - Based on observed system behavior in previous rounds, should the generation capacity be increased or decreased? → Installation costs and technology options will depend largely on system size.
  - What demand side management options are effective and acceptable? → Necessary especially when demand nears system capacity.
- Deciding organizational and management structures.
  - How would the community enforce demand side management strategies, system policies and regulations? → It is complex to enforce policies in rural communities. Design of such mechanisms must come from the community.
  - What type of organizational structure would work best for the micro-grid? Who will own and manage the micro-grid? → The community understands their requirements and social structures best.
- Deciding tariff structures.
  - Should the tariff be raised in order to generate revenue? → Ability to pay for micro-grid services is important to recover costs. However, rural users may have limited ability to pay and should decide on their own tariff structure.
  - What will revenue be used for, only cost recovery? What about an optional community savings fund?
- What will future load profiles look like? → Players can test potential future scenarios and load profiles to forecast future demand.

The Simulation Gaming Process for Capacity Building

A summary of intended learning outcomes is given in Table 7.1.

Table 7.1 Intended learning outcomes for capacity building using the simulation gaming process

Game feature	Action	Learning outcome
Household consumption playing	• Adding/removing appliances as if buying and discarding • Turning on/off appliances as if using in real-time	• Players will better understand their own household load profile and electricity use and can identify peak loads • Players will have a grasp of how different load profiles affect expenditure and be able to roughly estimate monthly charges and decide whether to lower consumption if costs are too high (assuming an energy-based tariff)
System-wide load profile and warnings	• Viewing system load profile in real-time against capacity	• Players will appreciate that capacity is limited and understand the need for both individual and collective load management • Players will learn about system load profiles, community peak loads and total electricity usage and behavior
Discussion rounds	• Collectively discuss findings, experiences and observations from the game • Discuss best way to manage consumption and micro-grid	• Players/community members will come together and work out issues with managing a shared resource • Community will apply existing governing structures to support decision-making process and strengthen local institutions • Community will apply existing (if any) resource sharing management to electricity use. E.g. agricultural communities that share water resources
Tariffs, revenue generation	• Viewing energy use against tariff, costs and revenue • Changing tariff in order to generate more revenue for the community micro-grid • Testing of future scenarios	• Players will understand the importance of cost recovery and how best to afford and use electricity for productive end use • Players will learn how different tariffs and corresponding consumption can contribute to greater revenue for a community savings fund. This could open up the opportunity to articulate desired services and capabilities for community development

Results: Simulation Game Screenshots

See Figs. 7.2 and 7.3.

Discussion: Case Study Observations

Development of the game is currently ongoing and has only been tested in mock-community settings. A beta version was trialed in August 2013 among university students and young professionals participating in an energy access workshop, and was used as a teaching tool for community participation and micro-grid planning. The participants were from various countries and originated from both rural and urban areas. They were divided into teams of 3–4 per group, each group representing households. The game was played on networked laptop computers, although future versions of the game will be played on mobile devices (i.e. tablet) for easier deployment.

Most of the case study participants have mainly experienced grid electrification and thus were new to the unique challenges in using and managing a micro-grid.

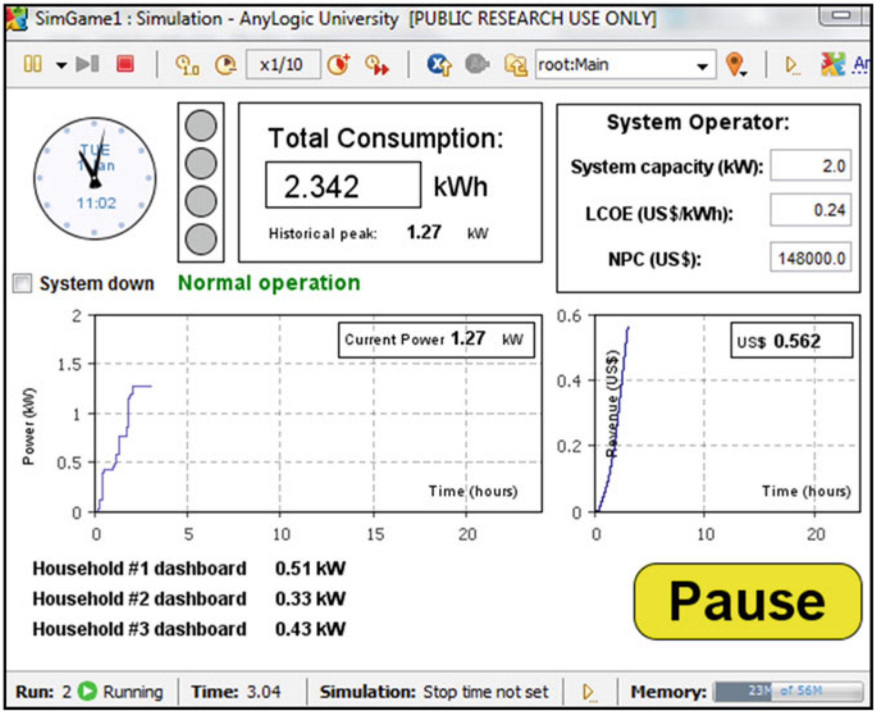

Fig. 7.2 System window showing micro-grid load profile

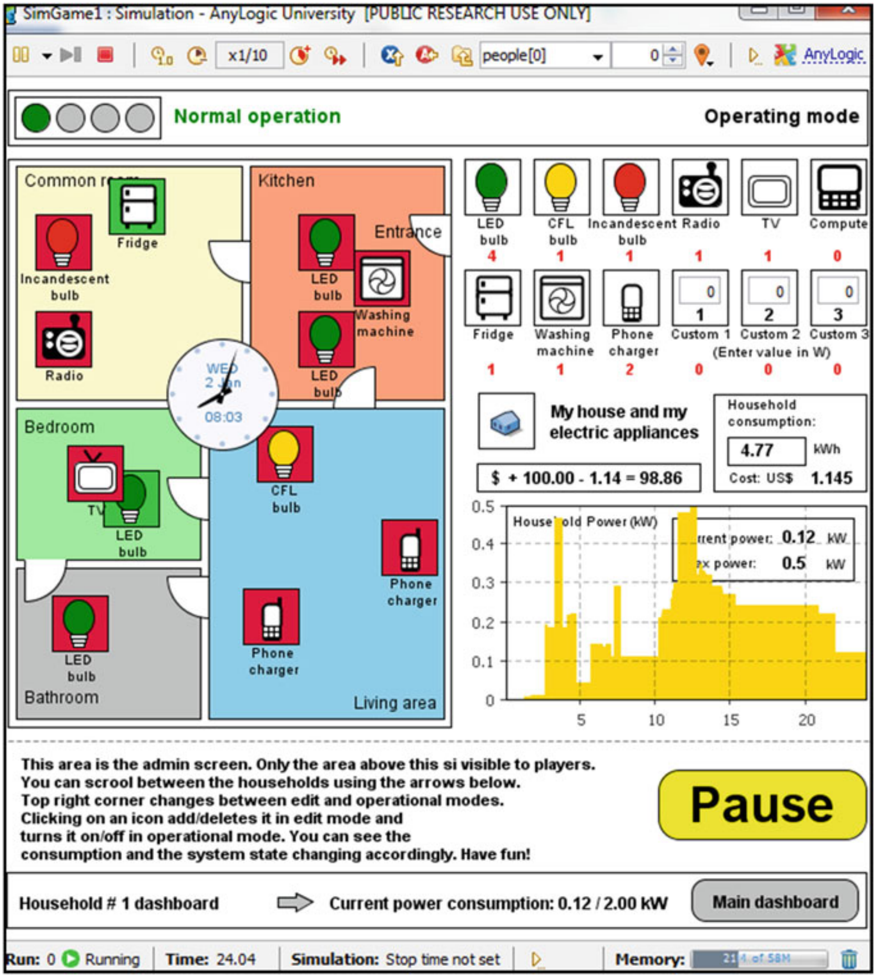

Fig. 7.3 Individual household player window

The first few game-rounds (after initial familiarization) saw participants prioritizing their individual households, which in turn overloaded the system causing blackouts. As facilitators attempted to guide the discussion towards increasing system capacity or implementing demand side measures, some interesting and unanticipated social interactions took place. Namely, households began to blame one another and demand for the prohibition of energy-intensive appliances. Within a gaming environment, participants felt freer to behave as they wanted. This is not an undesirable outcome. On the contrary, the simulation game provides participants with the freedom to experiment with different behaviors in order to observe system impact. For example, a future version of the game may include the option to ‘steal’ electricity, a prevalent problem with micro-grids. The game by itself is not meant to be biased in that it favors a desirable (or undesirable) behavior. It has been developed to remain as flexible as possible to enable participants to choose what normative actions and decisions work best for them.

It was observed that although the household teams could easily participate equally in discussions, the collective decision-making process still depended on group power dynamics or how comfortable participants felt voicing their opinions. However, the total system load profile displayed contributions of every household (an optional feature) and hence non-participating players could still be drawn out to discuss their contributing loads.

Like other participatory methods, the facilitator role is critical and requires an objective, unbiased (towards a particular solution) individual, knowledgeable about micro-grid delivery. However compared to conventional surveys and questionnaires, the simulation gaming design process has greater flexibility and can be applied in different local and social contexts without much customization. It is also dynamic in nature, providing immediate feedback and learning to players. In the trial, after three game-rounds, participants were collaborating well, had decided on a system capacity that suited their energy needs, and were no longer overloading the system.

The simulation game as a design tool was also useful in testing effectiveness of demand side management options. In the trial, participants were able to choose and test between limiting individual household capacity and voluntarily decreasing consumption when the game's warning signals displayed that the system was nearing capacity. During one game round, households were given the option of reducing their consumption within a specified time period when the system reached a critical state. Three out of the four households immediately reduced consumption when the warning appeared, while the remaining household waited until the others had reduced consumption. This provides interesting insight into human behavior and the game could help devise new demand side management strategies.

Ultimately, participants recognized that cooperation was necessary in order for everyone to have access to reliable electricity. The beta version trial was considered successful in providing an interesting and enjoyable learning experience for resource management and cooperative, participatory design. The process does have limitations, the most important one being that the simulation gaming process does require a certain level of community organization in order to successfully make design decisions. A hands-on, physical version of the game that works without devices is also being considered. The physical version will be for communities that have very little experience with technology and operating devices. Although the game would not be as dynamic nor will it provide immediate household load profiles, a physical version of the game will still be able to impart concepts such as cooperation in using a limited micro-grid capacity and making decisions as a community.

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