Energy 74 (2014) 567–575

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Micro-energy markets: The role of a consumer preference pricing strategy on microgrid energy investment

Isaac Faber*, William Lane, Wayne Pak, Mary Prakel, Cheyne Rocha, John V. Farr

Center for Nation Reconstruction and Capacity Development, Department of Systems Engineering, United States Military Academy, West Point, NY 10996, United States

ARTICLE INFO

Article history:
Received 28 August 2013
Received in revised form
2 July 2014
Accepted 7 July 2014
Available online 5 August 2014

Keywords:
Energy security
Energy optimization
Energy investment
Energy pricing
Microgrid
Smartgrid

ABSTRACT

The fragility of the modern electrical grid is exposed during random events such as storms, sporting events and often simply routine operation. Even with these obvious flaws large utilities and governments have been slow to create robust solutions due to the need of large capital investments required to address the issues. In this light creative economic and engineering solutions are desired to finance the needed upgrades. Driven by the requirement to have uninterrupted power that meets customers desires this research focuses on linking consumer preferences to a type of energy source in order to best fulfill stakeholder priorities. This approach is in contrast to the current and prevalent lowest cost methods to producing and consuming energy. This research yields a preliminary 'micro-energy market' that consists of an energy network architecture, pricing methodology and mathematical template which quantifies potential economic inefficiencies. If exploited these inefficiencies could be used to fund investment into various energy sources that provide unmet needs such as reduced carbon footprint, renewable, quality, and local production. These inefficiencies can be best exploited within the structure of a microgrid. Identification of opportunities on this smaller scale can provide an incentive for producers to develop a robust set of production facilities of varying size and characteristics to meet the consumer preferences. A stochastic optimization model of a microgrid implementation for a small military installation is used to evaluate the effects of this pricing methodology. The energy production of the resulting microgrid would be optimized to meet consumer preferences and minimize economic inefficiency.

Published by Elsevier Ltd.

1. Introduction

Lack of regulation, strategic investments in the grid, localized nature of power production and distribution, and old technology have all contributed to a fragile, inefficient grid that is neither resilient nor reliable. Power outages or an attack from an adversary could interrupt power to critical infrastructure and would greatly degrade a community's ability to sustain itself resulting in a possible crippling of the economy. In recent years energy infrastructure has gained increasing concern. The motivation of cost, environmental impact, and a growing population has increased the scrutiny of the electrical power system, and by extension the economies affected by them. A reengineering of the electrical system along the lines of the internet, as shown in Fig. 1, could yield potentially significant benefits. With this focus on evolving the energy infrastructure a systems perspective is needed now more than ever. The benefits of such a change should result in an improvement in reliability, survivability, and cost to both producers and consumers of energy.

The architecture of communication over distributed networks is currently thought of in the context of a set of layers such as the OSI (Open Systems Interconnection) 7 layer model. In this type of model both the producer and consumer have the same set of processes and can readily be democratized and decentralized. These models help to efficiently decompose the routing and transmission of information according to the needs or constraints of the network participants. Such approaches yield robust and scale-able systems. In part this is because consumers can readily become producers and vice versa. A similar perspective may be leveraged in the energy field as well. With the advent of benefits from SmartGrid technology, a formal layered architecture perspective for energy generation, transmission, and consumption would be necessary and beneficial. In this architecture there is a constant flow of information about Real-Time Pricing (RTP) from consumers to producers which feed the technical controls of the system. It also feeds

* Corresponding author. Tel.: +1 845 938 4311.
E-mail addresses: Isaac.faber@usma.edu (I. Faber), john.farr@usma.edu (J.V. Farr).

http://dx.doi.org/10.1016/j.energy.2014.07.022
0360-5442/Published by Elsevier Ltd.

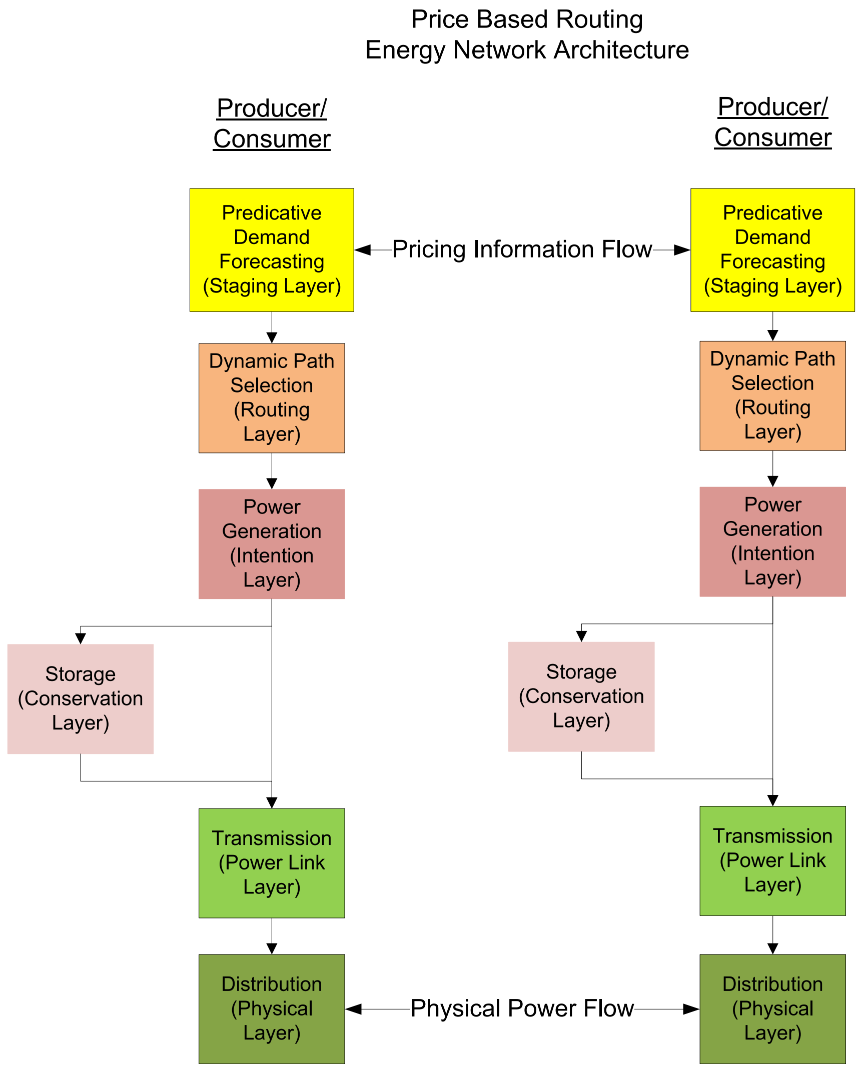

Fig. 1. Electrical network architecture.

economic information which produces incentives to adjust consumption and production behavior. It has been shown that not using RTP leads to inefficient outcomes [2]. In many markets this type behavior is being studied, for example one paper found that RTP may allow the Nordic Power markets to achieve a savings of 6% in total annual investments [1]. There are, however, several drawbacks to RTP in the current system in that producers must anticipate its effect on real time demand. This is challenging to large producers as they typically forecast demand 24–48 h in advance. One study addresses some these concerns and proposes a method to achieve demand-side management [3]. Even with these approaches the old 'hub and spoke' energy model will create friction with true RTP. Most RTP models being studied and developed are discretized at 1 h increments instead of the continuous pricing of most commodity markets (see Refs. [5–7]). This window (1 h) allows for the technical constraints of a large energy system to react to changes in demand. However, with the architecture proposed in Fig. 1 energy systems could encourage to smaller producers to potentially address these types of inefficiencies.

The important differences between information and energy transmission would necessarily yield a significantly different architecture. However, many of the concepts and approaches would be similar. The key difference is the replacement of bandwidth with a price based energy routing scheme. Implied from this tentative architecture is that consumer demand is central to the network and is typically expressed in pricing. The energy grid will act similarly to a data network in that particular energy loads can be applied or routed based on demand. This demand is random in nature and can include issues dealing with multiple preferences such as reliability, sustainably, as well as cost and energy efficiency. The essence of an energy network is that routing will be price based and dynamic. This is a significant departure from the current switch based low-cost driven network. This approach will require new methods of understanding and algorithms for addressing how producers and consumers communicate their needs to each other.

While the purpose of the paper is not to establish a ridged formal architecture there are some common themes that need to be in place in order for the grid to improve. Fig. 1 shows that there should be two fundamental connections between producers and consumers. The first is a flow of information and the second is a flow of energy. It is the information that will determine the nature of the follow of energy. The layers between the two flows can be thought of as analogous to decomposition of information into technical directions. Currently technical directions are by in large determined by historical information of technical requirements (customer's previous loads, weather, etc.). With expansion of