Fair Dynamic Pricing for Advanced Metering Infrastructure

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ABSTRACT

Advanced Metering Infrastructure (AMI), a subset of smart grid technologies, improves information exchange between electric utility operators and consumers. AMI allows for real-time dynamic pricing where the utility operator can charge variable prices depending on load demand and the varying cost of delivering electricity. While many studies have shown that dynamic pricing improves system efficiency and reduces costs for most consumers, there is much less discussion of the relative fairness of various dynamic pricing structures some of which have the potential to be regressive compared to traditional flat-rate pricing. This is considered unfair by ratepayer advocates and fairness issues often arise in discussions of dynamic pricing at state level public utility commissions. While a tradeoff between efficiency and equity exists, this author argues that only minor compromises are necessary if the right dynamic pricing options are used. Forms of dynamic pricing that guarantee no increased costs for any individual consumer are less likely to be labeled as unfair. If utilities offer default dynamic pricing structures that are universally perceived as fair, AMI will face one less hurdle to widespread acceptance.

INTRODUCTION

Advanced Metering Infrastructure (AMI) is a collection of technologies (smart meters, new two-way communications infrastructure, and automated utility management systems) that enable consumers and utility operators to make more informed decisions [1]. AMI is the next logical step from existing automated meter reading technologies, which only allow meters to send data to the utility. AMI allows utility operators to respond more quickly to service outages, monitor power quality issues, and reduce meter reading costs, errors, and intrusiveness. Over the long-term, utility operators can collect very detailed energy usage data that enable them to optimize the distribution system and improve resource deployment.

However, the most widely anticipated benefit of AMI technology is the ability to reduce utility peak loads. Historically, utilities have used demand response programs with large industrial or commercial customers. These customers voluntarily reduce their energy usage during peak load times through either direct requests or load-control from the utility in return for some incentive [2]. AMI allows utilities to accomplish the same task more efficiently and on a much larger scale through real-time consumer load monitoring and pricing signals. Peak load reduction allows utility operators to avoid rolling blackouts during peak demand and to forego building or purchasing power from peak generating facilities that are more costly to operate than the system's base load facilities [1].

This reduction in peak load demand is achieved through AMI by providing a time-variant pricing signal to which consumers can respond. There are many forms of time-variant pricing, but they are all generically referred to as "dynamic pricing." While there are many operational benefits to AMI technology, dynamic pricing is considered by some to be an integral part of AMI implementation. Rick Morgan, a commissioner on the D.C. Public Service Commission, has said, "There's no point in having smart meters if you're still going to have dumb rates." [3] Collectively, the estimated U.S. peak electricity demand reduction by the end of this decade could approach almost 10% or over 80,000 MW of generating capacity [4].

HURDLES TO IMPLEMENTATION

Despite the many benefits, there are a few issues that impede the adoption of AMI. The most widely studied are questions over the real-world effectiveness of AMI technology. A number of pilot programs have investigated the size of efficiency gains and cost savings in relation to the cost of implementation [4, 5]. These studies suggest significant reductions in both peak loads and overall demand. However, to perform a realistic full assessment of AMI implementation, other potential social costs must also be considered. The most commonly raised social concerns include:

- Health concerns regarding the radio frequency radiation emitted from some smart meters
- Privacy issues regarding who has access to consumer's detailed energy usage data and how it can be used
- Security issues regarding how vulnerable AMI is to theft of services, hacking, and terrorist activities
- Fairness issues regarding whether AMI helps or hurts some consumers more than others

While the public health issue is often raised by opponents of AMI technology, it is also the most studied via the proxy of mobile phones which emit much higher levels of radio frequency radiation [6]. Furthermore, it is possible to avoid the issue by deploying AMI without wireless communications (e.g., using power line communication technologies [7]). Likewise, AMI privacy and security concerns are issues common to other Internet-related communications technologies [8], so considerable relevant literature exists and many researchers are already working in the fields of Internet privacy and security. On the other hand, fairness issues are more difficult to assess based on similar technologies because electric power is already a ubiquitous technology in developed nations and changes to the system are more likely to affect the entire society. Additionally, there appears to be a direct trade-off between efficiency and equity that may make a dilemma unavoidable [9]. For this reason, equity issues tend to be the dominant concern among regulators [4].

The perceived risks of getting AMI implementation wrong are substantial. In developed nations, electricity is a necessity that is particularly important to sensitive populations: the very young, the elderly, the disabled, and those in poor health [10]. Fear of unaffordable electric bills may cause elderly residents to forego the use of fans or air conditioners during heat waves [11]. This suggests that the wrong form of dynamic pricing may send the wrong message to low-income urban elderly consumers to reduce their electricity consumption during a heat wave [10] just as public health officials are suggesting the opposite. High heating and cooling costs are also associated with food insecurity among low-income elderly [12]. While AMI can also be used for other metered utilities such as natural gas or water, peak load issues for those are less

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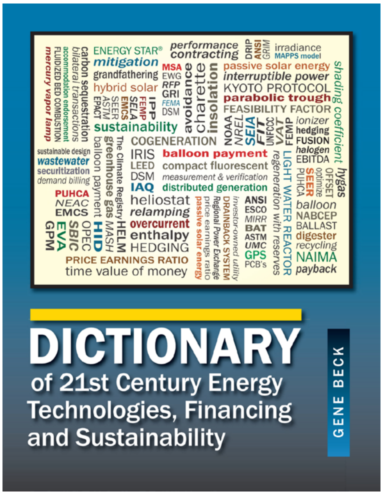

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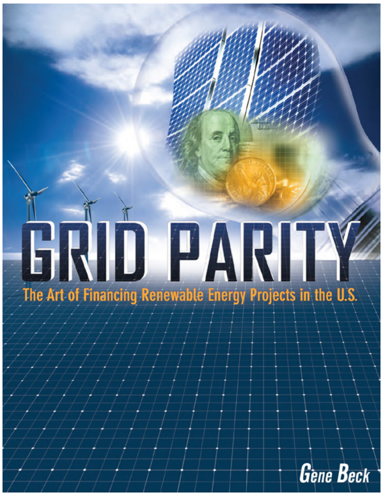

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important than for electricity, which must be generated on demand; the focus of AMI applications to water and gas are conservation and operational efficiency rather than demand response [13]. Given the necessity of these utilities for human health and welfare, it is imperative that the fair distribution of costs and benefits be well examined to protect the most vulnerable populations in society. This is particularly true as AMI is applied to developing nations, e.g. [14, 15].

DEFINING EQUITY IN DYNAMIC PRICING

To maximize the benefits of AMI technologies, the implementation of AMI requires pricing changes. Market-based utility pricing, first described in 1971 [16], has several forms. The most commonly discussed are:

- Time-of-use pricing—consumers pay pre-determined rates that vary throughout the day
- Critical peak pricing—consumers pay pre-determined higher rates during peak demand periods
- Real-time pricing—consumers pay market rates all the time
- Peak-time rebates—consumers pay a flat rate, but can earn rebates from lowered peak usage [17]

These time-variant pricing structures contrast with traditional flat pricing, where users pay a flat rate per unit of electricity consumed regardless of time or amount. The general idea with dynamic pricing is that higher rates during peak demand periods will cause consumers to reduce usage or shift energy use to off-peak periods. Using critical peak pricing, Californian residential consumers in an AMI pilot program reduced peak load by 25% when using a "smart" thermostat and 13% without one over a 5-hour peak-load event [18]. Additionally, the higher peak costs are usually more than offset by reduced energy costs during off-peak hours that accrue from improved utility system efficiency [17].

However, new electricity pricing structures can also negatively impact electricity consumers. Moving from a traditional flat pricing scheme to a dynamic pricing structure trades protection of vulnerable consumers for system efficiency [9]. While dynamic pricing is closer to the economic ideal of consumers being charged what they are willing to pay, it sacrifices three qualities of flat pricing that are particularly beneficial to low-income electricity users: affordability, flexibility, and predictability [9]. That is, flat pricing is a regulated rate intended to prevent price swings that could hurt low-income consumers. While flat pricing is less efficient than free-market pricing and promotes overconsumption, it is protective of low-income high-use consumers. Likewise, flat pricing is better for electricity users who do not have the flexibility to shift electricity use away from high demand times, such as the homebound. Finally, flat pricing's predictability is particularly important to someone who needs to budget limited financial resources. Collectively, these qualities of flat pricing outline an argument for flat pricing being more socially desirable than dynamic pricing.

On the other hand, it can be argued that market-based dynamic pricing is only seen as unfair based on the false assumption that the status quo is fair [17]. That is, flat pricing is averaged across all consumers so that consumers using less electricity are subsidizing consumers using more electricity during peak demand [17]. When dynamic pricing is applied, the cross-subsidy is removed and some consumers immediately see lower electricity costs, while other consumers see higher electricity costs before any system efficiencies take effect. In theory, the "losers" in the new dynamic pricing structure can use information provided by AMI to reduce their peak usage and lower their electric bills [17].

Between these two opposing positions, some also support dynamic pricing as the most equitable method, so long as means-tested low-income consumers are offered rate assistance [19]. However, since utilities do not track consumer income, there is currently no simple method for locating eligible consumers [10]. Likewise, participation in energy assistance programs has historically been far below the eligible population and any dynamic pricing rate assistance program is also likely to fall short of protecting all low-income consumers [20].

While many studies have found efficiency improvements from AMI and dynamic pricing implementation, few of these studies have focused on equity issues. One notable exception used load, billing, and satisfaction data from 457 participants in California and found that about 5% of low-income critical peak pricing participants saw electricity bill increases of over 10% [2]. In the same study, more high-income participants saw electricity bill savings than low-income participants suggesting that critical peak pricing is regressive.

Another study found that low-income consumers reduce their consumption less than high-income consumers under dynamic pricing and sometimes increase usage on critical peak days [21]. This was originally assumed to be caused by low-income consumers having below average consumption to begin with. However, there is often a low correlation between income and energy consumption [2]. Thus, it appears the cause of low-income consumers benefiting less from dynamic pricing is the inability to shift activities during peak demand and/or the inability to purchase newer automated home equipment that could maximize AMI benefits [10].

THE DECISION PROCESS

Due to the nature of providing basic utilities, electricity services are generally monopolistic and government regulation acts as a substitute for a competitive private market [22]. In the U.S., wholesale electric rates are overseen by the Federal Energy Regulatory Commission (FERC), which regulates interstate transmission of electricity and other utilities. State level public utility commissions regulate retail electricity sales. These rates have been traditionally based on the average cost to provide service among similar consumers [22]. Any change in pricing structure must be approved by the state level public utility commission. Some forms of dynamic pricing, such as time-of-use or peak-time rebates, are relatively small changes to current pricing structures, while true market-based pricing (i.e., real-time pricing) constitutes a major shift. Subjecting residential consumers to wholesale energy markets may expose them to the most expensive generator in the market [10] with oversight exclusively in the hands of the FERC.

The natural inclination of many engineers and managers is to maximize system efficiency. However, the decision process for regulators often focuses on issues other than efficiency. The following is a brief discussion of some of the many ways to view the decision process to illustrate this important point.

For example, the debate can be framed as a choice between two classic economic efficiency models. One approach is the Pareto criterion [23] where a particular dynamic pricing scheme should be adopted only if it improves at least one stakeholder (individual consumer or utility operator) without hurting any others. Alternatively, a Kaldor-Hicks criterion [24, 25] can be used where only an averaged social net benefit is required. While the Kaldor-Hicks criterion is the basis for cost benefit analysis and is commonly used in policy-making, many state public utility commissions often operate on the more conservative Pareto criterion. That is, their decision is based on a desire to minimize the number of energy consumers that will have increased energy costs or disproportionate additional energy costs. Many delays in the implementation of AMI and related pricing structures have been associated with utility regulators attempting to avoid increased utility costs for voting ratepayers [26].

Of the most commonly tested dynamic pricing structures, time-of-use, critical peak pricing, and real-time pricing structures can create situations where some consumers will have higher electricity costs while the majority will have lower costs after switching from flat-rate pricing. Because critical peak pricing appears to yield the highest average peak load reductions in pilot programs to date [4], a decision to use critical peak pricing would suggest a Kalder-Hicks criterion for AMI implementation. Conversely, selecting a peak-time rebate structure would suggest a Pareto criterion.

In the field of decision theory, the "minmax" criterion, where a decision maker selects the option that minimizes the maximum loss, could also be used to describe regulators typical behavior. This loss-averse decision style is well documented in prospect theory [27], and contrasts with the rational utility-maximizing approach of cost benefit analysis. Regulators are risk-averse and often will not accept an electric bill increase for a small percentage of low-income consumers even if most low-income consumers will benefit [20].

The decision can also be described in terms of moral philosophy literature using Rawls' procedural conception of equity [28] where a binding system of rules is created using rational self-interest without knowing one's place in the system [9]. Using this approach, the regulator's decision criteria for a pricing system should also be to minimize the worst-case scenario for the most disadvantaged members of society rather than to maximize the average or most likely scenarios for all members of society.

Lastly, we could also argue that a simple cost benefit analysis is the incorrect decision model for electricity rate decisions based on public perception of rights. That is, consumers in developed nations associate electricity with basic rights and that association implies that they should be shielded from wholesale energy market volatility. Electric utility policy decisions must explicitly acknowledge these beliefs when implementing AMI and new pricing structures [29]. Moving all residential consumers to the most market-based forms of dynamic pricing may cause an immediate jump in monthly electric bills for some consumers and subsequent charges of unfairness [22] and future public resistance to the entire smart grid transition [10].

PROPOSED SOLUTIONS

Many policy solutions have been proposed to address the issue of potential negative impacts to low-income residential consumers. These include: educational campaigns on how to use AMI technology to lower energy usage, providing bill protection that phases out over several years, using only peak-time rebates, and excluding residential consumers and small businesses from dynamic pricing altogether [10, 17, 20]. The last option assumes that large businesses have the economic and professional resources to manage their risk and make optimal use of dynamic pricing [19]. On the other hand, most residential consumers have no experience, training, or tools to deal with short-term price variations [10]. Thus, excluding residential consumers from dynamic pricing would alleviate social welfare concerns and still have little overall effect on system benefits since commercial and industrial consumers represent the majority users of electricity [20]. However, this could also be seen as unfair treatment because residential consumers would not be given the opportunity to save money on their electric bill or enjoy the many other benefits of AMI implementation.

A more promising option is the use of peak-time rebates, which has been described as a "carrot-only" option whereas other forms of dynamic pricing are a "carrot-and-stick" approach [30]. Because consumers are generally risk averse, voluntary enrollment and acceptance rates of peak-time rebates are higher than other forms of dynamic pricing [30]. More importantly, because there is no consumer risk for higher electricity costs, peak-time rebates can be used as the default enrollment when installing AMI; consumers need only be informed that using the new AMI features can help them reduce their electric bill [30].

Public utility commissions, which are influenced by the competing interests of utility operators and ratepayers (and ratepayer advocates), have the dual objectives of equity and efficiency when approving electricity rate structures [20]. Proposed changes to the electricity distribution system which are perceived to be both less equitable and less efficient than current practices are clearly rejected. Likewise, changes that are both more equitable and efficient than current practices are clearly accepted. Difficulties arise because there is often a tradeoff between fairness and efficiency [20]. The various ways equity and efficiency can be defined further complicate the decision process, which can alter both their degree and direction. Given the many ways of defining fairness previously described, a pragmatic definition of fairness from the perspective of the public utility commission will be used. Ratepayers and their advocates are least likely to claim that changes to the system are unfair when their electric bills remain the same or are lowered. Thus, utilities have the best chance of having a proposed rate change approved when no ratepayer sub-group is adversely affected compared to the status quo—especially a population that has public sympathy and active advocates. This corresponds with the Pareto efficient solution, which requires that no stakeholder in the policy decision be made worse off. Given the reward-only nature of peak-time rebates, no consumers should have increased electricity rates and higher bills. This should translate into fewer charges of unfairness by ratepayer advocates. Assuming all forms of dynamic pricing are beneficial to utility operators, it is prudent that they submit options, like peak-time rebates, that are the least likely to face opposition from ratepayer advocates. Offering a protective dynamic pricing structure as the residential consumer default along with other more market-based pricing structures as options achieves both total customer participation and meets minimum equity standards while improving system efficiency. If utilities select a dynamic pricing structure that is perceived to be fair, AMI technologies will face one less hurdle to widespread acceptance.

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