Are Smart Grids a Smart Investment?

Hourly Load Analysis of 800,000 Utility Customers at 200 of the Largest US Utilities

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Summary

Analysis of comprehensive smart grid technology applications at 200 of the largest US utilities shows potential smart grid savings of 115,145 MegaWatts (MW) with avoided costs of more than $120 billion and net savings after smart grid costs of $48 billion. This study is the first to apply individual utility customer end-use hourly electric loads to evaluate smart grid costs and benefits. Data for more than 800,000 residential and commercial utility customers in the 200 largest US utilities were applied in the study.

Studies to date, including a recently released FERC analysis, rely on assumptions about elasticities and electricity pricing to estimate changes in total utility hourly loads or broad customer class aggregate hourly loads.

Instead of applying the elasticity/aggregate load approach of previous approaches, this new study applies load control and pricing program impacts directly to individual customer end-use loads such as air conditioning, water heating and so on to determine utility-level impacts.

The utility customer hourly load data applied in this study consists of more than 800,000 residential and commercial utility customers records for the 200 utilities. The commercial sector is defined to include commercial, institutional and government utility customers. These utility customer records were drawn from MAISY Utility Customer Hourly Loads Databases.

Commercial customers provide about one-quarter of the potential avoided cost savings or $31.7 billion. Individual utility avoided cost savings range from $49 million to more than $5.5 billion. Subracting costs of a comprehensive smart grid deployment provide net savings that range from negative savings to $3.2 billion. Benefits of comprehensive smart grid systems vary widely across utilities even within individual states and depend on a complicated mix of factors including dwelling unit size, age, electric appliance holdings, demographics and so on. Percentage reduction in total residential and commercial coincident peak demand ranges from 16.2 percent for Sierra Pacific Power to 30.6 percent for Public Service New Hampshire.

Results indicate that more than 10 percent of the 200 utility applications are close enough to break-even that more targeted strategies are appropriate. More than one-third of the utility applications reveal benefit cost ratios less than 1.5 suggesting careful development of smart grid strategies to ensure that economic benefits exceed costs. Detailed customer analysis available with the MAISY databases shows, however, that all utilities can significantly improve returns on smart grid investments by targeting individual market segments with specific smart grid technologies.

Insights provided by "bottom-up" utility customer end-use hourly load data like that applied in this study will be an essential component in development and evaluation of smart grid deployment at individual utilities.

Utility Customer Hourly Load Data

Utility customer data were drawn from the MAISY Utility Customer Hourly Load Databases. MAISY databases have been developed from more than 2 million individual utility customer records. Each database provides a representative sample of customers including building, operating, occupant, equipment and energy use characteristics. Energy use detail includes hourly electricity use at the individual end use level (space heating, air conditioning, water heating, and so on).

The MAISY Utility Customer Hourly Loads Databases have a long history in applications to evaluate energy technology electricity peak demand and energy use impacts. Utility demand side management and energy efficiency technology impact analysis began in 1995, followed by fuel cell, combined heat and power (CHP), cool storage, wind, flywheel and other technology analysis beginning in the late 1990s. MAISY clients include utilities, states, DOE research laboratories and energy technology companies including United Technologies, Carrier, Toyota, Ingersoll Rand, Aisin, Bloom, Ice Energy, IdaTech and others.

It is important to note that the recent FERC report referenced above and later in this study incorrectly states "hourly load data were not available for all … states or for all customer segments within states. Indeed, no data at all were found that distinguished between residential customers with and without central air conditioning." (p58) These data are, in fact, available in the MAISY databases and have been applied in the studies mentioned in the previous paragraph.

Smart grids

Smart grids reflect the integration of state-of-the-art communication and control technologies applied to every aspect of the generation, transmission, distribution of electricity including remote and onsite control by utilities and utility customers of equipment in homes, commercial, institutional and government buildings and industrial processes. In its most comprehensive application smart grid applications allow utility customers to both reduce and shift equipment electricity use to off-peak periods

depending on price signals provided by the utility and as a result of customer commitments to "sell" electric loads back to the utility system.

The smart grid concept also includes traditional load control programs used by many utilities to cycle water heating and air conditioning equipment during peak demand periods. Results of several dozen utility experiments show that a combination of equipment control and price feedback technologies often double the impacts of load controls. Most residential and commercial programs consist of a relatively small number of customers whose participation is voluntary, resulting in a self-selection bias that makes application of these results to the wider utility population difficult. Limited information on these program results, their typically unique designs and relatively small number of participants, relative to utility populations, make it difficult to apply elasticities estimated from these programs in other utility service areas and states.

The regulated nature of the utility industry (distribution utilities are still regulated in competitive states) requires that estimates of costs and benefits of smart grid programs be quantified in advance to justify rate increases required to cover the cost of implementing these systems. These evaluations are important as comprehensive smart grid technology implementation could potentially top $70 billion.

A Comparison With Previous Analysis Methodologies

Several studies have been conducted to estimate the economic benefits of smart grid initiatives. A 2004 study by the Rand Corporation is one of the more widely referenced works. A new state-level study sponsored by FERC was released on June 18, 2009.

Both studies apply elasticities estimated from smart-grid related utility programs. Smart grid-related programs vary widely with respect to their technologies, program designs and program participant. An excellent overview of fifteen demand response studies is provided by Faruqi and Sergici (2004).

The Rand study applies national energy use characterizations, several elasticities and several assumptions on program penetration to estimate national impacts within a microeconomic framework. The model includes supply elements in a traditional economic modeling approach.

The FERC study mentioned above and released on June 18, 2009 was required by the Energy Independence and Security Act of 2007 to include state level analysis of demand response. The FERC study also applies elasticities and program penetrations to five broad customer class load shapes including residential with and without air conditioning, small, medium and large commercial and industrial (C&I) utility customers.

All studies to date, including the Rand and FERC analysis, rely on assumptions about elasticities and electricity pricing to estimate changes in total utility hourly loads or broad customer class aggregate hourly loads.

Instead of applying the elasticity/aggregate load approach of previous approaches, this new study applies load control, pricing programs and other smart grid impacts directly to individual customer end-use loads such as air conditioning, water heating and so on to determine utility-level impacts.

This study reflects the first "bottom-up" analysis of smart grid costs and benefits by initiating impact analysis at the individual customer and end-use (air conditioning, water heating, etc.) hourly load level and summing results to provide customer segment, customer class and utility impacts.

MAISY Smart grid Analysis Methodology

MAISY Utility Customer Hourly Loads Databases conceptually lend themselves well to smart grid analysis. Each Utility database includes a representative sample of utility customers. Each customer record contains information on dwelling unit, occupancy, equipment and energy use characteristics including hourly building electricity loads developed from individual end-use electric loads such as air conditioning, water heating, lighting, and so on.

The objective of the current study is to identify maximum potential peak load reductions that can be achieved for both residential and commercial utility customers on a sustained basis during peak seasons. The results of this study should be viewed as a potential that can be achieved with smart grid technologies rather than a forecast based on an assumed penetration of smart grid technology applications.

Residential customers in summer peaking utilities typically contribute most heavily to peak periods in late afternoon when occupants return home, turn up air conditioners, turn on appliances including TVs and stoves and ovens. Dwelling units with electric water heating contribute to peak electricity demand with sink/faucet use and with tub/shower uses. Electric clothes dryer and washing cycles (when accompanied by electric water heating) can also contribute to residential electricity use in peak periods.

Smart grid technologies can provide traditional load control functions, cycling air conditioning, water heating and swimming pool pumps, while more advanced options provide individual equipment control to these and additional end uses through programmable devices accessible by both the utility and the utility customer. These technologies permit households to respond to price signal to lower thermostat setting and schedule major electric appliances. The MAISY analysis applies load controls and scheduling of major electric appliances in households including air conditioning, water heating, swimming, electric dryers, washing machines in houses with electric water heating to smooth out loads from these end-uses during peak periods.

Customer behavior is also enabled with smart grid technologies either through programmed responses or simply as a response to information on real-time prices. Related behavior includes reduction of summer thermostat settings, use of cold water in washing and air drying for cloths, use of microwave rather than stovetop burners, reduced

shower/tub water temperatures, turning off lights and unwatched TVs and other actions. A variety of studies indicate that these behavioral responses are approximately equal to impacts of load control activities. The current study applies the same percentage change to behavioral load shape reductions achieved with load control and scheduling activities. This approach effectively distinguishes between different customer behavioral responses as a function of electric appliance holdings with smaller behavioral impacts for dwelling units with natural gas water heating, cooking and so on.

The fact that smart grid impacts are achieved at the individual customer level means that smart grid impact analysis can be provided for any customer dimension or combinations of customer dimensions in the MAISY databases. For instance, results can be presented by income, dwelling unit type and size, demographic characteristics, business type and size and other factors. This information can be important in developing smart grid strategies and evaluating smart grid program achievements.

Compared to residential customers, commercial, institutional and government utility customers reflect considerably less potential for smart grid peak demand savings. Increased summer thermostat settings and precooling provide the greatest demand reduction opportunity. Additional savings can be achieved by turning lights off or through lighting adjustments accomplished with energy management and control systems. Some reduction can be achieved with office equipment shutdown, limitations on elevator use and other behavioral responses. This analysis applies a cycling load control strategy to commercial, institutional and government air conditioning systems to smooth out loads and a reduction of fifteen percent to reflect increased thermostat settings and some precooling. This estimate is consistent with the limited information on commercial customer precooling and a change in building thermostat setting to 80 degrees. A ten percent reduction in lighting and other loads is assumed. Reduced waste heat from the ten percent reduction also cycles back as an addition reduction in air conditioning loads of approximately five percent.

Commercial buildings with energy management and control systems (EMCS) have considerably more demand management potential than described above; however, since these systems are still in relatively limited use and reflect a considerable investment to install in existing buildings, the impact of smart grid EMCS interactions is not addressed in this study.

The analysis described above was applied for each residential and commercial customer in each of the MAISY Utility Customer Residential and Commercial Hourly Load Databases for the 200 largest utilities in the US. These utilities represent slightly over 70 percent of all residential and commercial electricity use. This analysis can also be conducted using the MAISY data for any of the more than 3000 additional US utilities.

Analysis Results

Total smart grid savings for residential and commercial sectors in the 200 largest US utilities are shown in Table 1 below.

Table 1. Total Smart grid Savings

Peak Savings (GW)		115.1
Residential Savings	84.8	
Residential Savings	30.3	
Reduction in Peak (%)		20.8
Residential	28.0	
Commercial	12.0	

Total savings of 115.1 GW represents 20.8 percent of peak demand. Percentage reduction in total residential and commercial coincident peak demand varies widely across utilities ranging from 16.2 percent for Sierra Pacific Power to 30.6 percent for Public Service New Hampshire.

Analysis of individual utility coincident peak load reductions shows that a variety of factors determine reduction potentials. Interactions of equipment, building, operating and customer characteristics along with weather are so utility-specific that rules of thumb based on experiments and programs at other utilities are likely to be unreliable indicators of smart grid load control and load shifting potentials at individual utilities.

This study differs from the Rand and FERC studies in several important aspects preventing a direct comparison of results. Both Rand and FERC studies include residential, commercial and industrial customers while this study focuses only on residential and commercial customers.   The Rand study conducted an aggregate US analysis, the FERC study is a state-level analysis while this study provides utility results for the largest 200 utilities. However, some comparison with the FERC study can be provided by calculating percentage reductions for utilities in the same state in this study and comparing to state-level estimates from the FERC study.   Of the ten most populous states, 5 of the state estimates differ by more than 10 percent. Differences in two states were more than 20 percent including Illinois (this study: 20.5, FERC 15.1 percent reduction) and Ohio (this study 23.6 percent, FERC 17.5 percent). These differences appear to reflect more than FERC's inclusion of industrial customers in their analysis. If industrial customer smart grid response is greater than residential and commercial responses, then FERC savings should be greater while an industrial customer response that is less than residential and commercial responses will result in FERC savings that are less than results of this study. However, FERC results compared to results in this study are almost evenly divided between positive and negative difference. For instance FERC percentage savings were greater in four of the ten largest states compared to results from this study.

FERC's aggregation of commercial and industrial customers into single C&I (commercial and industrial) segments may have created estimation problems. For

instance, more than half of commercial contributions to peak loads in Illinois and Ohio occur in the large C&I class (>200 kW). However, modeling manufacturing plants, offices, hospitals and other commercial responses in a single class is questionable since smart grid responses are so different across these building types and the proportion of manufacturing to commercial peak contribution varies significantly by state. Aggregating C&I customers at the utility level is not recommended for these reasons.

Significant variation in peak load reduction exists across utilities even within the same state. Table 3 shows savings for Louisiana utilities. Total percentage reductions range from 16.7 for Entergy, New Orleans to 27.6 for Dixie Electric Membership Corp. These results show the importance of applying utility level data to consider smart grid costs and benefits.

Table 2. Louisiana Utility Smart Grid Peak Reduction Comparison

Percent Reduction in Peak Demand

Residential	Commercial	Total	Utility
30.5	12.0	23.4	Entergy Louisiana Inc
29.6	12.5	23.0	Cleco Power LLC
28.4	13.2	21.2	Southwestern Electric Power Co
20.9	15.6	16.7	Entergy New Orleans Inc
28.7	14.1	27.6	Dixie Electric Membership Corp
22.8	10.7	21.7	Southwest Louisiana E M C

Utility Benefits and Costs

One objective of this study was to determine the economic feasibility of instituting comprehensive smart grid initiatives at the customer level, that is, deploying advanced smart grid technologies to all utility customers. Benefits are calculated as avoided costs of new generation, transmission and distribution. This analysis used the most recent Department of Energy combustion plant cost of $670/kW. The same figures for transmission and distribution avoided costs used in the Rand study were applied here ($125/kW and $ 250/kW respectively) for total avoided cost benefits of $1045/kW. While $250/kW is likely to be a reasonable average cost of distribution across the US, (thought the cost estimates are now somewhat low since the data were developed a decade ago), distribution costs vary widely across utilities. For instance, the distribution cost for Con Edison from the original study is more than $1,500/kW. Consequently, the average $250/kW is applied here to all utilities to reflect average utility costs. Since costs vary around all of these averages for individual utilities, only the total cost results are reported here.

Costs of comprehensive meter programs are assumed to be $500 for each residential and small commercial customer, $5,000 for medium commercial customers (between 20 and 200 peak kW) and $20,000 for large commercial customers. The benefit-cost results change only slightly when medium and large commercial customer costs are modified

reflecting the fact that medium and large commercial customers are no more than several percent of total residential and commercial customers in most utilities. These costs include utility costs of developing the infrastructure required to support real time pricing, load control and other programs along with equipment and installation costs.

Utility analysis shows that nearly all utilities will save enough in avoided costs with a comprehensive smart grid deployment to at least cover smart grid development and deployment costs; however, many utilities barely break even. For example about 10 percent of utilities achieve benefit/cost ratios less than 1.2 and should be considered at risk of incurring costs that are greater than benefits given uncertainties concerning actual deployment costs. More than one-third reflect benefit cost ratios less than 1.5. Customer-detailed analysis shows, however, that all utilities can significantly improve returns on smart grid investments by targeting individual market segments with specific technologies.

Advantages of Customer Hourly Load Analysis in Utility Studies

Customer class analysis applies elasticities to estimate smart grid reductions in peak electricity demand. These elasticities are estimated from results of smart grid-type initiatives already underway at individual utilities.

An elastiticity shows the percentage change in peak kW divided by a percentage change in price. While sophisticated statistical techniques are often used to estimate elasticities, many determinants of demand reductions are not represented in the statistical analysis or represented imperfectly resulting in the following variations across programs:

- Composition of appliance holdings other than air conditioning (e.g., representation of water heating, electric dryers, stoves/ovens, etc.)
- Building age
- Building size
- Occupancy characteristics
- Existing electric rates
- Smart grid rate structures
- Etc.

It is not surprising that elasticity estimates across similar studies can vary by as much as 50 percent or more nor is it clear how representative the estimated behavior is when applied to customers outside the program.

Other issues such as combining commercial and industrial customers into aggregate classes also create problems as pointed out in a previous section.

The utility customer end-use approach applied in this study begins at the end use level, removing much of the uncertainty associated with the aggregate load curve/elasticity approach. For example, knowledge of water heater hourly loads in a representative sample of customers provides a basis for determine the impact of traditional load cycling

control. While additional responses from pricing strategies rely on estimates of behavioral responses, knowledge of each customer's electric appliance holdings and the baseline hourly loads of appliances which can be affected by behavioral usage modifications provides a framework for determining reasonable representations of behavioral impacts.

Because the utility customer hourly load methodology is based on a statistically valid representation of utility customer end-use appliance holdings and their hourly electricity use, results of the smart grid analysis can be determined for each sample customer including before and after peak load contributions of water heating controls, reduced hot water use, air conditioner controls, reduced thermostat setting and so on. Since these results have a foundation in actual electricity use in individual appliance and dwelling units, it is easy to evaluate analysis results based on a "reasonableness test."

Utility Customer/End-Use Hourly Load Strategies to Support Utility Smart grid Program Development and Evaluation

This study illustrates the intuitive and straightforward application of end-use (air conditioning, water heating, etc.) utility customer hourly load databases to evaluate smart grid program development.

Utility customer database detail supports direct representations of actual load control and smart grid technologies to individual end-use hourly loads providing a true bottom up approach to program development and evaluation. The alternative is to apply elasticities to customer class hourly loads and load profiles to drive a top-down aggregate representation; however, this approach provides little insight on program development and evaluation issues and is of questionable accuracy when applied in individual utility applications.

This study illustrates the process of evaluating costs and benefits of smart grid initiatives. In addition to applying customer and end-use detailed representative hourly load databases, information on generation, transmission and distribution avoided costs, technology costs relevant for the utility size and deployment and utility infrastructure support costs must be developed. These data vary significantly by utility and even by geographic location within the utility service area.

By focusing on end-use hourly electricity use within individual utility customer buildings, the utility customer database approach provides a consistent accounting of impacts of specific technologies and their impacts at the customer, customer segment, customer class and utility level. This information provides a basis for developing a resource planning strategy for utility smart grid deployment that insures economic benefits will exceed program costs.

Utility Customer Database information can be used to forecast benefits and costs over time using penetration assumptions and forecast utility customer growth. All standard economic cost tests (Participant Test, Ratepayer Impact Measure Test,

Utility Cost Test, Total Resource Cost Test and Society Cost Test) can be applied to the results of a Utility Customer Hourly Load based analysis.

This framework also permits extensive scenario analysis, risk analysis and customer segment evaluations where segments can be defined by any variable in the database (income, business type, etc.).

Finally, a Utility Customer Hourly Database analysis framework provides an easily maintained system that can be used continuously to evaluate ongoing smart grid activities and to adjust strategies to maximize utility smart grid benefits.

References

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