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Benefit Analyses of Irvine Smart Grid Projects

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SUMMARY

This work has been conducted under the auspices of a joint U.S.- China research effort, the Climate Change Working Group (CCWG) Implementation Plan, Smart Grid. The wider objective of this effort is to develop common approaches to benefits analysis that can provide transferable methods and results to accelerate dissemination of results and deployment of smart grid technology. Two example benefits analyses are reported, both in Irvine, southern California. These first two analyses were conducted with the U.S. Department of Energy's (DOE) Smart Grid Computational Tool (SGCT), which is built on methods developed by the Electric Power Research Institute (EPRI). The approach is based on familiar financial indicators, and all benefits are monetized. A logic flow is established by the user that moves from smart grid assets to functions, and ultimately to estimates of the benefits they generate. The analyses here cover a range from historic to prospective. Southern California Edison's Irvine Smart Grid Demonstration (ISGD) project is one of 16 regional demonstrations co-funded by DOE and private partners under the particularly significant 4 plus billion-dollar Federal program executed under the American Recovery and Reinvestment Act (ARRA-2009). This project has been completed and a considerable data set is available for analysis. Three sub-projects are analyzed: a neighborhood of deeply retrofitted homes intended to approximate performance close to a California standard for new zero net energy homes effective in 2020; a grid scale battery installation: and, a distribution Volt-VAR control demonstration. Excellent results were obtained for the Volt-VAR control demonstration, but the 9 demonstration zero net energy homes proved far from economic. The grid scale battery deployment also yielded positive results. While the ISGD ZNE homes are far from being economically attractive, these were intended to be a demonstration and their upgrades were expensive. The UCI Microgrid analysis covers a much different situation. Multiple campus assets involve a diverse set of technologies that have been acquired over many years. Consequently, the input data available is mixed. Some sub-projects that have been in place for some time have generated useful results, while others are still under development and results are mostly conjecture. Four specific technologies on the UCI campus are covered: the central 19 MW combined heat and power (CHP) plant, PV arrays totalling 3.6 MW of mixed vintages, a microgrid controller currently under development, and a 2 MW-0.5 MWh battery, which is just now being installed. The SGCT concludes all 4 projects are attractive. The CHP plant, PV arrays, and the battery report benefit-cost rations in the 3 to 7 range. The microgrid controller however, appears strongly desirable. Its main benefit is improved reliability, which is generally valuable, as are energy savings, while environmental improvements yield lower benefits.

KEYWORDS

benefits analysis, microgrids, smart grid, combined heat and power.

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INTRODUCTION

The smart grid is rolling out internationally, and multiple approaches to benefits analysis (BA) have appeared, and an understanding of their differences is needed. A coherent basis for international evaluation of project performance can facilitate comparison and transfer of results, and accelerate smart grid deployment. Comparative BA of smart grid demonstrations are presented for two co-located projects at the University of California, Irvine campus (UCI). The two demonstrations are Southern California Edison's (SCE) Irvine Smart Grid Demonstration Project (ISGD), and the UCI campus itself. The EPRI BA method, as embodied in the SGCT, defines a benefit as the monetized impact of a smart grid project to a firm, a household, or society in general [1,2]. All benefits must be expressed in monetary terms, must accrue to the 3 stakeholders, consumers, utility, or society as a whole, and must lie in the following four benefit categories.

a) Economic: reduced costs, or increased production at the same cost
b) Reliability and power quality: reduction in interruptions and power quality events
c) Environmental: reduced greenhouse gas emissions and other pollution
d) Security and safety: improved energy security, increased cybersecurity, and reductions in injuries, loss of life, and property damage

The benefits estimate is based on the difference between the monetary values associated with a base-line scenario, which represents the system state with- out the project, and a contrasting project scenario. In general, benefits are reductions in costs and damages, such as deferred capacity investment, improved power quality, or reduced environmental insults, etc., whether to firms, consumers or to society at large.

Figure 1: Logic Flow of the SGCT

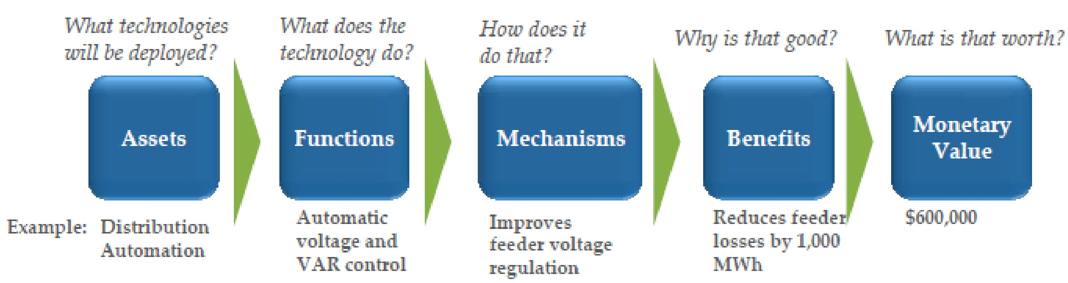


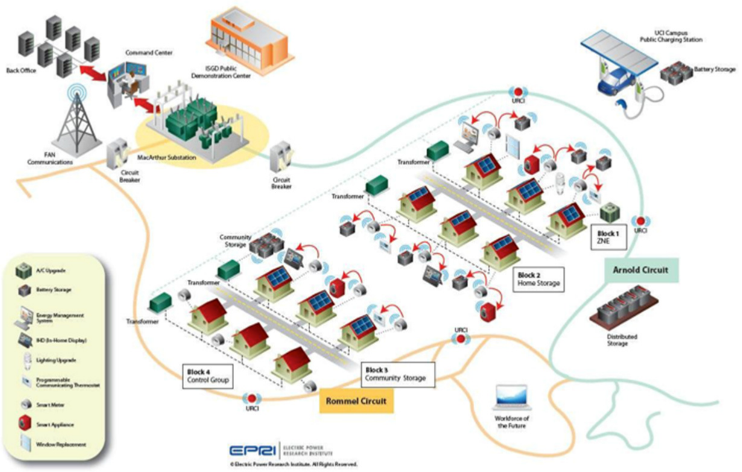
Figure 1 shows SGCT logic, starting from a listing of smart grid assets, then identifying asset functions, and ultimately monetizing benefits. The first step lists all the smart grid assets deployed in the project for evaluation. Step 2 identifies the functions of each asset, for example, Distribution Automation can provide Customer Electricity Use Optimization, Power Flow and Control, Automated Feeder and Line Switching, Automated Islanding and Reconnection, Automated Voltage and VAR Control, and so on. Step 3 defines the impacts (i.e., mechanisms) of functions. Step 4 maps the benefits of each of those functions. Step 5 monetizes all the benefits. Since one function might have multiple benefits, all are summed up to estimate the project's total monetized benefit.

PROJECT DESCRIPTIONS

Irvine Smart Grid Demonstration Project: SCE operated the ISGD project, and many of the project components were located on or near UCI, which is 60 km southeast of the Los Angeles airport [3]. The purpose of the field experiments was to evaluate the physical effects of various technologies on the electric grid, and to quantify the associated benefits for different types of stakeholders. The project included four domains, with each domain including one or more of eight sub-projects, only 3 of which are included in this analysis: Sub-project 1: Zero Net Energy (ZNE) homes; Sub-project 3: Distribution Battery Energy Storage System (DBESS); Sub-project 4: Distribution Volt/VAR Control (DVVC).

i) Sub-project 1: Zero Net Energy Homes: One 9-home block from a faculty housing neighbourhood built in 2003 was used to demonstrate and evaluate strategies and technologies for achieving ZNE. A building achieves ZNE when it produces at least as much on-site renewable energy as it consumes over a given period, measured in California (CA) on an annual basis [4]. The homes include a variety of technologies designed to reduce energy use, to empower families to control their energy pattern, to improve grid performance, and to produce and store energy with photovoltaic arrays (PV) and residential energy storage.

Figure 2: Overview of the Irvine Smart Grid Demonstration Project



ii) Sub-project 3: Distribution-Level Battery: This sub-project involves a 2 MW/0.5 MWh battery connected to the Arnold 12 kV distribution circuit that keeps distribution circuit load within a set limit. This mitigates overheating of the substation getaway, and reduces peak load on the circuit.

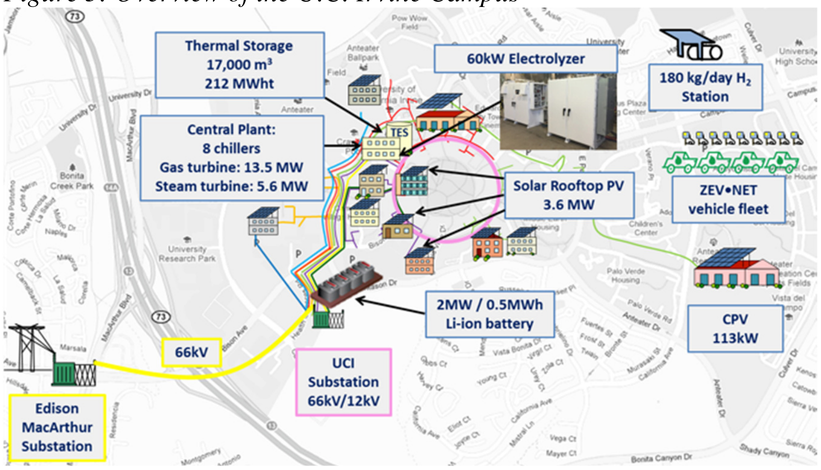
iii) Sub-project 4: Distribution Volt/VAR Control: DVVC optimizes the customer voltage profiles in pursuit of conservation voltage reduction. This often proposed measure is helpful to CA utilities, which are required to maintain voltage as close as possible to the minimum acceptable level, nominal voltage minus 5%, i.e. between 114-120 V, at the customer connection. DVVC technology significantly improves this capability, and can also provide VAR support to the transmission system. Field experiments showed an average energy savings of approximately 2.5%, making this demonstration a major success, and SCE intends to deploy the technology system-wide.

U.C. Irvine Campus: As shown in Figure 3, the UCI Microgrid is a test bed that (1) is served by SCE through 2×15 MVA trans- formers at the UCI Substation stepping down voltage from 66 kV to 12 kV, (2) encompasses 3×12 kV circuits, (3) includes nearly 4 MW of solar power, (4) owns a 19 MW natural gas fired combined cycle plant with heat recovery (CHP), (5) incorporates centralized chilling including a large thermal energy storage tank (17,000 m3/212 MWh thermal), and (6) serves all major buildings with district heating and cooling. The UCI Microgrid also contains a diverse set of technologies including: (1) electric vehicle charging at multiple parking locations, (2) a 60 kW electrolyzer for production of pipeline hydrogen, (3) hydrogen fueling for fuel cell vehicles, (4) dual-axis tracking concentrating PV, (5) advanced building energy efficiency measures, (6) building monitoring and control, and (7) power quality and thermal metering. Since the Irvine campus has many advanced systems developed over a long period in pursuit of multiple projects and goals, a simple global BA is precluded, 4 specific technologies are covered.

i) Sub-project 1: Central 19 MW CHP Plant: The Central Plant consists of 8 electric chillers, a steam turbine chiller, a thermal energy storage tank, boilers (used only for backup), a 13.5 MW gas turbine, a heat recovery steam generator, a duct burner, and a 5.5 MW steam turbine. The plant serves all campus heating and cooling, as well as the 96% of campus non-cooling electricity, the balance being served by solar resources (3.5%) and utility imports (0.5%). The power requirement averages 13.4

MW with an annual peak of 18.6 MW. Campus cooling load averages 11 MW thermal (263 MWh thermal per day) with a typical peak demand of 49 MW thermal. The storage tank can shift, on average, 65% of the chilling load to nighttime, when electricity prices are lower and chilling more efficient. The heating load is served entirely through recovered heat and the duct burner.

Figure 3: Overview of the U.C. Irvine Campus



ii) Sub-project 2: PV Arrays Totaling 3.6 MW: UCI has 893 kW of fixed panel PV installed on the rooftops of 12 buildings and an additional 2.6 MW installed on 3 parking structures. The capacity factor for the rooftop panels, in operation since 2008, was 0.187 in 2012, in this coastal climate. An additional 113 kW of CPV with dual-axis tracking was installed in 2012, and there is an estimated total campus potential of 22 MW of dual-axis tracking and 15 MW fixed panel PV. Although campus solar resources are still at a low penetration, 3.5%, they are already causing the gas turbine to be turned down close to its minimum output imposed by emissions compliance and the inability of export, both of which present challenges for future solar development.

iii) Sub-project 3: Microgrid Controller (MgC): A recent DOE award will move the UCI Microgrid further toward full automation through development of the MgC being developed in partnership with SCE and ETAP, which will be generic for deployment at a wide array of different microgrid types. It will provide (1) seamless islanding and reconnection, (2) efficient, reliable, and resilient operation whether islanded or grid-connected, (3) existing and future ancillary services, (4) for the microgrid to serve the resiliency needs of participating communities, (5) communication with SCE as a single controllable entity, and (6) increased reliability and efficiency with reduced emissions.

iv) Sub-project 4: Lithium-ion Battery (LiB): The recently installed 2 MW-0.5 MWh lithium-ion iron phosphate battery consists of battery, auxiliary, and 12 kV interconnection skids. The battery system will be utilized to reduce electricity imports and as a balancing resource during islanding. In both appli- cations, the battery system will act to buffer small transient mismatches between load and generation. The application of interest for the benefit study here is the first, reducing utility imports. UCI's CHP operators are skilled at following load within a typical error band of 100-200 kW, but still requiring some electricity imports to prevent export, which trips the Central Plant. The target import is currently 500 kW, but the battery should reduce the band, allowing a lower import set-point of 300 kW.

RESULTS

Irvine Smart Grid Demonstration Project: These SGCT results shown in Table 1 indicate that ZNE is far from being economically attractive at current project performance and expenditures. The equipment cost, about $146 k/home would need to be about 94% lower to achieve break even, i.e., Benefit-Cost (B/C) ratio, greater than 1. The ZNE homes were a demonstration of an early stage technology, and are expected to become more economic over time. The results of this analysis should therefore only be considered illustrative for the purpose of evaluating the SGCT. In contrast, DBESS and DVVC appear to be economic, the latter strongly so. Sub-project 3 results suffer from some methodological limitations listed below.

Table 1: Benefits, Costs, and B/C Ratios for ISGD Sub-Projects

	ZNE	*DBESS*	*DVVC*
NPV of Cost	$(4.64M)	$(0.85M)	$(0.59M)
NPV of Benefit	$0.30M	$2.14M	$7.58M
NPV of Net Benefit	$(4.34)M	$1.30M	$6.99M
B/C Ratio	0.1	2.5	12.9

In both ZNE and DVVC more than 80% of the benefits are from reduction of electricity cost, which is a consumer benefit. For Sub-project 3, almost 70% of the benefits come from deferral in generation capacity investments, while 25% derives from reduction in losses, with the remaining benefit from transmission and distribution deferral. There is no beneficial stakeholder other than the Utility in this sub-project. The SGCT also has a number of limitations. For example, the tool calculates the peak reduction benefit based on power capacity, but ignores whether a given system has sufficient energy capacity to sustain the given power level for the peak duration. The tool also does not reflect charging/discharging inefficiencies and auxiliary loads for energy storage systems, nor does it include land acquisition costs.

U.C. Irvine Campus: Table 2 shows the net benefits for each project considered.

Table 2: Benefits, Costs, and B/C Ratios for U.C. Irvine Sub-Projects

	CHP	*PV*	*MgC*	*LiB*
NPV of Cost	$ (30.6M)	$ (13.7M)	$ (1.14M)	$ (0.51M)
NPV of Benefit	$ 124M	$ 43.2M	$ 242M	$ 3.47M
NPV of Net Benefit	$ 93.1M	$ 29.5M	$ 241M	$ 2.96M
B/C Ratio	4.0	3.2	212	6.8

The MgC project shows an extremely high value, driven by its highly valued reliability improvement. It was assumed outages caused by the SCE system would be solved by islanding, yielding a decrease in System Average Interruption Duration Index (SAIDI) from 1.17 to 0.17 h/a. The CHP plant also shows significant value, largely a result of the economic benefit associated with optimized generator operation, and current low gas prices. The net benefit of installing PV is much lower than the CHP plant and MgC projects, resulting from the high investment cost of the PV. For the PV to compete with the CHP, cost reductions are still needed. The LiB case also shows a high benefit-cost ratio compared to the other projects although the absolute value of the net benefit is much smaller than the other projects.

ACKNOWLEDGEMENTS

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