EDGE MODEL
EXECUTIVE SUMMARY

JANUARY 31, 2013

Rocky Mountain Institute®

1820 FOLSOM ST. | BOULDER, CO | 80302

Context

A growing body of work has begun to provide needed analysis and quantitative rigor to support the technical viability of integrating significantly higher amounts of renewable energy and energy efficiency to power the U.S. electricity system. This work can be broadly categorized into two areas: 1) regional and/or national planning studies, and 2) technical operations integration studies, often at a regional or utility-specific scale. RMI's 2011 book *Reinventing Fire: Bold Business Solutions for a New Energy Era* extensively modeled pathways to meet future U.S. energy needs over the next 40 years largely based on efficiency and an electricity system powered 80% by commercially available renewable energy technologies. The National Renewable Energy Lab's (NREL) *Renewable Electricity Futures Study (REFS)* corroborated these findings in a collaborative study of more than 100 contributors from 35 organizations including national labs, industry and universities. Meanwhile, over 200 international studies have concluded that there are no insurmountable technical barriers to reliably integrating up to 30% variable renewable supplies into the grid, and several European systems are already demonstrating the feasibility of penetrations of 20-50% today.

However, there is comparatively little analysis into the role that distributed energy resources[1] (DERs) could play as part of a future electricity resource portfolio, hindering the ability to holistically understand the potential for efficiency, demand response, and local generation to displace other generation or grid investments, at potentially lower cost and/ or increased efficiency. Existing modeling efforts have not meaningfully captured the critical performance characteristics and variables that drive the costs and values of DERs. The complexity of the analysis required has led to a hefty reliance on operational rules-of-thumb while evaluating economic impacts to just a limited group of stakeholders in the context of a restricted subset of regulatory environments. As a result, existing analytical tools have not been sufficient to inform effective decision-making and the institutional, market, and regulatory implications of increasing generation, coordination and communication on the distribution network.

Meanwhile, accelerating DER adoption is already starting to directly challenge conventional approaches to economics and operations across the electricity value chain. Most U.S. electric utility business models, which have evolved on the basis of control, ownership and scale efficiencies from central station electrical supply, transmission, and distribution, are poorly adapted to quantify, capture or optimize the value streams associated with DERs. In this environment, incumbent utilities often associate DERs with increased transaction costs, challenges to system operations, and revenue loss.

In short, better analytical tools are necessary to support effective decision-making regarding the potential and implications of DERs. This analysis should include an evaluation of the net effect of DER integration on grid operations and future resource requirements, and of the economic implications for the system's stakeholders. Critical questions include:

1. What is the net effect of DER integration on system operations and future infrastructure requirements?
2. How can utilities, customers, and third-party stakeholders be properly rewarded for the services they provide to the grid?
3. How can we structure policies and regulations to align stakeholder incentives and encourage innovation and investments that reduce the overall system cost?

[1] Distributed energy resources include end-use efficiency, distributed generation (rooftop solar, community solar, cogeneration, etc.), distributed storage (demand response, electric vehicles, thermal storage, etc.), and distributed intelligence (smart grid, home automation, etc.).

EDGE Model Overview

To address these needs, RMI has developed the Electricity Distribution Grid Evaluator (EDGE) model. The EDGE model is a MATLAB-based simulation tool designed to comprehensively assess the DER value proposition in different regulatory and utility business model environments based on a detailed assessment of the technical and operational implications. Though designed to study an individual utility or region (e.g., a balancing area), the model maintains the flexibility to be adapted for use with many different utilities or regions. The ability to alter the model's parameters allows RMI to identify conditions that optimize value, and to test the effects of new, innovative business models and rate structures.

The EDGE model provides an analytical basis for assessment of the costs and values created by all resources, including DERs, from the unique perspectives of five key stakeholder groups:

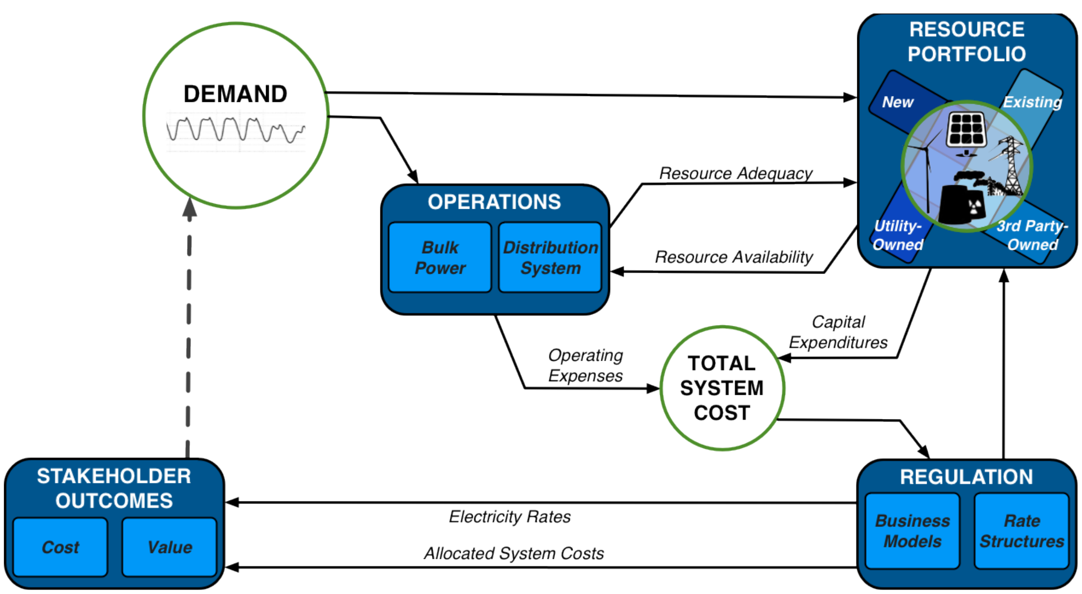
1. Utilities
2. Traditional customers (i.e., non-participating)
3. Participating customers (e.g., customer-generators)
4. Third-party service providers
5. Society

To determine the outcome for each stakeholder group, the EDGE model incorporates the principal drivers of value in electricity system planning and operations—*location*, *timing*, and *controllability*. These drivers are then integrated over multiple timescales—*sub-hourly* distribution system simulation, *hourly* bulk power dispatch, and *annual* resource portfolio planning—subject to certain constraints. These constraints include:

- Regional supply limitations;
- Operational limitations (including both planning and operating reserves);
- Specific policy requirements (e.g., renewable portfolio standards).

This holistic approach enables accurate translation from the localized effects of DERs on the distribution system into benefits and costs, and produces a wealth of detailed data that allows for rigorous post-simulation analysis.

Figure 1: Schematic of the EDGE model.



Model Structure and Components

The EDGE model is designed with a modular structure. The simplified interaction of these modules is depicted in Figure 1 above, and the functionality of each module is described below.

Resource Portfolio Module

The resource portfolio module analyzes the annual resource investment needs of a selected electricity system, and chooses from a broad portfolio of supply- and demand-side assets that could help meet those needs over time. The purpose of the resource portfolio module is to perform the tasks traditionally associated with utility planning and procurement. However, the module also considers the potential for mixed resource ownership/control by non-utility stakeholders, particularly DERs.

Growth in unplanned, non-utility resources[2] may occur outside of the purview of utility and regulatory processes, and therefore represents an independent variable with the potential to force sub-optimality in the system. Depending on the characteristics of the simulation being studied, growth in non-utility DERs is either accepted as an exogenous input to the resource portfolio module, or is calculated using a market-penetration model.[3] The latter approach, along with a simple econometric demand growth model, creates an important feedback loop between electricity rates and future resource portfolios.

The module attempts to optimize the planned portion of the electricity system by minimizing cost across several dimensions:

- Construction of new resources, including both generation and T&D capacity expansion;
- Operation of resources during the planning period to meet load (i.e., fixed and variable operation and maintenance (O&M) and fuel costs);
- Decisions to mothball and/or retire resources, and the creation of "stranded assets";
- Demand for ancillary services and storage.

At the end of each simulation year the resource portfolio module produces an updated resource capacity mix, including operating characteristics, costs, and ownership details.

System Operations Module

Utilities have traditionally exercised a high degree of control over operational management for most electricity system assets at the distribution level. However, a utility's (or grid operator's) future role could increasingly entail coordinating a vast array of supply- and demand-side resources that are owned and/or operated by independent actors. To capture the operational implications that stem from this dynamic, the system operations module simulates both the economic dispatch of bulk power, and the operation of distribution systems.

Bulk Power Dispatch Submodule

The bulk power dispatch submodule is an hourly, least-cost dispatch function designed to test whether a resource mix can be operated reliably in a given year. The primary inputs to the dispatch submodule are the system demand profile and the resource mix, both of which are direct outputs from the resource portfolio module—it is important to note that the dispatch is currently not transmission-constrained. With these inputs, the dispatch submodule simulates the scheduling and dispatch of generation assets to meet the system's load in each hour of the year. This simulation produces a series of outputs, which are later used to determine stakeholder outcomes. Outputs include:

- Operational statistics, which show capacity dispatched and resource curtailment;
- Cost-to-serve;
- Reliability metrics (e.g., Loss of Load Probability).

---

[2] Examples might include: customer-owned, behind-the-meter PV; PV leased from a third-party owner; or privately-owned microgrids.

[3] Utility-procured DERs are considered separately, as part of the optimization of the planned portion of the system.

Distribution System Submodule

The distribution system (DS) submodule is used to assess the net operational effect of a resource mix at the distribution-level. Using EPRI's OpenDSS platform, the DS submodule simulates the operation of distribution circuits at different DER penetration levels and mixtures, performing time-series simulations for both baseline and increased DER-penetration scenarios. These simulations are conducted at a high temporal-resolution[4] using a representative set of distribution circuits, and then scales those results to the entire utility. The DS module captures the dynamic, localized effects of DERs on network conditions and line losses during normal conditions, while also testing security by observing system stability under specific contingencies.

To initialize the DS module, a set of inputs from other EDGE modules is used. Noteworthy inputs include load profiles (for individual customers); DER adoption patterns and rates; and infrastructure asset availability, ownership, and operational control. Once initialized, the module uses OpenDSS to simulate and record the effects on the system's physical performance (in terms of voltage, frequency, etc.). The DS module is then able to convert the resulting technical performance data into economic costs and benefits using infrastructure maintenance and capital cost parameters, and extrapolate them from the representative set of circuits up to the entire utility. The final output from the DS module is a summary of distribution system impacts (positive or negative) and their associated costs. Metrics used include the change in:

- Voltage extremes and support requirements;
- Power factor requirements;
- Demand for ancillary services;
- Network losses;
- DER usage patterns;
- Equipment performance, stress, loading and degradation;
- Deferral, displacement, and/or requirement of infrastructure investment;

Rates and Regulation Module

In contrast to the resource portfolio and system operations modules, which are simulation-based, the rates and regulation module focuses on accounting. The module performs two primary functions:

1. Determine the utility's revenue requirement.
2. Calculate the retail electricity rates given these revenue requirements and a set of rate structures.

Informing these calculations are the simulation results, particularly the hourly and annual operating costs, and sets of both rate structures and regulatory parameters (e.g., allowed return on equity, tax rates, plant depreciation allowances, etc.). In the context of traditional regulatory constructs, utility rate structures, and business models, this entails making the leap from wholesale operating costs to the utility's all-inclusive cost-of-service. These traditional rate structures include net-energy metered (NEM) flat rates, block rates, and time-of-use rates.

However, because the rate structures and incentives designed to stimulate the early adoption and scale-up of DERs (i.e., NEM) will become problematic as adoption rates increase, the rates and regulation module also tests new forms of incentive regulation and methods for revenue generation. This allows EDGE to examine any number of potential alternative regulatory, utility, and customer strategies to respond to a shifting electricity market (e.g., shared savings, performance-based earnings, "innovative" rate structures, etc.).

---

[4] The exact resolution modeled depends on the specific simulation being conducted. Increments may be on the order of anywhere between seconds and minutes. OpenDSS is capable of simulating at even greater resolution, but impacts at this level of granularity are not currently needed for this application.

Stakeholder Outcomes Module

Upon completion of each annual simulation, the stakeholder outcomes module assesses how the costs and values of the system's performance would be allocated between actors under a particular regulatory structure. Identifying these economic implications is critical to better understanding the problems and challenges facing stakeholders in the electric system, and to identifying the essential characteristics of workable long-term solutions. Outputs from this module include financial implications to each stakeholder group:

Customers

Financial metrics differ by customer class, although some metrics are applicable to all customers.

All Customers

- Annual electricity bill (under each rate structure)
- Reliability experienced
- Rate stability

Participating Customers

Participating customers (those who provide generation, demand response, etc.) have other unique considerations:

- Additional credits (e.g., for generation, ancillary services, etc.)
- Return on investment (if investment in capital was required)

Service Providers

"Service provider" refers to an entity that provides an electricity-related service to another system stakeholder. The EDGE model groups these entities into two distinct groups: utilities and third parties. Like the customer classes above, each of these groups has certain distinct metrics by which their financial health might be gauged, as well as certain measures that apply to both. The latter category includes:

- Total debt
- Net worth
- Working capital (WC)
- Diversification (of generation types, fuel sources, etc.)

Electric Utilities

Utility ownership and operational structures are highly variable, depending on the degree to which they are regulated, whether they are privately or publicly owned, and in which power system infrastructure components they are invested. As such, not all of the following metrics apply to every utility that might be studied using the EDGE model:

- Customer diversity (i.e., degree of reliance on industrial customers)
- Cash flow interest coverage
- Ratios:
    - Cash from operations (CFO) pre-WC to debt
    - CFO pre-WC minus dividends to debt
    - Debt to capitalization
- Construction work in progress (CWIP)
- Total assets (including plant, T&D, etc.)
- Common stock (value of, and number of shares outstanding)
- Retained earnings

Third-Party Service Providers

- Net profit margin,
- Return on equity (ROE),
- Earnings before interest, taxes, depreciation, and amortization (EBITDA).

Society

- Total resource cost test.

Model Applicability

The EDGE model is an electricity system simulation tool that assesses the economic implications of system management decisions on that system's stakeholders. The model is both holistic and spatio-temporally complex, and it considers decision-making and impacts at multiple levels of the system planning and operations processes. It can be used to study not only the effects of increasing DER penetration on a system, but also the impacts that the introduction of new rate structures, targeted regulatory changes, or alternative business models might have on stakeholders' economic vitality.

Caveats

The EDGE model is a powerful tool, but is not intended to be universally applicable. The model is designed to study utility-scale effects—it is not meant for use at the national level, where transmission constraints, regulatory diversity, and additional reliability concerns may become increasingly relevant. Although the EDGE model includes the ability to study distribution system impacts, it is in no way intended to replace utilities' existing distribution management systems, and is not designed to study a system's *entire* collection of distribution circuits. Rather, it provides insight into the likely distribution system impacts, which may then be studied in further detail using more complete network models.

For additional information please contact:

Virginia Lacy
Senior Consultant | Electricity Practice
vlacy@rmi.org | 303.567.8640

James Sherwood
Analyst | Electricity Practice
jsherwood@rmi.org | 303.567.8599