

# DESIGNING A SECURE AND EFFICIENT DISTRIBUTED GENERATION POWER SYSTEM: POLICY, CONSUMER AFFAIRS, AND COMPUTER SIMULATION ISSUES

Ralph Badinelli, Virgilio Centeno, JoAnn Emmel, Michael Gregg, Richard F. Hirsh, Boonyarit Intiyot, Irene E. Leech, Jaime de la Ree, Benjamin K. Sovacool, Tim Thacker, Fei (Fred) Wang, and Regina Goods  
Virginia Polytechnic Institute and State University (Virginia Tech), Blacksburg, Virginia, 24061 USA

## ABSTRACT

This paper highlights three elements of work designed to explore the integration of distributed generation (DG) technologies into the existing utility system. The social science members of our interdisciplinary group report on the potential and real advantages of using small-scale, decentralized technologies to generate power. They also describe many impediments to widespread use of the technologies. The consumer affairs group, meanwhile, has worked to understand the amount of effort needed to introduce DG technologies into a system that the general public comprehends poorly. Finally, the business members report on their work in creating a vigorous computer simulation model that can analyze the risks and benefits of introducing DG technologies. Beyond its use for considering business factors, the model, which employs GIS technology, has great potential for educating students in business and engineering disciplines.

## KEY WORDS

Distributed generation, renewable energy, business policy, public policy, consumer affairs, energy management curriculum.

## INTRODUCTION

Our interdisciplinary group works on conceptualizing and implementing the development of clean and efficient distributed generation (DG) technologies. These technologies include fuel cells, microturbines, and renewable energy sources, such as wind turbines and solar photovoltaics. The engineering cohorts continue to develop the interfaces between small-scale DG technologies and the existing electric utility grid. In this report, however, we focus on the work of the social science, consumer affairs, and business/education cohorts. The social scientists (in the policy cohort) have worked to understand the potential and real advantages of DG technologies. Perhaps more important, they endeavored to fathom the non-technical impediments to their implementation. A major impediment remains the lack of understanding by the general public of the way the utility system works, as is demonstrated by the consumer affairs group. Evidence from experiences in Virginia demonstrates that much effort needs to be expended to win customer acceptance for DG or other power technologies. The business cohort (in collaboration with some of our engineer partners), finally, is pursuing the use of computer simulation as a robust tool for educational case studies in the field of power systems design, engineering, and management.

## 1. RESEARCH SUMMARY

1.1. Social Science Research: Understanding the Advantages of DG and Impediments to its Use

On one hand, DG technologies offer huge potential (and real) advantages. On the other hand, their widespread use is thwarted by non-technical forces. In this section, we explore the advantages of DG technologies.

DG encompasses a wide range of technologies. Many renewable energy systems—such as wind turbines and photovoltaic technologies—are small and decentralized, and they serve as examples of DG technologies. Even generation equipment that employs fossil fuels, such as natural gas and coal, can be considered as valuable DG resources, especially when they exploit waste heat generated through combustion or fuel conversion. These include cogeneration plants (also known as combined heat and power [CHP] facilities). They may also consist of very small steam turbines known as microturbines that produce power in the range of 25 to 500 kW while employing waste steam for water or space heating needs.[1] Phosphoric acid fuel cells are also being pursued as DG technologies. The devices (which are being tested in 200 kW to 11 MW sizes) take in hydrogen-rich fuel and create electricity through a chemical process rather than by combustion, thus yielding few particulate wastes.[2] The process also yields heat, which can be used as a profitable by-product. Beyond these DG technologies are modular internal combustion engines that run on diesel fuel or gasoline. In their smallest versions (about 1 kW), they provide backup power for recreational vehicles and homes. In larger packages, these engines provide backup electricity for

hospitals and other large commercial enterprises. DG facilities may be established as isolated “islands”—disconnected from the transmission grid—or attached to it. In the latter case, they may constitute the primary producers of power for a user or serve as backup units. They can also be set up to add power to the grid for use by other customers.

The economic viability of these DG technologies has improved in recent years. Advances in microturbines and reciprocating gas engines have lowered the cost and increased the efficiency of the small scale generation technologies.[3] Enhancements in net metering, fuel conversion technology, and thermal engineering have accompanied developments in automation and control, improving the economy of small units and reducing the need for periodic maintenance and inspection.[4] Small system technology can also be mass produced at a lower unit cost. For example, numerous companies offer fuel-cell technology, which is viewed as having virtually no emissions, in ready-to-connect packages. Many policymakers also perceive gas turbines as having low initial investment, steam generation capabilities, and installation flexibility.[5]

Consumer advocates note that DG technologies can provide more efficient electrical power. The transmission of electricity from large and centralized plants typically wastes between 4.2 and 8.9 percent of the electricity, since wire resistance, inconsistent enforcement of reliability guidelines, and growing bottlenecks all degrade the effectiveness of transmission systems.[6] Since customers pay a share of the cost of the transmission system in their electricity bills, employment of localized generation equipment can conceivably yield affordable and higher quality power. Moreover, self-generators can sell excess power to the grid and earn revenues, especially during times of peak demand.

Additionally, industrial managers, commercial business owners, and contractors have begun to recognize advantages of local power generation. Combined heat and power technologies permit these power users to recycle thermal energy that would normally be wasted. Energy-intensive industries, including iron and steel foundries, chemical processing facilities, and paper and pulp manufacturers already use CHP technologies to maximize the efficiency of their onsite electricity generation. Office and industrial managers have also begun to use CHP technologies to reuse energy normally needed for district heating (where excess heat is pumped through buildings in lieu of electrically produced heat) and surplus power provision (where the extra thermal energy from combustion is reused to produce more electricity). CHP technologies also provide value in aquaculture, greenhouse heating, desalination of seawater,

increased crop growth, frost protection, and air preheating.[7]

Beyond efficiency, DG technologies can provide more reliable power for digital and telecommunications industries that require uninterrupted service. One study conducted by the Electric Power Research Institute noted that power outages and quality disturbances cost \$119 billion in 1999, with between \$21.2 and \$33 billion lost in California and New York alone.[8] A comparable study undertaken by the American Superconductor Industry estimated that power outages cost California more than \$10 billion every year.[9] The cost of a two-hour blackout for chip manufacturing and semi-conductor industry alone can cost as much as \$48 million.[10] These numbers help explain why several companies already rely on DG facilities to ensure consistent power supplies.

Surprisingly, perhaps, DG facilities offer enhancements for the transmission of power. By producing local power for users, DG technologies can decongest the grid by reducing demand during peak times, one of the causes of the 2000-2001 California crisis and the 2003 blackout on the Eastern seaboard.[11] Most important, by constructing large numbers of decentralized power facilities rather than a few large plants located distantly from load centers, DG use can reduce the need to upgrade and expand transmission facilities during a period when investment in such facilities remains restricted due to siting policies and local opposition. Further, the logic of management and financing used for transmission facilities currently does not provide many incentives for new construction. In several cases, owners can make more money when transmission capacity is nearly reached. At these times, customers have no choice but to use the grid, and they pay whatever price the market will bear. DG gives them an alternative by allowing them to produce power locally. And in an increasingly security-minded era, proponents argue that DG technologies may enhance protection of the grid. Decentralized power generation reduces the terrorist targets that large nuclear and conventional facilities and natural gas refineries offer. It also helps the system by diversifying fuels, enhancing emergency stand-by generation, and insulating the grid from failure better if a large power plant goes down due to an attack.[12]

Finally, some environmentalists and academics have argued that DG technologies provide benefits to society. Large, centralized coal- and gas-fired power plants emit pollutants, such as carbon monoxide, dioxins, sulfur oxides, particulate matter, hydrocarbons, and nitrogen oxides. For many years, the Environmental Protection Agency (EPA) has reported the correlation between high levels of sulfur oxide emissions and significant health effects, including cancer and asthma. Moreover,

combustion of fossil fuels tends to create acid rain, which suppresses crop growth and leeches nutrients from the soil. Because larger plants concentrate the amount of power they produce, they focus their pollution and waste heat, which destroys fragile ecosystems and reduce marine biodiversity. On the other hand, some recent studies have confirmed that widespread use of DG technologies substantially reduces emissions: A British study estimated that domestic CHP production reduced carbon dioxide emissions by 41% in 1999. A report on the Danish power system argued that widespread use of DG technologies have reduced emissions by 30% from 1998 to 2001.[13]

## 1.2 Consumer Affairs Research: Learning about Consumer Knowledge and Interest

The consumer group seeks to gauge consumer understanding and interest in DG technologies. The research is important for two reasons: 1) consumers make up an important political constituency that can influence the policy makers and regulators who have power to erect or dismantle impediments to the use of new technologies; and 2) consumers feel the impact of the use of new technologies in the form of higher or lower electricity prices and in the form of perceived benefits or disadvantages when DG technologies are located near them.

The group's research demonstrates that, in Virginia at least, average consumers are not aware of how the electric system operates or how utility restructuring affects them. Virginia's residential retail electricity rates have historically been below the national average, with the western part of the state enjoying rates among the lowest in the nation. Consequently, Virginia consumers have had little incentive to learn how power is produced or distributed.

The lack of knowledge is especially disturbing given several events occurring in the state. For example, a new transmission line has been approved and built in southwestern Virginia, largely across national and state forestland. Moreover, a few small gas fired generation plants have been built, an urban coal fired generation plant is closing, a company is seeking approval to build a new wind generation project, and permits for two nuclear plants have been extended. Currently, the operator of a large nuclear plant is seeking permission to expand. However, since none of these activities has received more than regional media attention, few citizens, except those directly affected by them, have shown much interest.

Electricity restructuring in the state, officially begun in 1999 with the enactment of SB 1269 [14], has done little to raise consumers' consciousness. When consumer advocates and legislators repeatedly asked the news

media to provide better coverage of the process, they were told that the issue was too complex for citizens to understand. In their lackluster coverage, journalists demonstrated, unfortunately, that they too did not fully understand how restructuring would affect consumers.

Investor-owned utilities attempted to provide information to customers, telling them that changes were coming and that they would generally benefit consumers. Although electric cooperatives and municipal electric providers used their own communication tools, especially in-house magazines, to explain the meaning of restructuring, few consumers paid attention.

Pilot programs designed to test processes needed for the competitive market drew extremely limited participation in the eastern part of the state because few competitive providers chose to participate. Repeated efforts to redesign pilot programs to entice participation by were unsuccessful, largely due to the unwillingness of incumbent providers to accept reduced revenue or to give up market share. In western Virginia, consumers were notified that they might receive competitive offers for electric service. But offers failed to arrive, since no new service provider felt it could battle an incumbent utility that already offered low rates.[15]

Some decision makers realized that consumer knowledge of a market-based electric system had to be significantly improved. In fact, even the restructuring legislation contained terms requiring the SCC to undertake an extensive consumer education program, and it allowed the Commission to collect a small fee from consumers to pay for the program.[16] The Commission established a consumer advisory board and contracted with private firms to conduct an extensive advertising and grass-roots educational campaign, known as Energy Choice.[17] The public relations team developed a survey designed to measure the impact of the campaign, collecting data every six months. The first report revealed how little Virginians knew about electric utility restructuring.[18]

After two years, when the state faced a large budgetary shortfall, the governor took the money collected for the consumer education program and placed it in the state's general fund. The move effectively killed the Energy Choice program.[19] Though research showed that consumer awareness had improved slightly, it remained at a low level. Because business owners were targeted as a critical initial audience for the educational program, it is not surprising that their knowledge exceeded that of residential consumers.

Two years since the program's suspension, it still appears that a vibrant competitive market will not develop in the near future. Decision makers do not want to be accused of misleading consumers about the availability of a

competitive market, and they therefore extended the transition period through 2010. The extension also means that capped rates will remain in place, though they can (and have already been) raised due to increased fuel and other costs incurred by utilities. Thus, many consumers do not think they have really had capped rates, especially since the investor-owned utilities have reported increasingly positive financial returns in recent years. However, few analysts anticipate that the rates will become high enough to attract competitive providers to Virginia until the capped rate period ends. This lack of activity, and the appearance that the traditional system has not changed, mean that most consumers have forgotten what they learned during the Energy Choice campaign.

The gloomy situation does not augur well for widespread acceptance of any type of change within Virginia's electricity system. It poses a huge burden on those seeking to improve the efficiency and security of the system using DG technologies.

### 1.3. Business/Education Research: Methodology for GIS-Based Simulation Studies for Power Systems Education.

The business/education research group is constructing a computer simulation software package, called the Virginia Tech Electricity Grid and Market Simulator (VTEGMS), as a robust tool for educational case studies in the field of power systems design, engineering, and management. In conjunction with case studies, text, and lecture materials, computer simulation forms a flexible educational support system (ESS). Computer simulation is unique among modeling techniques to support case analysis and decision modeling for such complex systems. Examples of the decision domains that our educational tool must support include:

- Public policy decision problems—environmental policy planning, market regulation planning, infrastructure planning
- Engineering decision problems—protection system design, generation and transmission technology selection
- Business decision problems—generation capacity planning, unit commitment, optimal dispatch, demand side response, trading strategy, financial risk management

For each of these decision problems, the cause-effect relationship between decision alternatives and key

performance indicators (KPIs), such as long-run cost, reliability, pollution, market equity, financial risk, etc., must be understood and analyzed. Decisions related to power systems have outcomes that play out over a long time and can take on many scenarios due to randomness in system parameters such as loads and market prices. Furthermore, the relationships between decision alternatives and KPIs for power-systems decision problems are typically complex and nonlinear.

In a simulation model of a power system, the power flows through each network element, and the cash flows associated with the power flows can be modeled for each hour of each day. From hour to hour, the simulation program updates the status of each generation unit, load and network element and stores this status in computer files. From these outputs, the KPIs of the power system are computed. The interested reader is referred to Banks [20] for more information about the structure of simulation programs and simulation modeling. Amelin [21] provides an overview of simulation models specifically for modeling electricity markets.

A simple example of the need for simulation modeling is found in the case of the unit dispatch decision. The simulation model for this decision would compute, for any given dispatching plan and for any given scenario of loads, the total generation cost as well as other performance measures. To assess the KPIs of risk and expected cost of a dispatching plan, we would like to compute the generation cost over many 24-hour time horizons, each one representing a possible scenario. In this way, we obtain a representative sample of system performance from the population of all possible scenarios. Figure 1 shows a sample of scenarios of a time series of generation cost. We summarize the data in Figure 1 by computing their average and the value at risk evidenced by these data. Value at risk is a measure of financial risk commonly used in the energy industry. In this case, we compute VAR as follows:

$$VAR = C_{90} - \mu_c$$

where  $\mu_c$  = the mean cost, estimated from the sample to be 1,774 and  $C_{90}$  = the cost at the 90<sup>th</sup> percentile point of the distribution of costs, estimated from the sample to be 1,850. The two measures of expected cost and VAR are KPIs that capture the expected financial value of the dispatching plan and a measure of financial risk associated with the dispatching plan.

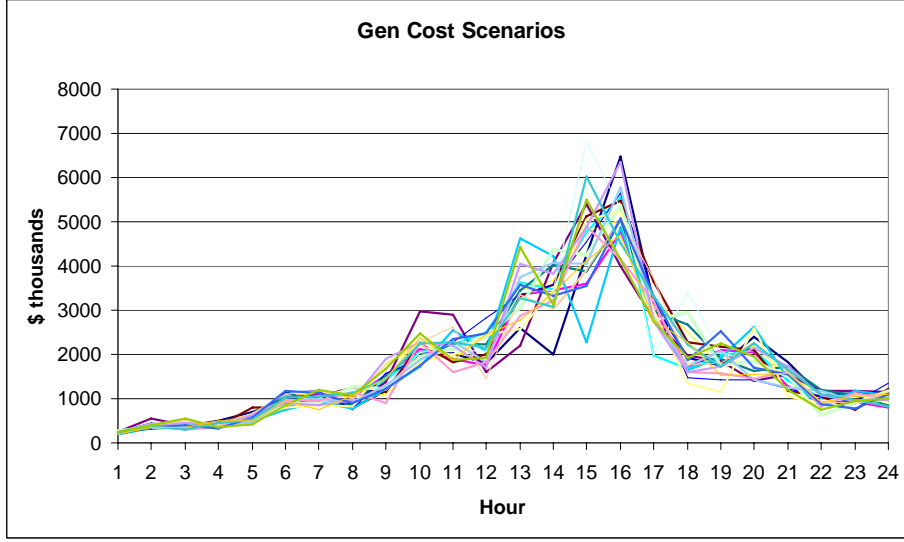


Figure 1: Generation cost scenarios

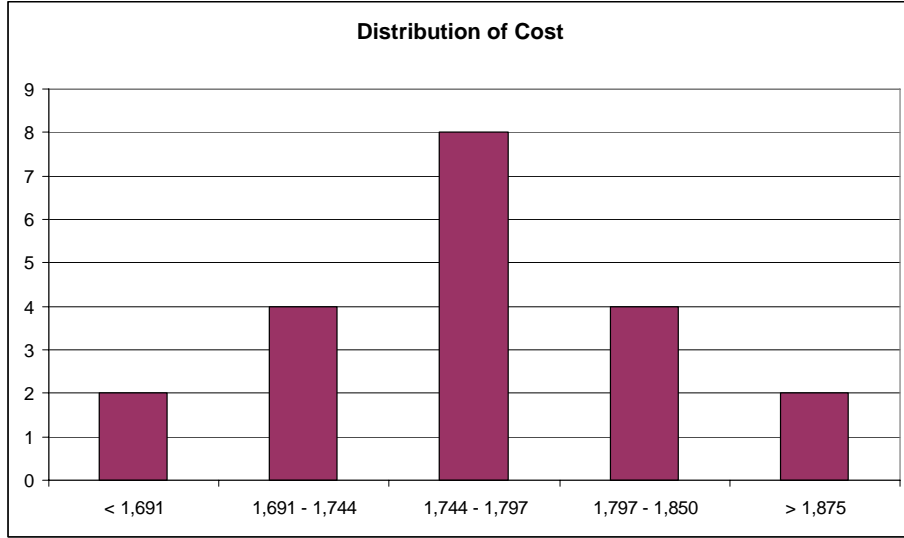


Figure 2: Distribution of Sample of Costs

Formulas (1) – (3), adapted from Soares and Medeiros [22], shows a typical load forecasting formula that is embedded in our simulation model to represent load for hour,  $h$ , of day,  $d$ , of a simulated horizon.

$$L_{h,d} = L_{h,d}^P + L_{h,d}^S \quad (1)$$

where,

$$L_{h,d}^P = \alpha_0 + \rho d + \sum_{r=1}^H \alpha_r \cos(\omega r d + \theta_r) + \sum_{i=1}^K \mu_i \delta_i \quad (2)$$

$$L_{h,d}^S = \phi_0 + \sum_{i=1}^p \phi_i z_{h,d} + \varepsilon_{h,d} \quad (3)$$

$L_{h,d}$  = total load

$L_{h,d}^P$  = potential load

$L_{h,d}^S$  = irregular load

$\alpha_0$  = initial base load

$\rho d$  = trend component of load

$\sum_{r=1}^H \alpha_r \cos(\omega r d + \theta_r)$  = cyclical variations in load represented by  $H$  harmonics of an annual cycle.

$\sum_{i=1}^K \mu_i \delta_i$  = load adjustments for the day of the week, holidays, etc.

$\phi_0 + \sum_{i=1}^p \phi_i z_{h,d}$  = autoregressive components of load

$\varepsilon_{h,d}$  = random component of load assumed to be normally distributed with a mean of zero and a standard deviation of  $\sigma_{h,d}$

For any day,  $d$ , and hour,  $h$ , all of the terms in these formulas except  $\varepsilon_{h,d}$  would be known parameters that the modeler would enter into the simulation program's database. The random component of load must be represented in the simulation program as a different value each time the load for day,  $d$ , and hour,  $h$ , is simulated. To do this, the simulation program generates a stream of numbers that have the properties of random drawings of numbers from a normal distribution with a mean of zero and a standard deviation of  $\sigma_{h,d}$ .

To simulate the power flows within VTEGMS, we need to solve a set of power-flow optimization problems (see Momoh.[23]) Solving such optimization problems is the most computationally intensive part of the simulator. Since the flows must be updated for every simulated time interval, the speed of the simulator could become a problem if the code for solving the optimization problems is not efficient. Writing an efficient optimization routine from scratch could be time-consuming. Fortunately, some proprietary software packages, such as CPLEX and IMSL, provide routines for these purposes. With years of research and development invested in these software packages, their routines are proven to be efficient and reliable. Consequently, the construction of VTEGMS is integrated with these routines.

## 2 EPNES GOALS

### 2.1. Social Science (Policy) Goals: Comprehending Impediments to Acceptance of DG Technologies

Despite potential benefits, the transition to a new DG paradigm will not occur effortlessly because of the existence of social, technical, political, and business related impediments. The most significant impediment may be the belief that decentralized units cost more than large centralized facilities. Cost projections for electricity often only include the capital cost of a generator, maintenance, and fuel. Such estimates exclude "external costs" in the form of pollution, decommissioning, and price swings for fuel and labor. These pricing schemes also fail to include many of the potential benefits—including reliability, efficiency, and security—that DG systems can provide. Consequently, policymakers and consumers often think that renewable technologies (in particular) cannot compete effectively on costs with traditional fossil fuel sources of electricity.[24]

The largest technical impediment consists of problems related to the connection of DG technologies to the grid. This interconnection conundrum really constitutes a set of aggregated technical problems: voltage control (keeping voltages within acceptable ranges), the balancing of reactive power (properly synchronizing power within the grid), and safety (ensuring the protection of people working on the grid, especially when parts of it are

blacked out). Customers using DG technologies today often rely on custom-designed electronics packages to resolve these problems. But the large cost to create such packages serves as a disincentive for many users. Recognizing this problem, an IEEE Standards Coordinating Committee has begun developing rules for interface technologies that would enable DG users to "plug" into the grid directly and safely. However, agreement on the specific details of the new standards remains years away. As of January 2, 2002, the list of committee members included 385 people, representing scores of investor-owned and public power utilities, manufacturers, government laboratories, state agencies, and consultants. Each player sees advantages and disadvantages to acceptance of any single technical standard, meaning that a consensus will be difficult to fashion. The problem illustrates the social nature of technological change, as different players in the system view benefits and costs differently.[25]

Possibly more important, regulatory and political inertia within the United States, in the form of financial subsidies and incentives, still favors fossil fueled electricity generation from large plants. For example, the tax code contained \$13 billion in production, research and development tax credits for energy production in the years 2000-2004. Of that amount, fossil fuel technologies received \$10.2 billion of incentives, nuclear power users got \$1.5 billion, and renewable energy technologies were allocated only \$400 million.[26] This unbalanced subsidization means, for instance, that wind energy technologies may not improve as rapidly as they did in the past.[27] Similarly, lingering monopoly rules and discriminatory rate structures (often taking the form of exit fees, backup tariffs, and connection surcharges) still exist in many states and create political obstacles to investments in DG technologies. Customers who seek to use DG often face extra charges imposed by utilities that seek to recover stranded costs.

### 2.2 Consumer Affairs Goals: Obtaining Consumer Acceptance of Changes in the Utility System

Skepticism of any changes in the utility system among consumers, especially those that involve DG, exists despite their experience of using a form of distributed generation technology long ago. Before electricity was widely available to rural areas, many Virginians employed windmills to provide power for their homes and businesses. Few citizens remember that time, and today, most windmill structures are gone, even on the most rural farms. Weather-related outages have led some consumers to purchase gasoline powered generators for short term use, yet most consumers have not had much occasion to employ them. Overall, no part of the state has seen widespread or high profile use of new distributed generation technologies.

Virginia's restructuring legislation focused on the needs of traditional energy providers, and most enticements for innovation have been directed at them. So far, few businesses and consumers have experienced significant price increases for electricity, thereby reducing any incentive to seek means of generating power for themselves.

Because of the September 11, 2001 attack on the Pentagon, which is located in northern Virginia, and the fact that the state houses several military facilities, security has become a major concern and focus. Many consumers are aware of local, state, and federal efforts to improve homeland security. Consumers in northern Virginia are more conscious of homeland security issues than are those in other parts of the state due to particular concern and attention focused there. Security of the electric system is an important part of that effort.

Meanwhile, Virginia has experienced periodic and widespread electricity outages from weather related events. Ice storms and hurricanes most typically cause these problems. Many consumers suffered without electricity for days at a time when repeated ice storms struck the state. In 1989, Hurricane Hugo left the western part of the state without electricity for about five days. And in 2003, Hurricane Isabel left a large portion eastern Virginia without power for more than a week.

Despite these experiences, Virginians appear to remain woefully unaware of DG technologies and their benefits in situations such as these. Given their general lack of understanding of the utility system, this conclusion comes as little surprise.

As a major research objective, then, the consumer affairs group has sought to accomplish two goals by developing rigorous surveys of consumer attitudes: first, it wants to understand better the state of knowledge of consumers. Second, from responses obtained from the surveys, the group wants to learn how to educate consumers to make educated choices about restructuring and DG technologies.

At first, the consumer cohort wanted to develop a questionnaire to obtain a sense of people's knowledge about distributed electricity and the security of the electric system. But members of the group quickly determined that such a survey would be meaningless without giving respondents useful information. The group therefore designed a short educational program, supported by a Powerpoint presentation. It further developed a survey instrument to collect information from consumers about their willingness to accept several distributed generation technologies and their concerns about environmental and price issues. The group also created an educational poster on DG that it displayed at a statewide professional meeting, where participants tested the survey instrument.

### 2.3 Business/Education Goals: Interfacing and Implementation of Computer Simulation

As a practical matter, a computerized educational support system (ESS) is effective only if its interfaces for learners and teachers are transparent and easy to learn. Coupling a GIS system to the simulation program provides a seamless interface for the user between data entry and key performance indicators (KPIs). Figure 3 shows a flow chart of the kind of ESS that we are building.

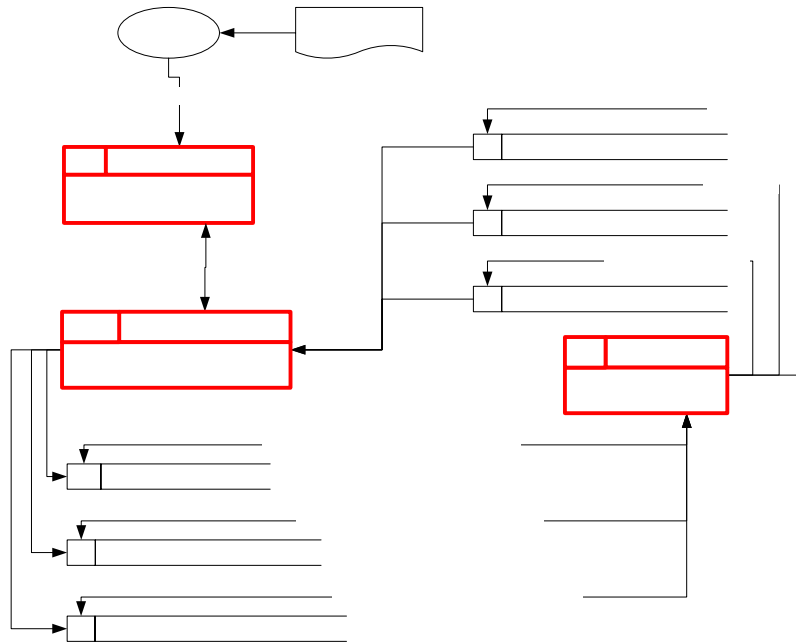


Figure 3: Data Flow Diagram of ESS

### 3. CONCLUSIONS AND FUTURE WORK

#### 3.1 Social Science (Policy) Cohort

This paper has suggested that opportunities exist for the increased employment of DG technologies in the utility system. Despite these opportunities, ominous risks appear for companies and individuals that seek to generate power largely for themselves. In many cases, it is understandable why DG has not yet seen greater penetration into the marketplace. However, some of those risks would diminish if government policy recognized better the subsidies it offers to conventional fuel users and made companies pay for the significant external costs they impose on society. Such a policy may be difficult to pursue for political and economic reasons. Still, policy should then provide incentives for DG enterprises to recognize the real, but difficult-to-quantify benefits to society overall, such as increased reliability, heightened security for the grid, and reduced (or stabilized) transmission costs.

Future work will focus on the historical, cultural, and institutional impediments to implementing policies that advance DG technologies. In particular, researchers will examine popular conceptions of electric power technology (using information also provided by the

consumer research group) to understand why opposition exists to small-scale but often-visible technologies that would otherwise fit nicely into a DG system paradigm.

#### 3.2. Consumer Affairs Cohort

Educating consumers about DG technologies appears to remain a formidable task. Even when the consumer affairs cohort surveyed professional educators who had voluntarily listened to a presentation on DG technologies, they found a remarkable lack of understanding about operations and potential benefits of the new hardware. After discussing the results of this test with other members of our multidisciplinary group, the consumer affairs members decided it is not possible to educate consumers about DG in such a way (i.e., in a short enough time) that reasonable, unbiased results would accrue. The consumer affairs group therefore concluded that it would be more useful to document consumers' existing knowledge and concern about the electric system and its security. Currently, the consumer cohort is developing a research plan and supporting instruments so that a consumer survey can be conducted in spring 2006. The results of the survey would help the policy group in particular as it tries to identify and overcome impediments to the use of DG technologies.

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### 3.2 Business/Education Cohort

The fields of energy engineering, management and policy are burgeoning with the challenges of new technologies, business models, and regulatory changes. Education of future professionals in the energy economy will require intensive exposure to realistic problems and decisions that the future holds. The breadth of this exposure, as is indicated by our hierarchical list of decision problems, is extensive enough to require ESS packages of widely varying scopes—from decision models for multi-year

horizons to models for hourly and minute-by-minute horizons. The packages must also be able to subsume decision models for broad public-policy regulations and massive capital investments to models for control of small distributed generation units. To date, there are several versions of simulation packages for modeling power systems. Each of these packages was designed for specific purposes and exhibits particular strengths as Table 1 indicates. We conclude that more simulation-based ESS packages are needed.

Package Name	Creator/Vendor	Scope	Key Features	Applications
VTGIS/EGMS	Virginia Tech	Distribution grids & distributed generation	Interfaced with ESRI's ARCGIS package	Future application in university courses in electrical engineering, business, public policy
GE Maps	General Electric	Regional grids	LMP computation, transmission constraints	Bid strategy, unit commitment, market studies, economic analysis
Aurora	EPIS, Inc.	Regional grids	Nodal and zonal LMP computation, transmission constraints	Power flow computation; valuation of generation & transmission assets, FTRs, LTCs
SimRen	ISUSI	Multi-region grids	Dispatches wind, solar, cogen as well as conventional generation	Generation technology selection, installed capacity planning
EMCAS	CEEESA	Adaptive systems model of regional energy markets	Agent-based modeling and simulation	Electricity trading strategies, economic analysis
STEMS	EPRI	Short-term markets	Agent-based modeling and simulation	Energy market design, trading strategies

Table 1: Comparison of simulation packages

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## BIOGRAPHIES AND CONTACT INFORMATION

Our research team consists of members of the Virginia Tech Consortium on Energy Restructuring, a group consisting of faculty members and graduate students working in six departments.

Representing the public policy cohort of the team, Dr. Hirsh has worked on the utility system for more than two decades and has published two books on the subject. Dr. Badinelli, the leader of the business cohort, performs research in the area of analyzing and optimizing complex business decision models. Dr. Leech, a consumer educator, is active in public policy and serves as President of the Consumer Federation of America and President of the Virginia Citizens Consumer Council. Dr. Emmel has worked on energy education grants and leads a statewide Energy Star education program. Drs. Centeno a member of the engineering cohort, helped develop the first prototype of the phasor measurement unit currently used by utilities and industry. Dr. De La Ree chairs the C-10 working group that deals with the effects of deregulation and the prevailing grid's protection systems. Dr. Wang is a member of the Center for Power Electronics Systems (CPES), one of approximately twenty NSF Engineering Research Centers in the nation and the only one focused on research in power electronics. Michael Gregg, an engineering educator, runs Virginia Tech's Green Engineering program.

Members of the group can be reached at the following addresses:

Ralph Badinelli	<a href="mailto:ralphb@vt.edu">ralphb@vt.edu</a>
Virgilio Centeno	<a href="mailto:virgilio@vt.edu">virgilio@vt.edu</a>
JoAnn Emmel	<a href="mailto:jemmel@vt.edu">jemmel@vt.edu</a>
Mike Gregg	<a href="mailto:greggmh@vt.edu">greggmh@vt.edu</a>
Richard Hirsh	<a href="mailto:rhirsh@vt.edu">rhirsh@vt.edu</a>
Irene Leech	<a href="mailto:ileech@vt.edu">ileech@vt.edu</a>
Jaime de la Ree	<a href="mailto:jreelopes@vt.edu">jreelopes@vt.edu</a>
Fred Wang	<a href="mailto:wangfred@vt.edu">wangfred@vt.edu</a>

**Graduate Student Assistants**

Benjamin Sovacool—Program in Science and  
Technology Studies

Jia Ru – Department of Business Information Technology

Boonyarit Intiyot, Chinmay Joshi, Rohan D’Souza —  
Department of Industrial and Systems Engineering

Tim Thacker—Center for Power Electronics Systems in  
the Department of Electrical and Computer  
Engineering

Regina Goods—Department of Apparel, Housing and  
Resource Management

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