# The Grid Intelligent Planning Framework: Planning Electric Utility Investments in a Time of Accelerating Change

Geoff Ryder, Fatimah Shahid, and Sui Yan

SAP Labs LLC, 3412 Hillview Drive,
Palo Alto, CA 94304, USA
{geoff.ryder,fatimah.shahid,sui.yan}@sap.com

**Abstract.** Over the next ten years, electric power utilities will be required to invest billions of dollars to meet public policy goals for a greener, smarter electricity grid. Renewable generation portfolio standards, electric vehicle infrastructure, advanced metering infrastructure, and the replacement of aging grid assets are some of the factors driving these new investments. The Grid Intelligent Planning Framework using GridLAB-D is an advanced forecasting solution that allows utility business and engineering experts to collaborate on forecasting models, and thereby to reduce the time needed for a capital investment planning cycle. This solution facilitates wise and timely investment decisions as the pace of change accelerates in the electric power industry.

**Keywords:** energy management, forecasting, risk analysis, capital investment, collaboration, electric power utilities, visualization.

## 1 Introduction—Planning Roles and Responsibilities

Electric power utility companies face profound challenges as they modernize their operations for the demands of the 21st Century. Some challenges affect the industry on a world-wide scale, such as the imperative to respond to climate change [1]; and some are specific to particular regions, such as the need to replace aging equipment [2]. In response to these challenges, significant new capital investments in generation, transmission, and distribution-level infrastructure will be required [3]. To make good decisions, utility planners build models of their operations that allow the impacts of future investments to be simulated. In this environment, planners need to build high quality simulations quickly that lead to sound investment forecasts. Accompanying this, we see a need for new solutions that speed up the business process of creating quality simulations [4].

Here we describe a software solution called the Grid Intelligent Planning Framework, or "GridIntell", that has the potential to achieve faster results. The human-computer interaction components of the GridIntell project are currently under development, and the work presented here reflects early user experience research and prototype development.

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As an introduction to the subject, consider the roles and responsibilities involved in producing a capital investment forecast. Table 1 describes key roles we identified through market research and stakeholder interviews. From demographic research on each role, we discovered what collaboration patterns, tools, and experience levels were commonly required to build forecasts. The roles fall roughly into three functional teams: an economic team (data analysts, energy economists), an engineering team (power engineers), and a management or supervisory team (business analysts, senior planning engineers, and on up to C-level executives). We verified that the end-to-end process is typically led by a senior planning engineer, who articulates the goals for the three teams, guides them in their work, and presents investment options to executives based on the forecasting results.

**Table 1.** Responsibilities and selected pain points for participants in capital investment planning processes at utility companies

| **Title** | **Responsibility** | **Pain Points** |
| --- | --- | --- |
| Energy Economists | ·Select economic parameters for simulation models; quantify model risks | ·Key demographic information changes faster than the forecasting project cycle |
| Data Analysts | ·Collect economic data; enter parameters and run simulations to support forecasts | ·Lack of comprehensive and easy-to-use modeling tools |
| Power Engineers | ·Builds models; simulates and recommends grid infrastructure upgrades | ·Lack of comprehensive and easy-to-use modeling tools |
| Business Analysts | ·Incorporate forecasting results into planning recommendations for CEO/CFO | ·Lack of timely support for generating forecasts |
| Senior Planning Engineer | ·Manages economics and engineering teams who build simulation models, and forecasts | ·Difficult for teams to coordinate model updates given new information |
| CEO/CFO | ·Set and review company financial goals | ·Lack of evidence to support business decisions |

A common theme among the pain points we observed was an absence of comprehensive, collaborative models, forcing the teams to work independently, and to then throw their results "over the wall" to the next team. That process in turn led to the senior planning engineer's pain point—an inability to quickly coordinate comprehensive model updates given new information—and thus led to suboptimal forecasts for the management team to review. Further research revealed unexplored avenues for collaboration that could address these pain points, and which we will describe in the following sections. Our new approach provides members of the different teams more useful touch points across the entire forecasting process.

## 2 Value Proposition of the Grid Intelligent Planning Framework for Electric Power Utilities

In his 2010 paper analyzing a collection of large scale energy modeling scenarios, Keles discussed the fact that it is extremely difficult to judge their robustness [5]. They depend on such a large number of unknown input parameters—prices of fuel inputs, generation technology, health of grid assets, population growth, business activity, energy efficiency of appliances, consumer behavior—that there is a large degree of subjective choice involved in every scenario design. In this situation, he finds that the best forecasting scenarios are achieved when the designers debate the model assumptions, change the parameters frequently, and rerun the models many times.

**Value Proposition:** *The Grid Intelligent Planning (GridIntell) Framework facilitates frequent model updates, as well as close collaboration among experts from different domains, resulting in what we believe will be higher quality forecasts from better-designed scenarios in a shorter time.*

Fig. 1 illustrates the process. Here, a cross-functional planning team at a utility company has been tasked with developing forecasts that will drive future capital investment projects. The design of a forecasting scenario starts at the top left, as the economics team determines demographic and business trends that affect the future demand for electricity. After collecting the necessary data, the economists may use tools from statistical inference, such as hierarchical regression models, to estimate future demand. They may also run discrete event simulation models to estimate and verify properties of complex economic systems for which closed-form calculations are not practical.

Second, after the forecasted economic parameters are ready, the engineering team uses them to guide their models of the utility's power grid assets. New economic parameters lead to an altered distribution of electric loads around the service territory, and the engineers develop physical models of the grid to predict where new investments in equipment are needed. Technical software—only accessible to specialists—is used in this step to compute quantities such as the real-time power flow through simulations of the grid (see [3], [6]).

Third, the combined economic and engineering results are turned over to a managerial decision maker to analyze. New investment needs suggested during the planning process must be reconciled with budget and regulatory constraints. While we expect the economics and engineering teams to try to take the constraints into account in advance, the scope of needed investments in future years will likely be so large as to cause constraint violations. The response at this step—to push for larger capital budgets, for regulatory changes, or for better options from the economics and engineering teams—must come from a management perspective.

We describe the serial progression through these three steps as a **long cycle**, and this could take days, weeks, months, or even years depending on the scope of the planning effort. Each functional team must finish before allowing the next team to begin work. In contrast, consider the best planning process suggested by Keles, with open collaboration, debates on the validity of assumptions, and frequent model updates. We describe this as a **short cycle**—it may well describe the patterns of work that occur *within* each functional team among collegial experts in the same domain.

Is it possible to achieve greater productivity by transforming the long cycle into a short cycle? In some cases, we believe the answer is yes. One sweep through the long cycle is probably required to collect data and establish a baseline for planning scenarios. But if management determines that adjustments to the baseline plan are needed, *the GridIntell framework enables collaboration in the manner of the short cycle to make the adjustments quickly*—thus avoiding multiple traversals of the long cycle.

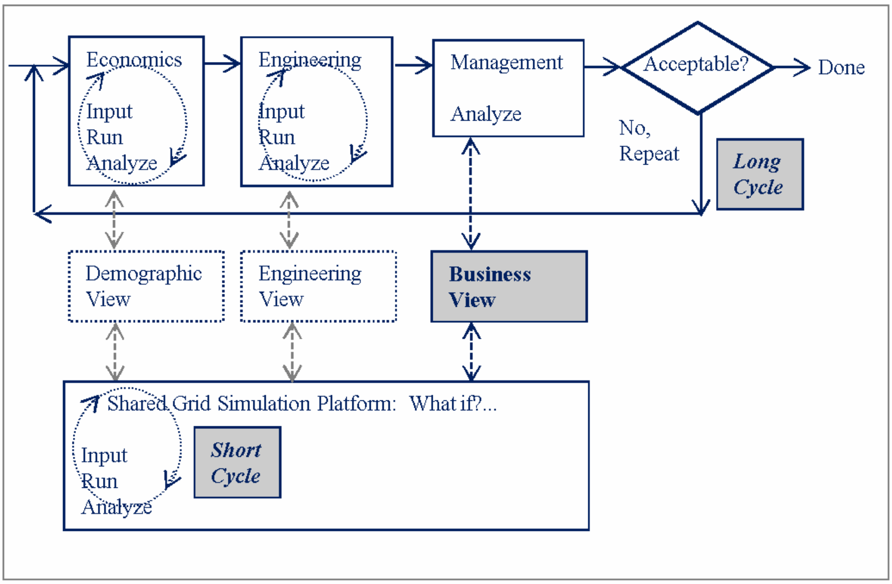


**Fig. 1.** The process of building accurate grid simulations involves multiple kinds of functional expertise. Here is a simplified example showing three types of contributors: economists, engineers, and managerial decision makers. The serial path through all functional domains can take significant time, which becomes a problem when the entire process must be repeated to answer new questions or fix faulty assumptions. The GridIntell framework allows some kinds of repeated analysis to move from the long cycle to the short cycle.

## 3 Implementing the GridIntell Framework

GridIntell provides two process elements to enable short cycle-style planning. The first is a set of graphical user interfaces shown in Fig. 1 as the Demographic View for economists, the Engineering View for engineers, and the Business View for managers. The second is the Shared Grid Simulation Platform, that can rerun scenarios as desired from any of the GUI views.

Each view offers a different set of parameters for a user to vary, and reports different key performance indicators (KPIs) to the user once a simulation is run. Table 2 gives some examples. The engineering team for instance seeks to determine if the quality of electric service will be reduced due to overutilization, and observes values for KPIs such as the Cumulative Average Interruption Duration Index (CAIDI) for simulated neighborhoods. Managers focus more on financial KPIs. The impacts of the economists' data are measured in the Engineering and Business Views, so economists can access KPIs from those views.

**Table 2.** Examples of how the three different views interact with the Shared Grid Simulation Platform of Figure 1

| View | Modeling Topic | KPI Output Example |
|---|---|---|
| Demographic | Electric vehicle adoption rate | -- |
| Demographic | Population and business growth | -- |
| Engineering | Utilization of grid assets | Transformer utilization rate |
| Engineering | Stress on grid assets, blackouts | CAIDI |
| Business | Capital expenditures | CAPEX per kWh |
| Business | Revenue from operations | Revenue per kWh |

In fact, we limit the scope of each view mainly to reduce complexity for the user, and not prevent access to results—we include menu options in each view to access all KPIs across all views. Depending on how the workflow is defined, we may not share privileges for uploading all types of data into the shared simulator. For instance, only users permitted to login to the Engineering View should be allowed to upload power engineering models into the Shared Grid Simulation Platform.

Fig. 2 shows how the four major software components of the Shared Grid Simulation Platform work together to simulate a model. A user logged into any one of the three GUI views may run simulations, though again the parameters they are allowed to vary will depend on the view. Once the run command is given, an On Demand Scenario Builder compiles a simulation source file. Data for this file may come from critical enterprise databases—customer relationship management (CRM), geographic information systems (GIS), enterprise asset management (EAM), weather databases, and predesigned scenario templates that define how to instantiate entities within simulations.

Note that these templates in turn must be designed by experts, and that design work is part of the long baseline planning cycle. The GridIntell framework envisions template-building tools in the Demographic View and Engineering View, but we will defer the discussion of those aspects to future papers.

After the source file is compiled, the Scenario Builder submits it to the Simulation Executive to be run. When the run finishes, business intelligence (BI) analysis tools format raw output data, run additional statistical algorithms, and present visualizations of KPI trends to the GUI, completing the short cycle.

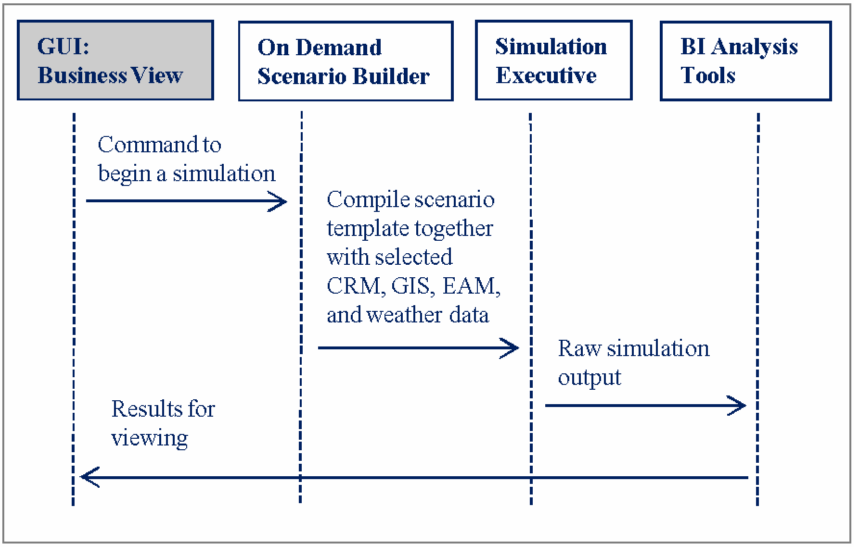


**Fig. 2.** The GridIntell solution framework contains four types of software. The user interacts with a graphical user interface—here we chose the Business View from Figure 1. After entering necessary configuration settings, the user hits "run", and the succeeding elements execute in turn to provide simulation results.

## 4 GridLAB-D as the Simulation Executive

At this point we have defined the GridIntell Framework such that users with different types of expertise may collaborate on a shared model—and this framework may conceptually achieve the value proposition of better and faster forecasts. It should be noted that three of the four categories of components in Fig. 2 have common implementations. For example, the GUI may be a browser application; the On Demand Scenario Builder could be a program written in a scientific scripting language; and there are many options for the BI Analysis Tool, from spreadsheets to more powerful enterprise software.

However, the Simulation Executive component is unique—it must be comprehensive enough to run models of interest to users of all three views. In our research we determined that an open source power system simulator from Pacific Northwest National Labs named GridLAB-D has the requisite functionality to fulfill this role (see e.g. [3],[7],[8],[9]). Table 3 lists some of its features.

For use within GridIntell, two characteristics of GridLAB-D stand out: it runs discrete-event models, essential to some types of economic modeling; and it computes the physical state of the grid using power flow solvers, which is essential to engineering calculations. It is not used primarily as a statistical calculator for methods such as regression analysis, but such features are commonly available in BI analysis tools, and so the fourth component of Fig. 2 can take care of those other modeling requests.

To illustrate how electric power utilities may use the simulation power provided by GridLAB-D to develop forecasts, we posit a hypothetical full-service California utility company called CalPower. The CEO of CalPower delegates to a planning team the mission of building forecasts of necessary generation capacity and multi-year investment plans. The team members are modeled after the user roles described in the Introduction.

**Table 3.** Selected properties of the GridLAB-D power system simulator

| Property | Specification |
|---|---|
| Type | Agent-based discrete event simulator |
| Economic models | Retail power market models |
| Engineering models | Choice of power flow solvers, climate models, library of generation, transmission, and distribution objects |
| Connectivity features | Weather files, event definition files, connectivity to common databases |

We consider a scenario based on California Executive Order S-21-09, which defines a Renewable Power Standard (RPS) mandating that by 2020 at least 33% of all electrical power delivered comes from solar, wind, geothermal, biomass or small-scale hydroelectric sources [10]. CalPower currently has achieved a 15% RPS. With the 33% RPS goal—as well as other goals such as reducing carbon dioxide emissions and meeting extra power demand from new electrical vehicles—the team at CalPower begins a new planning cycle to investigate solutions. The team uses the GridIntell framework to simulate the changes that will happen to the power grid between year 2011 and year 2020.

Through GridIntell, the planning team has uploaded scenario data such as CalPower's current generation portfolio, infrastructure and load models, market trend forecasts, and weather data. They also enter investment plan options that they can later evaluate according to KPI forecasting results provided by the simulation engine. Users with different expertise collaborate on these inputs within the GridIntell Framework. For example, the economists contribute market trend data and investment strategies, while the power engineers model the infrastructure and load at high resolution. Based on this collaborative work, the team built three investment strategies to compare: Plan A and B respectively emphasize wind and solar, while Plan C is more balanced between wind, solar, and biomass technologies.

With these input data, GridIntell generates KPI forecast values that describe the benefits and risks of each investment plan. The planning team will be able to summarize the findings similar to Table 4. Note that each plan has its own advantages and disadvantages due to its technology portfolio. For example, wind and solar are more unpredictable than biomass generation, but do not produce carbon dioxide ([11], [12]).

The simulation results not only help the planning team compare investment strategies, but also allow deep dive into the forecasting numbers to gain insights into the future. For example in Fig. 3, an analyst user drills down into a certain simulated year to observe the daily renewable energy generation pattern.

**Table 4.** The GridIntell simulation result allows the user to compare KPIs across different investment plans. Plan A and B are subject to high exception risks because wind and solar technologies are volatile and difficult to predict. Plan C is more steady thanks to the balanced portfolio, but is "dirtier" than Plan A and B because of its higher usage of biomass technology.

| Plan | Advantage | Disadvantage |
|---|---|---|
| A, wind focus | Lowest total cost | Lower service reliability |
| B, solar focus | Lowest OPEX | Lower service reliability |
| C, biomass focus | Lowest CAPEX, highest reliability | Highest CO2 emissions |

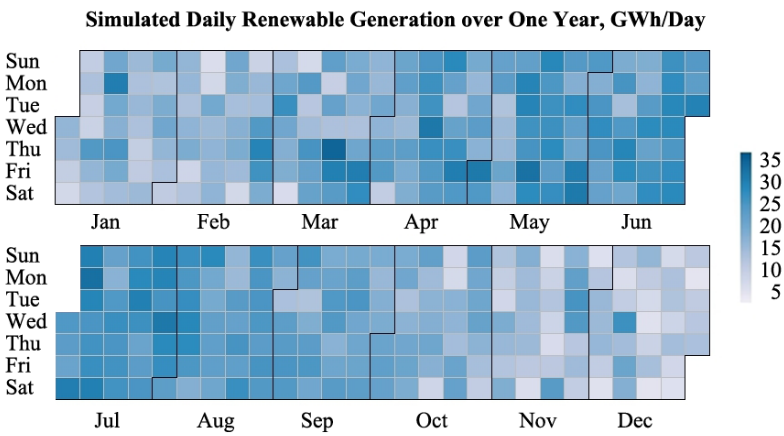


**Fig. 3.** As part of the RPS planning scenario, the user can obtain visualizations of renewable power generation totals over time. Here we show renewable energy production and use each day over the course of a simulated year. Two properties of the data stand out: there is considerable variation in the power output from day to day, and peak renewable generation in this region occurs in the summer. In the GridIntell framework, GUI users may also drill down by clicking on a day and observing higher time resolution trends that affect each diurnal power cycle.

## 5 GridIntell User Experience Validation Research Plan

The GridIntell Framework is currently a research project, and so is considered to be in the *conceptual phase* from the perspective of our user experience designers [13]. Based on our preliminary research, we have developed as phase two of the project a robust user experience validation plan that ensures GridIntell will meet the needs of utility planning teams. Key topics from this plan are shown in Table 5.

The conceptual phase provides an opportune time to organize information architecture and gauge future usability issues. In parallel with the user buy-in stage we just completed, user research obtained customer participation in future phase two user experience methods. The customer buy-in for both the solution and acting as customer innovation partners has provided us the foundation for phase two research.

**Table 5.** Areas for future User Experience (UX) validation research on GridIntell

| Research Topic |
|---|
| 1. Build detailed models of the critical work flows for each role in Table 1. |
| 2. Enumerate reasons that planning teams repeat the long cycle (Fig. 1). |
| 3. Determine what artifacts are used to justify decisions. |
| 4. Further explore how GridLAB-D functionality complements existing tools. |
| 5. Evaluate the confidence of planners in existing forecasting methods. |
| 6. Validate that the GridIntell framework improves timeliness and accuracy of forecasts. |

Our research plan is informed by recent works in the collaborative design space—from lessons learned, to methodology for design. Hupfer et al. have developed a series of collaborative design guidelines to aid in the development of solutions with a collaborative component [14]. Some approaches we use include:

- *In-depth interviews*, a semi-structured open-ended interview with questions centered on specific themes: tools, work flows, collaboration points. Audio and text transcriptions are gathered to develop user profiles.
- *Site visits*, to observe users collaborating in familiar surroundings, and convene focus groups of users [15]. Notes from these visits help us build affinity diagrams that inform UX scenario design tasks.
- *Cognitive walkthroughs* to validate initial low-fidelity mockups from the user interface design team [16].

Bedekar and Kennedy [17] illustrate the importance of user research for achieving sustainability goals, and show that an important opportunity for energy management solutions lies in revealing unknown processes to lay a foundation for new and innovation collaborations. Our user research plan seeks to reveal these unknowns and allow us to fulfill GridIntell's value proposition.

## 6 Conclusion

In this paper, we propose the GridIntell Framework with three key attributes that support improved capital investment planning forecasts for electric power utilities. First, it provides a collaborative workbench for efficient cooperation between experts in different domains that are vital to the planning process. Second, it provides comprehensive grid performance modeling and forecasting capabilities with the integration of GridLAB-D, a powerful discrete event simulation engine. Third, it offers a superior user experience with easy-to-use yet powerful visual analytics that reduce learning curves, improve individual productivity, and drive valuable business insights. We propose to build on our research and prototype development here with new user experience validation studies based on sound principles of collaborative design research.

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