# Integrated Generation and Transmission Planning Tools under Competitive Energy Markets: An Academic Perspective

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***Abstract*— This paper first briefly reviews the typical functionality and structure of market-based generation and transmission planning tools. Possible new functions are discussed to include bidding strategy models and system dynamics models. The former is used to reflect the behavior and the learning process of market participants and the latter represents an information feedback loop to account for long term impact of decisions. Improvements in algorithms and implementation are discussed. The discussion includes AC versus DC model, engineering model versus statistical model, Monte Carlo simulation for reliability, and distributed implementation.**

***Index Terms*—integrated generation and transmission planning, software tool, power markets, optimization.**

## I. Introduction

THE ongoing electricity deregulation has presented great challenges to power system planners. With the elimination of institutional boundaries, independent power providers have more freedom than ever to build generation resources at locations based on their own decisions. This causes new flow patterns and possible new transmission bottlenecks. Meanwhile, continuously growing load and shortage of transmission investment has resulted in costly transmission congestion. Hence, generation and transmission expansion under the present market structure has created increasing concerns for system reliability throughout various regions of the U.S. power system.

Based on this need, commercial software vendors have developed planning tools for generation and transmission expansion based on locational marginal pricing (LMP) markets. These tools include but are not limited to ABB GridView™ [1], GE MAPS™ [2], LCG UPLAN [3], Promod® IV [4], and Siemens PTI PSS™ LMP [5]. Certainly, each tool has its unique features and advantages but there are many fundamental similarities among the commercial tools.

This paper presents some discussion about market-based integrated generation and transmission (G&T) planning tools from an academic viewpoint. Possible new functionality and the improvement in implementation and solution algorithms will be the main topic of discussion. The paper is organized as follows. Section II discusses the typical functionality and structure of market simulators for G&T planning. Section III discusses the potential new functions to integrate into market simulation based G&T tools. Section IV discusses possible implementation and algorithm improvement. Section V concludes the discussion.

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## II. Functionality and Structure of Typical Market-based G&T Planning Tools

A typical integrated generation and transmission (G&T) planning tool for the competitive market, especially LMP based markets, should include the following features and models:

- generation cost model based on actual cost or bids,
- demand response and management,
- transmission system model including security constraints and nomogram constraints,
- HVDC and phase angle regulator model,
- bilateral contracts to model forward markets,
- financial transmission right to hedge price risk,
- pollutant model for environmental regulation impact,
- a chronological, typically hour by hour, security constrained unit commitment (SCUC) and security constrained economic dispatch (SCED) that are performed as a key function to simulate the actual market operation and to determine locational marginal price (LMP) at each bus,
- ancillary services including spinning, non-spinning, and supplemental reserves,
- reliability model in generation and transmission for risk-based analysis,
- coordination and interaction of short-term and long-term planning functionality,
- financial and accounting process to analyze the cost and benefit of a generation and/or transmission expansion project.

Fig. 1 summarizes the typical architecture of a market simulator based on information from [1].

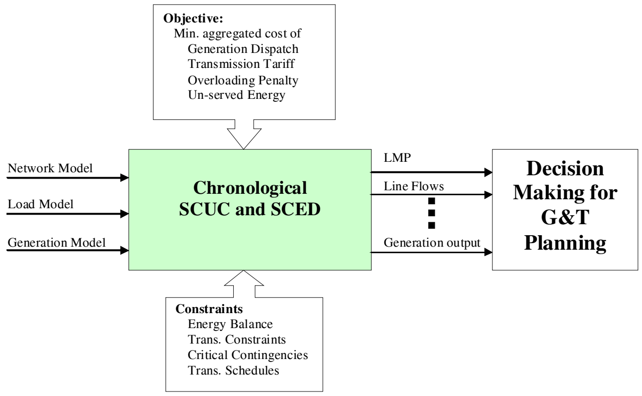


Fig. 1. A typical illustrative diagram of the structure of a market-based G&T planning tool.

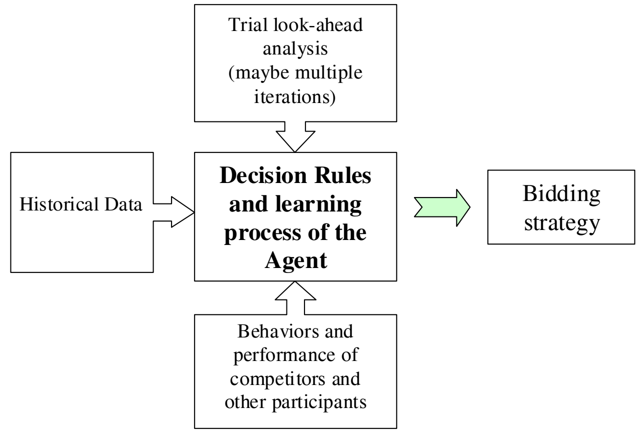


Fig. 2. Structure of an agent-based model for bidding strategy

## III. Potential New Functions to Integrate

This section discusses the potential challenges in market-based G&T planning tools from the viewpoint of possible new functions.

### *A. Bidding Strategy*

Bidding strategy represents the behavior of market participants to probe the market trend and adjust their biddings based on their judgment on how to maximize profit. For the present and near future, generation companies (GENCOs) or other sellers are at an advantage because the elasticity of load is very low. Studying bidding strategies is mostly still in the research stage [6-7]. In most commercial market simulation tools, the generation costs or historical bids are used to estimate future generation bids. This does not accurately reflect practical bidding and volatility in markets.

If the bidding strategy is included, typically an agent-based simulation model is needed. An agent is an autonomous and adaptive software module that can perform certain tasks upon request and ideally has learning capability. In market simulation tools, agents can be implemented to represent the learning and decision-making process for market participants in reaching long-term bilateral contracts or biddings at the day-ahead market and hourly-ahead market. Actual implementation may include a learning process modeled with intelligent approaches. Inputs to agents may include the past overall market signals in the long-run and competitors' behaviors in the short-run. Results of a few trial look-ahead simulation runs are also possible inputs to decision-making process. An example is shown in Figure 2.

An agent model can be integrated into the market simulation tool either as single or multiple scenarios. In a single scenario, for each simulated hour, the generation behavior will be determined as a typical or average case and the results will be deterministic. In a multiple scenarios, the bidding behavior can be modeled as different strategies with different probability levels. Hence, for each simulated hour, multiple cases are performed. Certainly, the actual implementation can be done in various different approaches.

### *B. System Dynamics Model*

Presently, many market-based generation and transmission planning tasks are performed based on fixed typical scenario studies without studying the impact of a planning decision. For example, when a transmission expansion is needed from the viewpoint of a transmission company (TRANSCO) or a generation plant is desired for a generation investor, it is performed in a two-stage study. In the first stage, a few options may be identified based on engineering judgment with some preliminary studies like power flow, stability, short circuit, and so on. Then, these options are input into a market simulation tool to evaluate the possible economic benefit. The one with the highest economic return would typically be selected as the final project plan. This approach does not allow for an integrated process which considers how a decision changes the environment in which one operates.

In forming competitive electric markets, the originally vertically-integrated and centralized electric industry has been restructured to a non-integrated and decentralized industry. Fig. 3 and Fig. 4 show the structural changes brought by restructuring. Before restructuring, the planning process included only the regulators and utilities, which can be fully overseen, but today the planning process includes the regulators, various market players and other interested parties. These inter-relationships cannot be centrally managed. Under this change, the traditional generation and transmission planning centralized decision framework is no longer adequate. As such, the planning process must move to a more decentralized structure. Moreover, the traditional strict physical models alone do not fully capture this complicated process. The system dynamics (SD) approach provides one method to address these complexities [8].

A SD model can include the simple models of the decisions made by the various market players. Based on simulations over the planning horizon, the effects of these uncertainties on generation and transmission planning can be observed [9]. As illustrated in Fig. 5, the model is closed-loop so that any decision impacts future decisions.

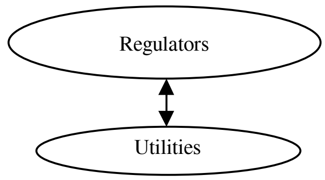


Fig. 3. Integrated structure before restructuring

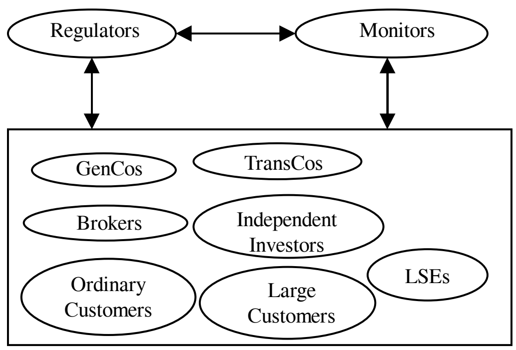


Fig. 4. The Decentralized structure after restructuring

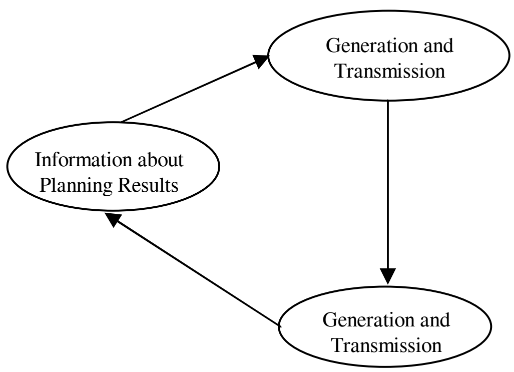


Fig. 5. Dynamic planning process

Broadly speaking, SD modeling follows these steps:

1) Simplify the original detailed system;
2) Collect and match actual system data for the simplified system;
3) Build the SD model;
4) Validate the SD model;
5) Simulate the SD model under different scenarios or policies;
6) Analyze simulation results.

## IV. Potential Improvement in Algorithms and Implementations

This section discusses the potential challenges in market-based G&T planning tools from the viewpoint of improvement in algorithm and implementation techniques.

### A. DC model versus AC model

Presently, main stream market simulators are based on a chronological simulation considering generation bids, load forecast, and transmission/security constraints. In each simulated hour, a security constrained optimal power flow (SCOPF) is performed. The solution is commonly achieved through linear programming (LP), which is based on linearized DC model. The advantage is the execution speed and the guarantee of solution. Also, it is easy to model transmission/security constraints. However, the DC linearization leads to solution inaccuracy. For long-term planning, this disadvantage may be justified by the advantages of speed and efficiency. But for short-term operation planning that needs higher accuracy, this linearization may not be adequate.

Non-linear programming (NLP) can be employed for solving a full AC optimization model, which models transmission network more accurately without ignoring the reactive component and voltage profile. Compared with the DC optimization model, the AC-based model is slower and more difficult to solve; however, higher accuracy can be achieved if initial parameters are tuned to ensure convergence. In addition, the AC model may be coupled with integer variables to reflect unit commitment. The resulting formulation as a Mixed Integer Non-Linear Programming (MINLP) is certainly more complicated to solve but modern techniques based on branch and bound are highly efficient.

Although some market simulators claim AC-based optimization model, current research shows significant computational problems [10]. A trade-off between accuracy and speed may be achieved using approximations, such as those proposed in [11].

### B. Engineering model versus statistical model

Chronological simulation is typically based on the inclusion of network model. It is also referred to as structural model or engineering model. Some research works have also been performed from the statistical viewpoint. This typically ignores network constraints. Hence, the OPF with detailed security constraints is not necessary. This is done by using historical data (load, generation, and planned network outage) and prices to train intelligent agents such as artificial neural networks [12] or to develop some representative rules to predict future market prices. This is a possible direction for future exploration in the commercial market simulators for generation and transmission planning.

### C. Improvement in Monte Carlo simulation for reliability

Power system reliability indices such as loss of load expectation (LOLE), loss of load probability (LOLP), and expected energy not served (EENS) are highly desired during the planning process to evaluate the possible risk of outages for a power system under market operation. Presently, the consideration of uncertainty remains a challenge in market simulators. The time-sequential Monte Carlo simulation can be added on top of market simulators to obtain reasonably accurate results of system reliability for a complex system with many uncertain variables like load variation, generation availability, and random transmission outages [13]. Considering the various operating conditions over say a year time span and the large numbers of equipment involved, accurate calculations for probability distributions may need millions (and probably more) of simulation runs. Clearly, this is not practical for any large system.

This has to be addressed by approximate models. For example, a limited number of representative system states may be sampled. This may include the states that one or more large generators experiencing simultaneous unplanned outages at different probability level. Under each scenario, transmission outages may be added on top of it using similar approaches. Load variation can be modeled at the upper layer of uncertainty to perform a chronological market simulation. Although this will still lead to a large amount of simulation, it should tremendously reduce the simulation relative to a complete chronological Monte Carlo simulation. There are some other research works such as in [14] that proposed pseudo-sequential Monte Carlo simulation. The possibility of looking at extreme or boundary solutions has also been proposed [15]. These research ideas can be potentially included in the future development of generation and transmission planning tools.

### *D. Distributed implementation to improve performance*

The other possible challenge is to implement market simulators in a distributed computing paradigm. With the development of distributed computing, today it is much easier for software application developers to create a networked computing environment as a low-end parallel computer. Some software languages/tools such as Java provide high-level abstraction for developers to create virtually connected distributed processors. The Java system handles the underlying communication of different processors such that developers can concentrate on power system application development. Fig. 6 shows a typical scheme of a distributed computing environment, where a central controlling processor performs as the controller or coordinator while many workers (or actual processors) carry out some portion of the actual computation of the overall simulation task upon the request from the controller.

A direct application is to assist AC-based optimization solvers that may require a large amount of post-contingency AC power flow verification runs within each hourly simulation. Since these post-contingency power flows can be essentially parallelized, distributed computing can be utilized without a tremendous cost for software development and maintenance. Another application is for Monte Carlo simulation when multiple cases can be decoupled to be computationally independent. Hence, the simulation can be easily distributed to different processors. The results from each processor are collected by the central controller for statistical accounting.

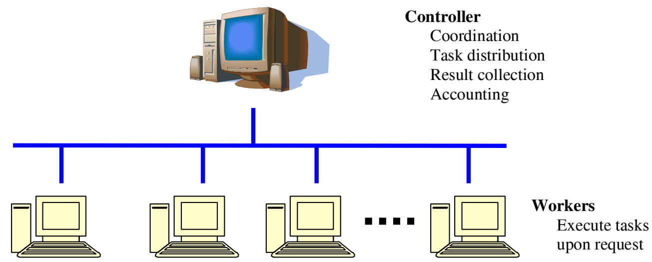


Fig. 6. Distributed computing scheme.

## V. Conclusions

This paper first briefly reviews the typical structure of market-based generation and transmission (G&T) planning tools. Possible new functions and improvement in algorithms and implementation are discussed. Some recent research works related to market simulation are identified for potential integration into commercial market-based G&T planning tools.

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## VII. Biographies

**Fangxing (Fran) Li** (M'01, SM'05) received his BSEE and MSEE degrees from Southeast University (China) in 1994 and 1997, respectively, and then his Ph.D. degree from Virginia Tech in 2001. He has been an Assistant Professor at The University of Tennessee (UT), Knoxville, TN, USA, since August 2005. Prior to joining UT, he was a principal R&D engineer at ABB Electrical System Consulting (ESC). His current interests include energy market, reactive power, distributed energy resources, distribution systems, reliability, and computer applications. Dr. Li is a registered Professional Engineer (PE) in the state of North Carolina.

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**Kevin Tomsovic** (F'07) received the B.S. degree in electrical engineering from Michigan Technological University, Houghton, in 1982 and the M.S. and Ph.D. degrees in electrical engineering from the University of Washington, Seattle, in 1984 and 1987, respectively. Currently, he is Head and CTI Professor of the Department of Electrical Engineering and Computer Science at University of Tennessee, Knoxville. Visiting University positions have included Boston University, Boston, MA; National Cheng Kung University, Tainan, R.O.C.; National Sun Yat-Sen University, Kaohsiung, Taiwan, R.O.C.; and the Royal Institute of Technology, Stockholm, Sweden. He was on the faculty of Washington State University from 1992-2008. He held the Advanced Technology for Electrical Energy Chair at Kumamoto University, Kumamoto, Japan, from 1999 to 2000 and was an NSF program director in the ECS division from 2004 to 2006.