

Market Feedback for Bounding Future Uncertainties in Power System Planning

A. Dimitrovski and K. Tomsovic¹

Abstract— *With the introduction of electricity markets, it has become clear that power system planning must be considered a dynamic process, particularly with regards to understanding investor behavior given incentives to build new transmission lines and power plants. The authors have recently introduced a hybrid approach combining system dynamics modeling with the more traditional power system planning. In this paper, we focus on one aspect of this larger body of work, namely, the importance of uncertainty and its impact on investor decisions.*

Index Terms— *Boundary load flow, Fuzzy sets, Interval methods, Power system planning, Risk behavior, Uncertainty modeling*

I. INTRODUCTION

FROM perhaps the beginning of power system planning, it has been recognized that long term planning entails a great amount of uncertainty about future conditions. The earliest attempts to address the uncertainties focused on analyzing typical scenarios. Such scenario analysis remains the foundation of power system planning at most utilities today. Probabilistic techniques, such as, probabilistic load flow [1], and sensitivity methods [2], were introduced many years ago. While these are an important step forward in terms of complexity, they have not been widely adopted in practice. Part of the difficulty arises from determining appropriate parameters for probabilistic models. In fact, the problem may be more fundamental since many of the uncertainties are not probabilistic in nature. Philosophically, probability assumes repeatable events and this is difficult to apply to future conditions 10 or 20 years in the future. Both sensitivity and probabilistic approaches suffer from separating the input uncertainty models from the decision-making process.

This vacuum has led researchers to introduce fuzzy sets, or interval methods, to approximate uncertainties [3] and incorporate expert decision-making. This has led to such interesting decision models as minimizing regret [4]. These types of approaches can be thought of as a generalization of sensitivity type calculations leading to a range of possible outputs based on a range of possible inputs coupled with criteria for choosing design options. The authors have developed a fundamental tool for fuzzy/interval analysis termed the boundary load flow (BLF) [5-7]. This tool allows

for determining a range of possible power flows given uncertainties in the nodal demands. Still, there are two major drawbacks in these fuzzy set approaches. Notably:

- Interval uncertainties tend to accumulate, so that, for large systems, or longer-term studies with greater uncertainties, the output intervals become so large as to be meaningless (if solutions can be found at all). The typical approach is to either reduce the uncertainties to narrower intervals or to relegate the uncertainties to specific subsystems.
- Future conditions are assumed a priori and do not account for the more practical considerations of how those conditions will evolve over time. For example, if one assumes a relatively small number of generators will come on-line while at the same time load growth remains strong, it is clear the system reliability will decrease. Still in practice, when such conditions develop, it is likely that various remedial measures or new plans will be put in place to address the reliability. Thus, the more extreme conditions will not arise.

We take our inspiration for this work from natural systems. It is well known, in studies of ecosystems, financial markets and control theory, that feedback can act to limit future uncertainties [8]. So, for example, one can predict future species populations in a relatively narrow range given that in a limited habitat large populations will reduce survival rates. These modeling studies are often performed using techniques from the field of “system dynamics” [9]. This is a top-down modeling approach where the emphasis is on including the relevant inputs and understanding the overall system behavior rather than the detailed understanding of the subsystems.

With the introduction of electricity markets, it has become clear that the power system planning must be considered a dynamic process, particularly with regards to understanding investments in new transmission lines and power plants [10]. The authors have recently introduced a hybrid approach combining system dynamics modeling with the more traditional power system planning [11]. In this paper, we focus on one aspect of this larger body of work, namely, the importance of uncertainty and its impact on investors.

II. BACKGROUND

This section briefly summarizes the modeling approach in our overall studies. The initial wholesale market model was constructed to help one understand if power plant construction would appear in waves of boom and bust. Such boom/bust patterns arise commonly in industries from commercial real-

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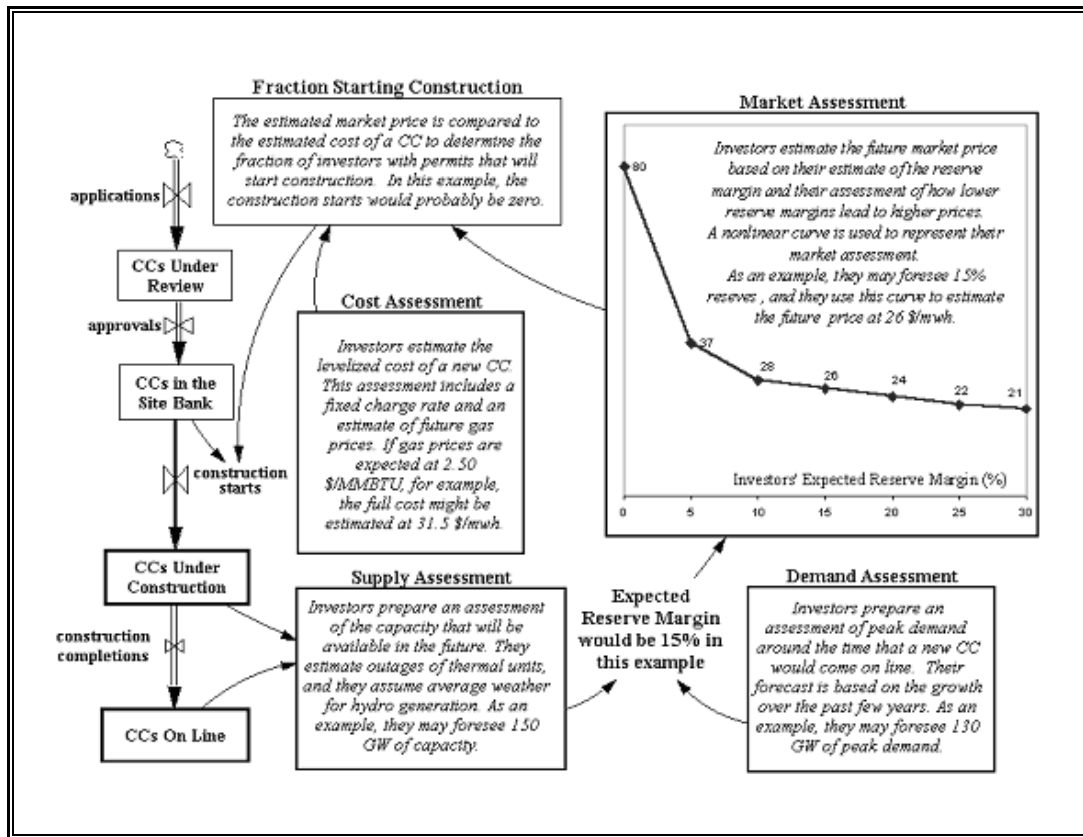


Figure 1. A simple model of construction of CC power plants [12].

estate to commodities. The salient feature tends to be wherever markets face long lead times to bring new capacity to market [10]. Historically, the construction of new power plants has also appeared in such waves and there is concerned that these will be exacerbated by deregulation. These cycles could be devastating due to dependence of the modern economy on a reliable electric supply.

Modeling the investment process for new generating capacity, includes the long delays for permitting and construction. Investors weigh the risks and rewards of investing in new plants, primarily gas-fired combined cycle (CC) capacity based on estimates of future market prices. The models have been tested on the Western Electric Coordinating Council (WECC) system and found to be successful in explaining the under-building that occurred in 1998-1999 and the over-building that appeared in 2000-2001 [10]. The boom and bust in this case arose from a combination of the delays in power plant construction and the limitations on investor's ability to anticipate the future trends in the wholesale market. The simple model of investor behavior as shown in Figure 1 is used. While the model is conceptually simple, simulations based on this model match historical data well.

In this paper, we focus on different perceptions of uncertainty from the point view of the investors in a power market. For this purpose, and to maintain simplicity, out of many possible uncertain parameters only one is assumed uncertain - demand growth rate. Demand uncertainty, in turn, makes future reserve margins and market prices uncertain. As

a result, profits are uncertain and investors face risky decisions. Investors' behavior when facing risky decisions is modeled according to the Utility Theory (for example, [13]). This theory states that there are three main types of risk profiles: risk-averse, risk-neutral and risk-taker. Figure 2 shows one possible model for risk-averse and risk-taking persons. What is important is the shape of the functions: concave for risk-averse and convex for risk-taker. The risk-neutral player is modeled as a straight-line in the utility vs. profit plane.

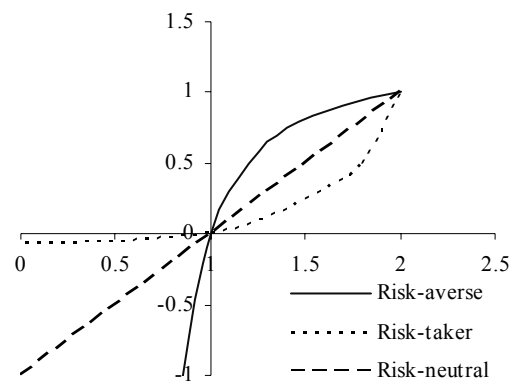


Figure 2. Risk profiles according to the Utility Theory

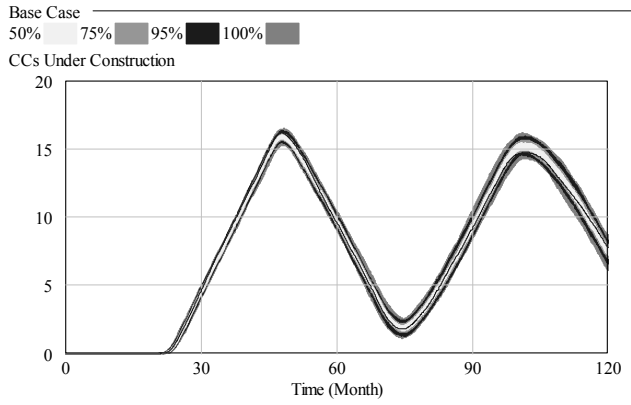


Figure 3. Continuously variable demand growth, investors are *risk-averse*

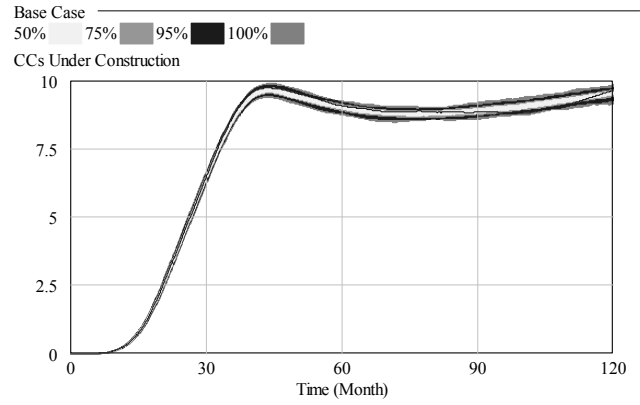


Figure 7. Continuously variable demand growth, investors are *risk-averse*

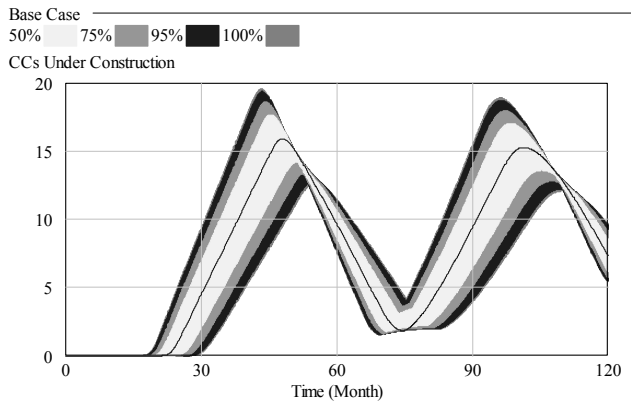


Figure 4. Discretely variable demand growth, investors are *risk-averse*

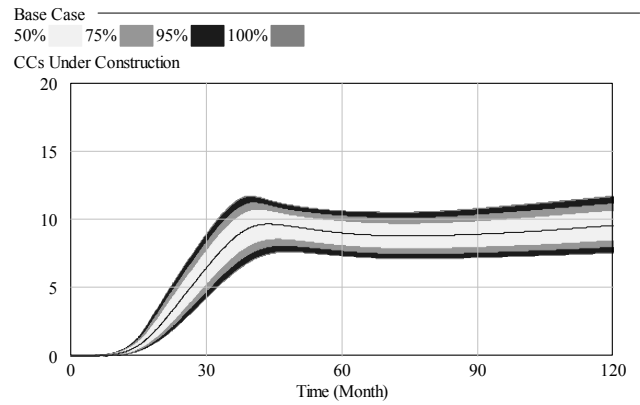


Figure 8. Discretely variable demand growth, investors are *risk-averse*

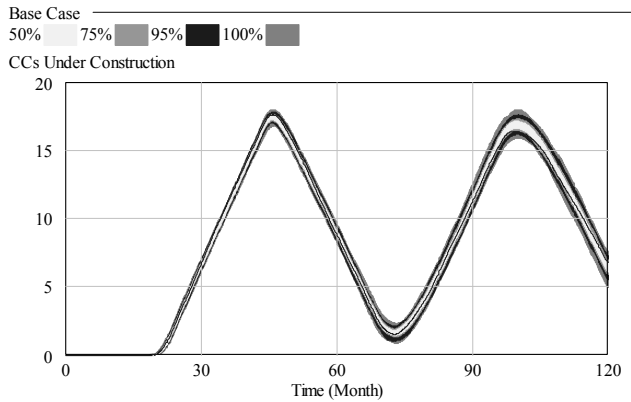


Figure 5. Continuously variable demand growth, investors are *risk-taking*

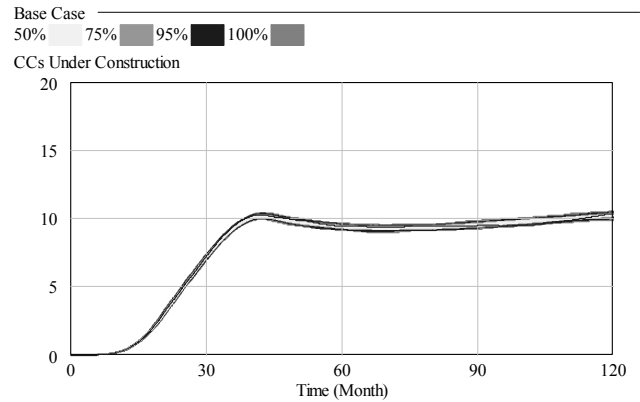


Figure 9. Continuously variable demand growth, investors are *risk-taking*

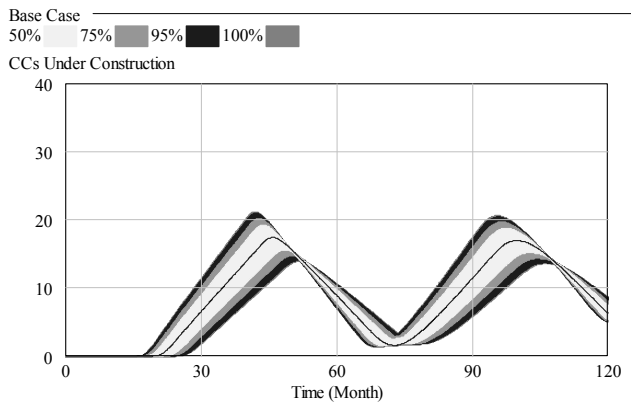


Figure 6. Discretely variable demand growth, investors are *risk-taking*

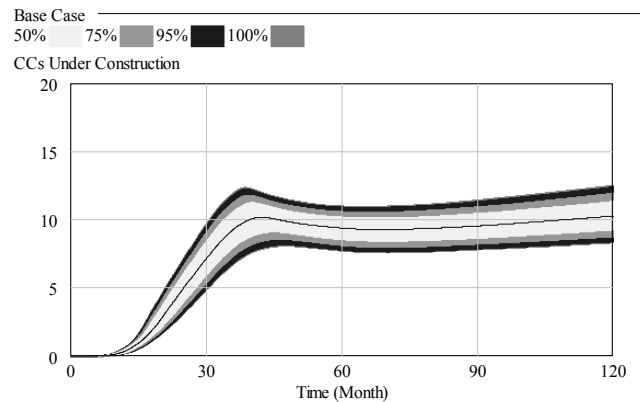


Figure 10. Discretely variable demand growth, investors are *risk-taking*

III. SIMULATION STUDY OF INVESTOR BEHAVIOR CONSIDERING UNCERTAINTIES

The model of investors' behavior under uncertainty from Figure 2 was integrated in the model of plant construction shown in Figure 1 and various simulations were performed. In the simulations, uncertainty was simulated in two different ways. First, it was assumed that the demand growth is a random variable with some distribution whose value changes during the course of each simulated run. That is, the demand growth is a continuous stochastic process. The simulations performed correspond to 'sequential simulations' used in reliability evaluations. Second, it was assumed that the random variable follows the same distribution from one simulation to another, but within a simulation run it remains constant. Thus, the demand growth is fixed in time although its realization is uncertain and follows the given distribution. This reminds of 'direct' ('non-sequential') simulations in reliability evaluations and is equivalent to sensitivity analysis.

Clearly, the sequential simulation is how a real power market will unfold. This is what careful investors should consider in their analyses. They may still speculate in different ways on future market conditions but they constantly readjust their position according to the past and current situation.

Figures 3-6 show the results of investors' decisions to construct new CC capacity. The results are given for the two different perceptions of uncertainty and two different risk profiles. The results from sequential simulations when all of the investors are risk-averse and risk-takers are shown in Figures 3 and 5, respectively. Figures 4 and 6 show the same results from non-sequential simulations.

In each case simulated, it was assumed that the demand growth rate follows uniform distribution in the interval from 2.5% to 3.5% annually. The resultant variable, the CC power plants under construction, follows a different, time-dependent distribution, which can be obtained numerically from a set of various percentiles. The results presented here show the boundaries at 50%, 75%, 90%, and 100% percentiles.

It can be seen from these figures that there is much more variation in the results, i.e. much more uncertainty, when development is considered statically. The graph 'strips' that show different percentiles are much broader for non-sequential simulations than those from sequential simulations, which include uncertainty in the dynamics. This, in turn, shows that a real market would inherently bound the uncertainties one would have to consider in power system planning.

Another interesting point is that the investors' risk profile does not affect the uncertainty as much as one may have expected. The levels of CC under construction do change, in this case the amplitudes of the cycles, but the breadth of the variation is very similar for the two extreme cases, when all of the investors are risk-averse or all are risk-takers.

Another interesting comparison, which may not be obvious at the first glance, is the time shift in the resultant pattern of behavior in non-sequential simulations. In other words, the variation is stretched across the time axis as well. In sequential simulations, investors perceive uncertainty dynamically and there is no time delay in their actions. As a result, the variation is across the y-axis only.

If some of the other parameters in the model are adjusted, then a fundamental change in the performance can be seen. For example, assume one, the leveled cost for a new CC plant is decreased from 32 \$/MWh to 28 \$/MWh, and two, the factor of accounted for plants concurrently in construction is increased from 50% to 100%. Under these conditions, the plant constructions no longer exhibit boom and bust cycles. Figures 7-10 repeat the earlier results for this situation. It can be seen that, although the pattern of behavior has changed, the same comments apply as from before.

IV. CONCLUSIONS

Power systems are both dynamic and uncertain in nature. Such is the process of power system planning. This paper focuses on one aspect of this complex problem, the impact of uncertainty on investor decisions in a restructured power market. Although market operations are a source of additional uncertainty in the system, this paper demonstrates that future uncertainties are bounded as a consequence of feedback. The investors take into account the past and current market conditions and make decisions accordingly.

When facing risky decisions investors take actions in line with their risk profile. Contrary to what may be expected, this paper also shows that risk-averse investors do not necessarily reduce uncertainty by their decisions, nor do risk-taking investors necessarily increase uncertainty. While they determine the overall level of activity, this tends to influence the expected value more so than the variance, which is the measure of uncertainty or risk.

V. ACKNOWLEDGMENTS

The authors would like to thank Prof. Andy Ford for his insights on uncertainty in dynamics systems.

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VII. BIOGRAPHIES

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