Determining Electricity Market Share with Chaos

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Abstract

Experimental economics and computerized market simulations can be important tools to explore the consequences of choosing various market rules of strategies used in a market. Much attention has been focused on the economic stability of a given set of market rules following the extreme prices in emerging markets seen in recent years. This research seeks to discover economically stable points of system operation generation and pricing. The role of randomness and chaos in these simulations will be explained and then utilized in a positive feedback model. This model is explained in detail, and is used to simulate a simplified deregulated power economy. With the random events recorded, the probability of certain solutions can be calculated. For each of these models, the triggering events can be studied and used to initiate actions proper for the conditions likely to follow. The effects of dynamic market equilibrium conditions are also investigated.

Key Words: Power Markets, Chaos Simulation, Positive Feedback

1. Introduction

For years power systems around the world were considered to be natural monopolies and were operated as such. While the capital-intensive electric infrastructure was being constructed, society was better off not duplicating transmission and distribution systems. Additionally the economies of scale gained by constructing larger plants made electricity production much cheaper. These economies of scale were possible because under monopolistic operation the utility was guaranteed the entire load in a particular area. With a completed electrical infrastructure in place, regulators seek the additional efficiencies that come with competition. Following "successful" deregulation efforts in the natural gas markets, airline industries, and telecommunications industries, the US has moved forward with efforts to deregulate electric power industry.

With deregulation comes increased competition. Open access allows new Generation Companies (GENCOs) and Energy Service Companies (ESCOs) to enter the market more easily than ever before. As in any competitive market, the market (formerly served entirely by one vertically integrated monopolistic utility) will be divided or shared among the participants.

To gain insight into market operation, much research has been done in modeling dynamic electricity markets. Computer models allow research to be conducted without losing millions of dollars in "real world" experiments. Many models of the economies and agent interactions in various industries have been developed, and many of the principles learned from studying other markets apply to power systems. However, in an electricity market additional restrictions related to the physical properties of electricity (e.g., $P_G = P_D$, power generated equals power demanded) must be considered. Some of these additional considerations are: requirements for minimum production levels, startup and shutdown costs, inherent economies of scale of certain technologies, and the most efficient production level of equipment [3]. In a competitive market, GENCOs strive to increase their profits (the positive difference between their selling price and their marginal cost). The consumers, in a similar manner, will attempt to purchase electricity at a price much below their marginal benefit. There are more aspects other than these relationships to be included in the model to predict possible future market situations.

Modeling dynamic economic systems using control theory is an expanding research topic. The theories depend on the specific case studies. Usually modeling the population control theories entails different equations than traffic control theories. But the basic concept is the same, i.e. to come up with usable equations that predict or control behavior based on logical decisions. For example, consumers are only willing to pay for an item if the price of the item is close to their marginal benefit. That concept can be programmed into a dynamic economic model. For more information on modeling dynamic economic systems using control theory the interested reader is encouraged to see refs: [1, 3, 5, 8, 9, 10, 11, 15, and 16].

2. General Competition Case

Competition drives technology and certain advancements in technology lead to efficiencies that might reduce the costs of a recent market entrant. This means that it could bid lower than the competition. If the power quality and reliability levels are the same for its electricity producing competitors and having the same type of generation, e.g. fossil fuel (such that externalities like Green energy preferences are not factored in), then ESCOs and/or consumers will schedule more with the least expensive company. The simple fact that new technology has reduced its costs has increased its market share. If the competition who invested their money in less efficient plants cannot afford the newer efficient equipment, their share of the market will suffer. Depending on the level of competition, their profit margins will be reduced, possibly putting them out of business. If they survive, their bids will still be included in price setting mechanisms in the Power Exchange (PX). Depending on the pricing mechanism utilized, their bids might raise the overall price, or the bidders in question might be scheduled for less desirable contracts.

3. Chaos in the Market

Many economic models include randomness to simulate data having characteristics that are close to historical data. This is very often true if the simulation is used for simulating or studying actions to be taken under future scenarios having events that singly no-one can predict. Unpredictable events happen often enough that they can eventually change a system very radically. To capture the effect of these events, it's often helpful to have an element of randomness in a simulation for realistic results.

Chaos (complex systems) theories stem from the study of nonlinear systems. Complex systems have extreme sensitivity upon initial conditions. This sensitivity dependence is been called the "Butterfly effect" in respect to climate forecasting. It refers to the slightest change (e.g., the difference between .4999999 and .5000000) and the system will behave dramatically different. There are three characteristics of a chaotic system. First, chaotic systems are deterministic, i.e. they have some determining equation ruling their behavior. Second, they are sensitive to initial conditions. Third, they are not totally random, nor disorderly, i.e. chaos has a sense of order and pattern. References [13,14] provide more detail about chaos and chaotic systems.

Power systems often experience seemingly and practically random events including such potentially disturbing events as lightning strikes and equipment failures, which can lead to system failures (blackouts or brownouts). Other events, which may affect contract prices, might range from new technological advancements or breakthroughs, the varying price of fuels, losing a game of golf to the right people, etc. So a little bit of chaos in power markets simulations can help a company to develop robust techniques that will withstand the market shifts.

4. Modeling Markets with Positive Feedback

Many models of dynamic continuous systems benefit by including a feedback loop of some kind. A feedback loop is used to adjust parameters used as inputs in equations that use past or predicted data. For example, with some initial conditions, X(t) is calculated. For the discrete X(t+1) to be calculated, its formula might need to use X(t), so it is fed back into the formula. This is also called recursive iteration. There are two broad types of feedback processes: negative and positive. According to Ruth and Hannon [1], positive feedback can lead a system away from an equilibrium by reinforcing a given tendency of a system, whereas negative feedback processes tend to lead a system into a state of equilibrium. Negative feedback is a way of reducing the amount of chaos in a system. Two examples of negative feedback to solve systems are finding equilibrium prices and amounts of power to be generated by each GENCO involve programmed feedback loops.

Positive feedback in a system allows it to reach a new, unpredictable equilibrium state [1]. However, W. Brian Arthur argues that increasing returns (via positive feedback) has the potential to discover many possible equilibrium points [2]. Running market simulations with a positive feedback loop and a random event generator can come up with many possible outcomes. Some of these outcomes might be realizable. Power systems operators and participants should identify the possible solutions and study the process by which given solutions are reached. In other words, decision-makers should single out the most probable chains of events and examine the end results. Approaching the problem from the other direction one can find the most probable outcomes and examine the steps it took to get there. This produces a model complete with flowcharts identifying important triggers/inputs that indicate a particular scenario is likely to occur. The observant agent is then able to quickly react and gain a slight edge over the competition.

5. Positive Feedback Example

The use of positive feedback to model a power market can provide how valuable insights into random events can change the profit margin of a company. For example, suppose a large GENCO is split into two separate entities. Their combined region is still large enough to require an Independent System Operator (ISO) and PX system to serve just the two of them. Following the breakup, they have about the same quality and capabilities and must now compete against each other. So the power demand equation is $P_{G1} + P_{G2} = P_D$ [3]. (Although it's rarely that simple with congestion and ancillary services factored into the equation.) If a positive-feedback random-event model simulation is designed for these two systems it would show that either of the GENCOs might eventually dominate the market. The following example was developed in part from an example in Ruth and Hannon [1].

The variables used in the following simulation are as follows:

Q1, **Q2** - the output of two producers

Z1, **Z2** - the cumulative production of each producer

F1, **F2** - the producers' (GENCO) market share

P1, **P2** - prices of each good

A1, **A2** - the "attractiveness" of the output to the consumer

TempQ1, **TempQ2** - the next output amount

where the "attractiveness" of the output is a measure of the willingness of the consumer to buy electricity due to the price. The lower the price the more the consumer is willing to buy and use the electricity while it's cheaper. The market share of producer one is given by the following equation:

$$F_1 = \frac{Q_1}{Q_1 + Q_2}.$$

Initially the outputs, which can range from 0 to 100, are set to one. The cumulative productions, which can range from 0 to 100, are set to one. The relationship between the price and the cumulative output is in Figure 1. It basically shows us the more produced the cheaper it is per unit until the price reaches the point of the suppliers marginal cost plus some amount of profit. The shape of the curve comes with economies of scale and is illustrated by the fact that GENCOs are not cost effective only producing a few MW of power. The relationship between the attractiveness and price is shown in Figure 2. It's a linear relationship that explains that reductions in price produce increases in demand for the product. For larger consumers of electricity there often is a great incentive to purchase large quantities. The parameters being varied in this example system are the market share of producer

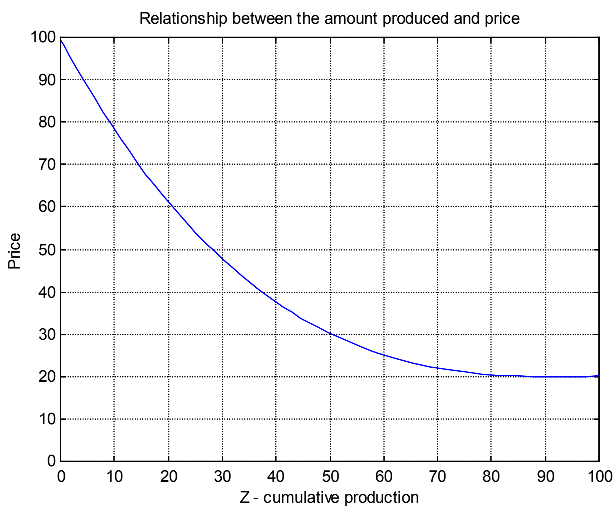

Figure **1**. Price vs. Cumulative Production

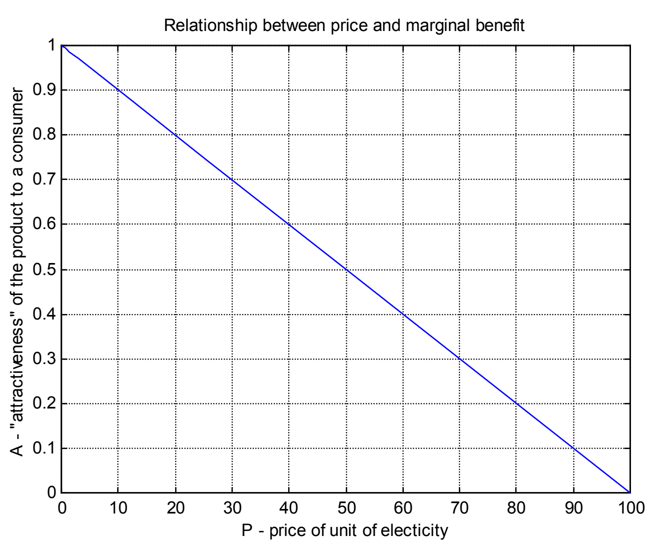

Figure **2**. Attractiveness vs. Price

one (F1) and the random number generator (a uniformly distributed random number between 0 and 1) which represents random events which may affect one's market share. If F_1 > random number then the $TempQ_1=Q_1*(1+A_1)$ and $TempQ_2=Q_2$, else $TempQ_1=Q_1$ and $TempQ_2=Q_2*(1+A_2)$. Hence, improving market share results in an increased demand. If the market share is not greater than some random event percentage the output will stay the same. The next cumulative production is based on the old plus the change in production (old output). The next output amount is given by this equation:

$$Q_1(t+1) = TempQ_1$$

So, production is largely based on market share, which to a certain extent is influenced by unpredictable events, represented in the simulation by the random number generator. If a company is fortunate and experiences fewer problems and has more efficient equipment, than it will likely dominate the market. The results of each simulation will be different because of the dependency on random numbers, which change each time. Figure 3, shows fifteen different simulations that were performed over forty-year (could also use months) cycles. Each plot is distinct, but it shows the path of events that can lead to a particular final result.

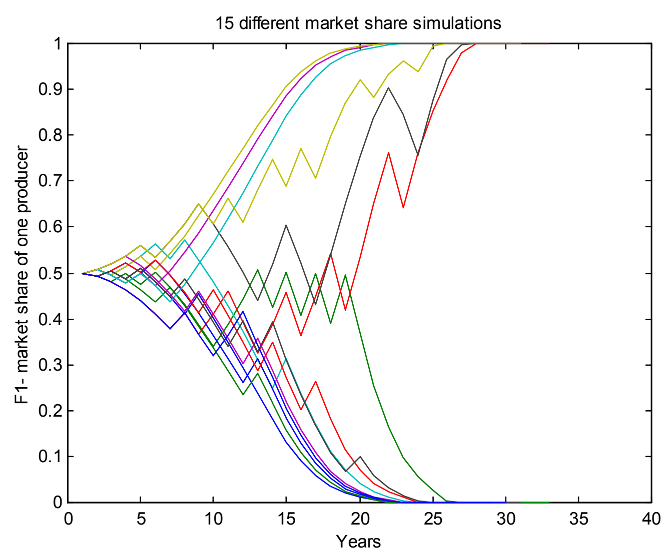

Figure **3**. Results of 15 simulations

6. Conclusions and Future Research

This type of modeling can be very insightful. Arthur pointed out that "once random economic events select a particular path, the choice may become locked-in regardless of the advantages of the alternatives" [2]. This is easily seen in Figure 3. None of the plots get past thirty years before it's final solution is determined. Most are set in their path by fifteen years. It's comparable to a ball rolling along the top of a hill. Once the ball gets too far to one side it rolls down never able to return to the other side. Figure 3 is a little severe for some power markets. It predicts a total takeover of the power economy by one company which may not be likely because of power wheeling and the back-up services that a second GENCO would provide. A company can gain market power in a certain area to the extent that it might need to be examined for having monopoly-like power.

The concept of Return to Scale (RTS) was investigated. The graph if Figure 1 was changed to curve up at the end so after a certain point the cost of producing more would increase the marginal costs. After running the simulator a few hundred times the only difference noted was a few plots made it past thirty years before its final solution was decided.

This simulation shows signs of being a truly chaotic system. It has equations determining its behavior. It is sensitive to initial conditions and the conditions beginning iteration. This simulation has a sense of order and pattern. It stays between the bounds of 1 and 0.

The next step is to find the probabilities of the different events and find the end result with the highest probabilities. The real task includes assigning real events to the random number ranges, e.g. lightning strikes .4500 -. 4999. Then run the simulation a couple of hundred times. Count the number of specified random ranges. Use real world probabilities of such events, like the number of lightning strikes per year on electrical generation of transmission equipment, and match up the probabilities and the sequences of events so there are approximately that many happenings a year. Thus the number of times that number range is picked compared to the number of lightning strikes a year. Some of the sequences will be close to impossible, e.g. eventually a sequence of lightning strikes every night on just one company's equipment will be recorded. This solution is highly unlikely but it's still a solution. The solution set will be the sequences with probabilities between .5 and 1 (1 being absolutely certain). Although the data from the other sequences should be kept, it doesn't have to be analyzed thoroughly because of its low probability. A few sequences will almost be repeated. So even if they have a low probability, include them in the solution set.

A positive feedback model that models the chaotic nature of the real market may be quite useful to regulators and potential market participants. It may be used as a prediction tool that considers a multitude of possible scenarios bounded by those conditions pre-specified by the analyst. It can generate more test market sequences than other economic models because the analyst doesn't a priori restrict the combinations of events to those which he/she "thinks" is likely to occur. Knowledge of potential basins of attraction (i.e., the resultant market share under given scenarios) can aid the regulators and market participants in generating markets that are fairly robust, and can direct future research toward those markets that may need more research. The potential events being considered in the chaotic simulations can be geared not only towards determining overall market characteristics, but can be tailored for GENCOs and ESCOs as they attempt to reduce their market losses.

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8. Biographies

James Nicolaisen received his BS in Physics from Morningside College in 1998 and is presently studying power systems while pursuing an MS in EE at Iowa State University.

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