SMART II: The Spot Market Agent Research Tool Version 2.0

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Abstract: Argonne National Laboratory (ANL) has worked closely with Western Area Power Administration (Western) over many years to develop a variety of electric power marketing and transmission system models that are being used for ongoing system planning and operation as well as analytic studies. Western markets and delivers reliable, cost-based electric power from 56 power plants to millions of consumers in 15 states. The Spot Market Agent Research Tool Version 2.0 (SMART II) is an investigative system that partially implements some important components of several existing ANL linear programming models, including some used by Western. SMART II does not implement a complete model of the Western utility system but it does include several salient features of this network for exploratory purposes. SMART II uses a Swarm agent-based framework [1,2]. SMART II agents model bulk electric power transaction dynamics with recognition for marginal costs as well as transmission and generation constraints. SMART II uses a sparse graph of nodes and links to model the electric power spot market. The nodes represent power generators and consumers with distinct marginal decision curves and varying investment capital as well individual learning parameters. The links represent transmission lines with individual capacities taken from a range of central distribution, outlying distribution and feeder line types. The application of SMART II to electric power systems studies has produced useful results different from those often found using more traditional techniques. Use of the advanced features offered by the Swarm modeling environment simplified the creation of the SMART II model [1].

Keywords: Complex adaptive systems (CAS) Agent-based modeling (ABM), Electric power system modeling, Swarm.

I. Introduction

Complex Adaptive Systems (CAS) can be applied to investigate complex infrastructures such as the electric power marketing and transmission system. ANL has worked closely with many U.S. and international electric power marketing and transmission organizations to model their systems. Western Area Power Administration (Western)(www.wapa.gov) is an example [3].

II. Western

Western markets and delivers reliable, cost-based hydroelectric power and related services. Western's service area covers 3.38 million square kilometers (1.3 million square miles). Western's wholesale power customers provide service to millions of consumers in

15 western states (Arizona, California, Colorado, Iowa, Kansas, Minnesota, Montana, Nebraska, Nevada, New Mexico, North Dakota, South Dakota, Texas, Utah and Wyoming). Western markets hydroelectric power from 55 power plants and 547 MW from the coal-fired Navajo Generating Station.

ANL has worked closely with Western over many years to develop a variety of electric power marketing and transmission system models. Western is currently using these models for ongoing system planning and operation as well as for analytic studies. The models include the following:

- The Spot Market Network Model (SMN) is a PC-based linear program with a graphical user interface that models the electric power spot market.
- The Generation and Transmission Maximization Model (GTMax) is a PC-based linear program with a graphical interface that models the electric power spot market and detailed hydroelectric dam operation.

The SMN is a component of the Argonne Production, Expansion, and Exchange Model for Electrical Systems. CAS models have been created in the Swarm environment loosely based on the SMN and GTMax [3]. These CAS tools do not implement a complete model of the Western utility system but they do include several salient features of this network for exploratory purposes:

- The Spot Market Agent Research Tool Version 1.0 (SMART I) uses a simple set of agents and interconnections to represent an electric power generation and transmission system similar to Western's.
- The Spot Market Agent Research Tool Version 2.0 (SMART II) uses a more advanced set of agents and interconnections to represent an electric power generation and transmission system similar to Western's.

SMART II is the current version of the system. Both models apply CAS techniques in the Swarm environment to investigate market price stability.

III. Market Price Stability

Market price stability is a key feature of modern deregulated power systems. In the short run it determines the volume of power transactions and therefore influences generation and transmission line usage. In the long run it determines economic incentives to maintain and add generation and transmission capacity and therefore influences system reliability. Market price stability can be investigated using the features of SMART II.

IV. Model Features

SMART II is based on GTMax and uses a set of agents and interconnections to represent an electric power generation and transmission system similar to Western's. Agents represent electric power marketing and transmission organizations such as Western, their customers and their competitors. Interconnections represent transmission lines. The emergent behavior of the agents allows the investigation of market price stability.

SMART II includes the many features. Important economic issues such as investment capital, demand growth for successful consumers, new generation capacity for profitable producers, and bankruptcy for noncompetitive organizations are considered. A transmission infrastructure with capacities on each line and complex routing across the network is used. Complex consumption value curves are also included.

V. Model Agents

SMART II uses two different kinds of agents to model the electric spot market. Agents are either electric power generators or consumers. The emergent behavior of the agents allows the investigation of market price stability.

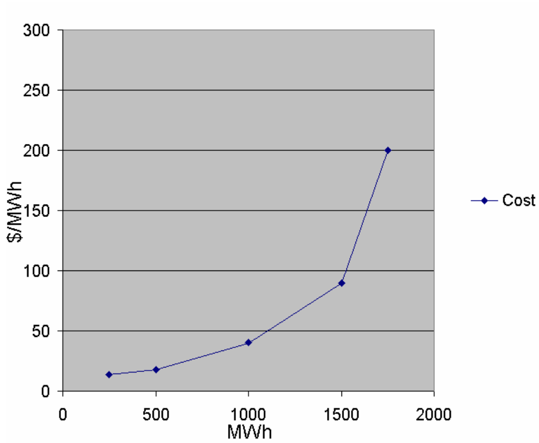

Figure 1: Generator Cost Curve

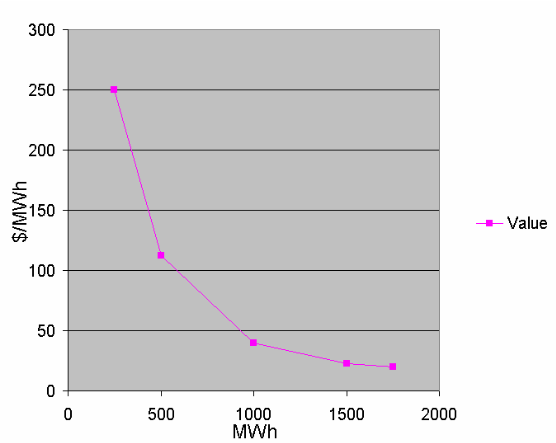

Figure 2: Consumer Value Curve

In each hour generators can choose whether or not to sell power based on their cost curves. An example cost curve is shown in Figure 1. Generators determine their production level based on the potential profit to be made. Each generator has investment capital that is increased by profits and reduced by losses. If a generator reaches a predetermined level of investment capital it can purchase additional production capacity in the form of new generators. New generators are similar to their owner and can connect to the distribution network in either the same location or a new one. Generators that run out of investment capital go bankrupt and no longer participate in the market.

Hourly profit levels determine the appearance of generators. Profitable generators are highlighted.

In each hour consumers can choose whether or not to purchase power based on their value curves. An example value curve is shown in Figure 2.Consumers buy electric power for their own use. Consumers buy based on the potential to use the purchased power to make a profit. This can include industrial users who produce goods based on electric power and populations of individuals who vary their demand based on power prices. If a consumer reaches a predetermined level of investment capital it can grow in the form of new consumers. New consumers are similar to their originator and can connect to the distribution network in either the same location or a new one. This can represent the growth of electric power-based businesses or an influx of people due to favorable economic conditions. Consumers that run out of investment capital go bankrupt and no longer participate in the market. Bankruptcy represents the decline of electric power-based businesses or the departure of people due to unfavorable economic conditions. Hourly profit levels determine the appearance of consumers. Profitable consumers are highlighted. Unprofitable consumers are dim. Bankrupt consumers are hollow.

VI. Model Lines

All lines have capacity limits. The capacity limits vary by the line type. Central distribution lines have high capacity limits and are drawn with thick marks. Outlying distribution lines have moderate capacity limits and are drawn with medium marks. Feeder lines have low capacity limits and are drawn with thin marks. Each individual line has its own capacity within the range of its line type. Line colors represent usage. Low usage is dark. High usage is light.

VII. Example Networks

An example SMART II network diagram is shown in Figure 3 and an actual view is shown in Figure 4.

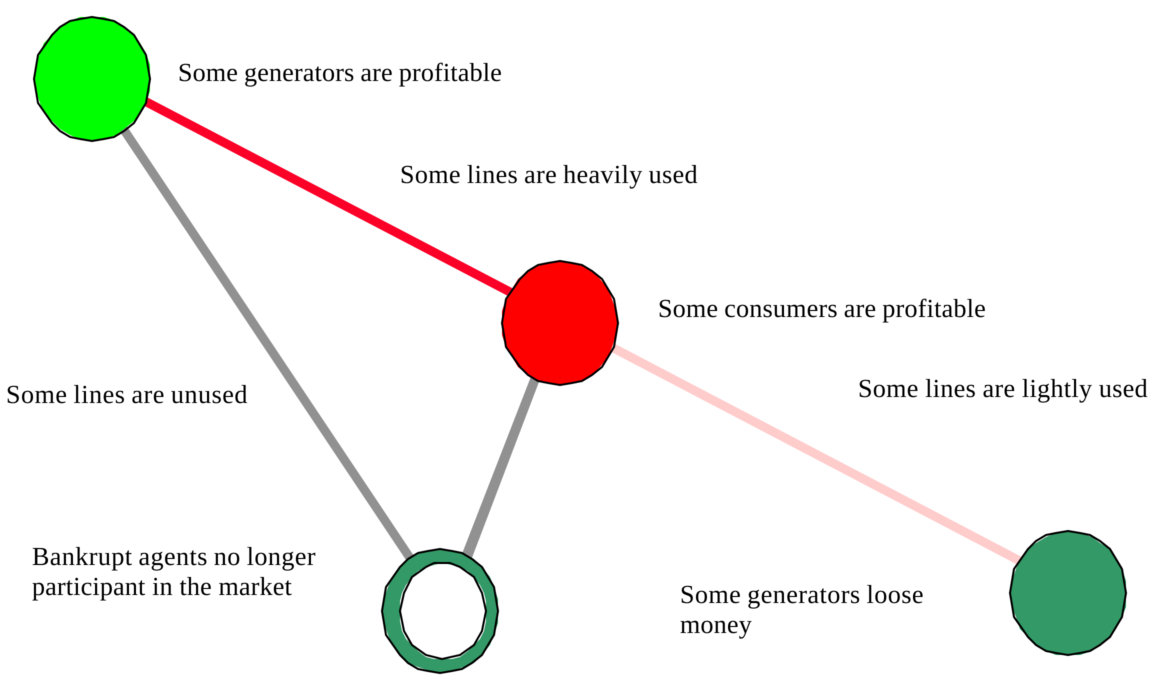

Figure 3: An Example SMART II Network Diagram

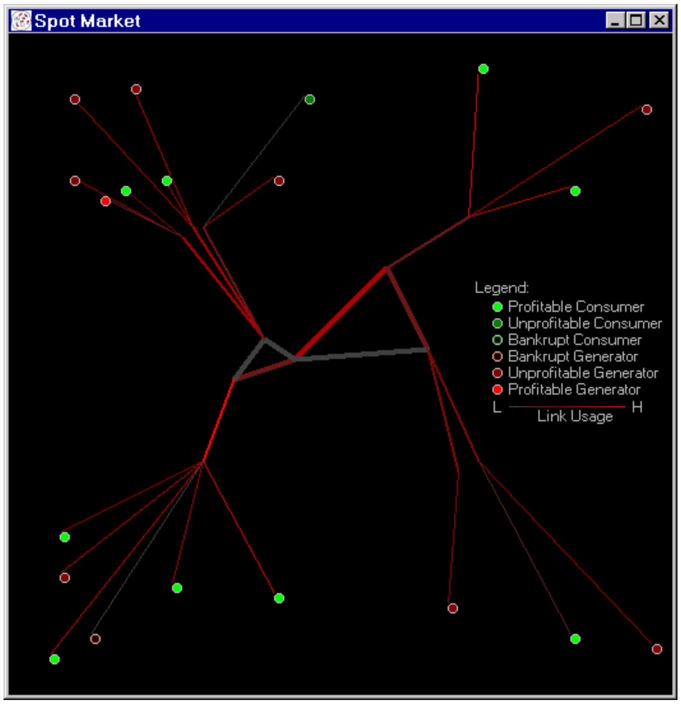

Figure 4: An Example SMART II Network

VIII. Emergent Behavior

The emergent behavior of the agents allows the investigation of market price stability. Agents learn about the cost and value curves of the surrounding agents over time and improve their own behavior to increase their profits. Momentary market price equilibrium form when agents agree on a market-clearing price. Agents learning similar things at the same time can work together to beat the market and disrupt market price equilibrium. For example, sets of generators sometimes slowly raise their prices as a group when each II Network Display learns that the others are willing to go along (i.e. the Prisoners Dilemma). This emergent behavior can lead to price spikes that collapse when one of the agents chooses to go against the trend. These price spikes represent market price instability. Examples of these price spikes can be seen in Figure 5.

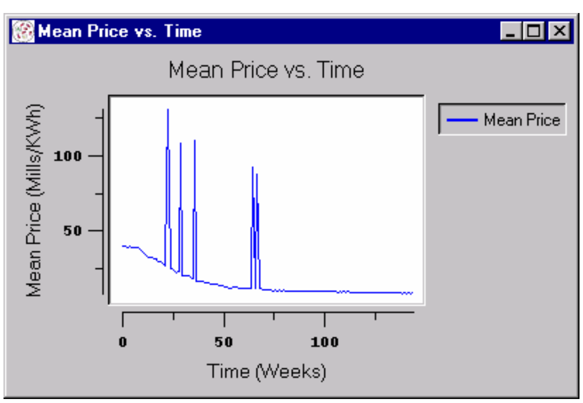

Figure 5: A Market Price Graph Showing Spikes

IX. Conclusion

SMART II indicates that certain transmission line configurations tend to encourage price spikes. The transmission system in Southern California, particularly around Los Angeles, has one of the transmission line configurations that encourage price spikes. Southern California has regularly suffers from market price instability. Greater market price stability can be deliberately designed into open market electric transmission systems by consciously avoiding specific configurations that encourage instabilities.

Developing the initial capability to create CAS models requires substantial organizational investment as demonstrated by the SMART effort. The use of the Swarm modeling environment makes this investment much more practical. Once this initial investment has been made models can be created that allow innovative studies. ANL has made this investment by creating and applying SMART. The application of SMART II to electric power systems studies has produced useful results different from those often found using more traditional techniques. Use of the advanced features offered by the Swarm modeling environment simplified the creation of the SMART II model [1].

X. Acknowledgement

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XI. References

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