CHAPTER 1

DEREGULATION OF ELECTRICITY MARKETS AROUND THE WORLD

INTRODUCTION

In 1990, the electricity industry in England and Wales was the first to introduce competition to the activities of generation and supply. Initially, supply competition was made available to only 5,000 large industrial consumers. However, in1994, competition was extended to an additional 50,000 medium size consumers such as small factories and businesses (Slark 1998). In the summer of 1999, the United Kingdom (UK) implemented the first full-blown competitive electricity industry, where the full compliment of 26 million consumers were allowed to choose among suppliers of electrical power. Other countries, such as Australia, New Zealand, Bolivia, Canada, and the United States, are all at various stages of deregulation of their electricity sectors. Similar to the model applied in the UK, the deregulation plan calls for competition to emerge in controlled phases.

With competitive electricity markets emerging throughout the world, executives and managers may wish to leverage this opportunity for their organizations. However, the world of electricity is complex and loaded with technical jargon to the newcomer. This chapter defines some of the jargon related to the buying and selling of electricity and explains some of the basic concepts of electrical power generation, transmission and distribution. In addition, this chapter describes the general approach used to conduct the research presented herein.

BACKGROUND

Because of the prohibitively large start up capital required to establish a presence in the electricity industry, every electrical power system in the world was born as a natural monopoly. Electricity is simply a commodity, much like natural gas and sugar, which can be bought and sold in a free market. However, electricity has several unique features that distinguish it from other commodities that we must consider if it is to be traded. Today's technology does not provide an economical means of storing electricity. Thus, unlike natural gas and sugar, electricity must be produced in the right quantity at exactly the right time. In addition, electricity cannot be differentiated by its originator once it reaches the transmission and distribution grid. Finally, the flow of electricity along the grid obeys the laws of physics. Each of these natural attributes poses considerable difficulty in creating a competitive trading market.

The actual production of electricity is a process termed "generation." Electricity can be generated in a variety of ways: hydroelectric involves the conversion of falling water into electricity, engines or turbines may be used to convert fossil or nuclear fuel into electricity, and wind or solar power may be captured and harnessed into electricity. Ultimately, the generation function involves the conversion of some form of energy into a bulk supply of electrical power.

Once electricity is generated, it is usually transported over great distances to the end users. The transportation process is referred to as the "transmission" function, which involves delivery of bulk electricity from the generators to bulk supply distribution points. Since the supply and demand for electricity must be balanced in real time, the transmission function also involves the scheduling and dispatch of all bulk electricity for all of the generators connected to the network. At the bulk supply distribution points, the voltage of the electricity is reduced to levels that are practical for delivery to local substations. At the local substations, the voltage is once again reduced to consumption levels. The process of local delivery and voltage reduction is known as "distribution."

For most users of electricity, the functions of generation, transmission, and distribution have appeared seamless because these processes have historically been provided as a "bundled" service by the installed monopoly. Deregulation of electricity markets involves a partial "unbundling" of this vertical supply chain. Separation of these functions facilitates a competitive market for electricity via "open access" to the power grid. With open access, potentially profitable economic opportunities are available to new entrants into the electricity market. However, unbundling the supply chain also creates ambiguities regarding divisible property rights for an indivisible physical network.

For the generation function, the ability to inject electricity into the network and trade a certain amount over a period of time is required. This will allow the management of generating facilities to focus their attention upon their core activities and streamline their efforts for the efficient production of electricity. In a competitive electricity market, buyers may choose their suppliers and thus, each unit of electricity has a specified source and destination. This is referred to as the "contract path" for the delivery of a specified amount of electricity.

The transmission and distribution functions are both basically a "wires business" which involves the coordination of delivery services across the physical network. The difficulty with unbundling these two functions is based upon transmission pricing issues. Because the actual path taken by electricity from source to destination is dependent upon current network conditions, the actual path may differ greatly from the contract path. Therefore, the true cost of delivering electricity is based upon current network conditions both at the transmission level and the distribution level. For this reason, it is likely that these services will be grouped together as deregulation takes place.

To facilitate deregulation of the electricity market, independent business units must be established to manage the transmission and distribution functions. In addition, these business units must be given physical property rights for certain parts of the network in order to provide reliable service and make effective business decisions. However, partitioning a physical power grid into economically viable districts involves many considerations. In this research we identify this new and interesting general class of districting problems as the Electrical Power Districting Problem (EPDP). We believe that in the very near future, many instances of the EPDP will arise as deregulation of electricity markets takes place around the world.

PURPOSE OF RESEARCH

Researchers intimate with the deregulation of electricity markets have expressed concern that the process is taking place without a complete understanding of the impact of long term decisions and that without the proper studies there is a risk of being "...locked into an inferior market design which will be costly to change" (Chao and Huntington 1998). Furthermore, without proper research, there is also a risk that the full social benefits resulting from the deregulation process will not be realized (Morgan 1998).

Researchers have historically shown a great deal of interest in applying management science tools to developing political districts and aligning sales districts. The considerations typically present in designing political or sales districts, such as compactness and contiguity, are also relevant concerns for the EPDP. However, the EPDP also has some unique characteristics. This research is intended to synthesize the various approaches to districting problems and identify the necessary and fundamental characteristics to appropriately model an EPDP.

To this end, this research has five objectives. First, to identify the issues relevant to an EPDP. Second, to investigate the similarities and differences of the EPDP with other districting problems published in the research literature. Third, to develop and recommend an appropriate solution methodology for the EPDP. Fourth, to demonstrate the effectiveness of our solution method for a specific instance of an EPDP in the Republic of Ghana. Last, to build a decision support system (DSS) that will effectively aid decision makers (DMs) at the World Bank in finding an acceptable solution to Ghana's EPDP.

RESEARCH METHODOLOGY

The research methodology used in this investigation is basically exploratory in nature. Districting problems have a long history in the field of optimization, dating as far back as 1956 (Brown et al. 1956). Since their first appearance, researchers have investigated a variety of issues related to districting problems and have provided an equally diverse set of solution techniques. The EPDP is particularly compelling because no one truly knows how the final competitive electricity markets will actually develop. In fact, the most mature emerging competitive electricity markets, Australia and the UK, differ in several design aspects. The opportunity for researchers to make a real impact is clearly at hand.

To facilitate the development of a mathematical model, it is necessary to make certain assumptions regarding the design of the financial market and pricing schemes that underlie any particular application of an EPDP. Two general frameworks have been proposed to support trading electricity on an open market: "nodal" and "zonal" pricing schemes. Nodal pricing establishes a fixed unit price for each bulk distribution point, whereas zonal pricing aggregates a unit price over a geographic region containing multiple bulk distribution points. In this research, we assume a nodal pricing scheme as the basis for creating electrical power districts. This approach is sanctioned by the World Bank and is also the scheme most popularly supported by the research literature (Hogan 1998, Schweppe 1998, Wilson 1998).

In order to evaluate the mathematical models that we develop herein, they will be applied to the actual electricity distribution system in the Republic of Ghana. The data required by the model (nodal price estimates, revenue forecasts for bulk supply distribution points, and the actual layout of the power grid) has been provided by the World Bank. We have developed several stochastic search algorithms and performed a series of empirical studies to determine the effectiveness of each solution technique in solving the EPDP. The empirical studies include an analysis of the actual case of Ghana as well as a sensitivity analysis that is independent of the Ghana case. Thus, the sensitivity analysis allows us to make more general conclusions about the effectiveness of our solution techniques. The sensitivity analysis was performed with the use of a random problem generator specifically designed for the EPDP.

SCOPE AND LIMITATIONS

The generalized districting problem is in the class of NP-Hard problems, independent of the problem representation (Altman 1995). Practical districting problems can grow to very large sizes making exact solution methods impractical and heuristics (methods based upon rules of thumb) the only reasonable choice. Thus, the scope of this investigation is limited to heuristic methods for solving the EPDP. Heuristic methods can often solve a difficult problem quickly. However, in exchange for their efficiency, they sacrifice the guarantee that their best solution is optimal.

Single criteria optimization methods often fail to capture all of the necessary aspects of problems faced by DMs. Many practical problems that are modeled as single criteria problems are better posed as multi-criteria problems. Previous attempts to incorporate multiple criteria into other districting problems have characterized the objective function as a single weighted objective aggregated across the multiple criteria (Zoltners 1979). The problem with this approach is that it requires the DMs to specify the weights for each criterion prior to the search. In addition, only a single optimal solution corresponding to the specified weights can be found during the optimization run. Characteristic of a true multi-criteria problem is the absence of a unique global optimum. Rather, multiple solutions to the problem often exist that are superior to (dominate) the others in the solution space.

In addition to developing search algorithms for optimizing an EPDP for the single criteria case, we also develop search algorithms for solving the multi-criteria formulation of the EPDP. In addition, the solution techniques that we developed are capable of producing multiple non-dominated solutions in a single optimization run as well as alternative solutions that are very close to the non-dominated set. We refer to this composite set of solutions as a "soft efficient frontier." We believe that by presenting a DM (or DMs) with a soft efficient frontier of solutions that can be easily visualized using the tools in our DSS, the DM is more likely to arrive at single districting plan (solution) that they are willing to implement.

PLAN OF PRESENTATION

Chapter 2 surveys the literature on districting problems and identifies the characteristics that are most fundamental to the EPDP. It goes on to describe a model for these characteristics for a single criteria optimization problem. This chapter includes a discussion of two well known optimization heuristics, simulated annealing (SA) and the genetic algorithm (GA), that have been applied to districting problems or related partitioning problems. Subsequently, an empirical study is performed using each generalized technique specifically adapted for the EPDP. A discussion of the results follows.

Chapter 3 develops the motivation for viewing the EPDP as a multi-criteria problem. It also provides a literature review of some solution methods that have proven to be effective in locating multiple non-dominated solutions in a single optimization run. This chapter investigates the merits of extending the solution techniques developed in chapter 2 (SA and the GA), to models involving more than one objective function. It follows with an empirical study of each solution technique to a multiple criteria representation of the EPDP for Ghana as well as a sensitivity analysis using a random problem generator.

Chapter 4 describes the implementation of a DSS designed for planning electrical power districts in the Republic of Ghana. Both methods proposed in chapter 3 are implemented in the DSS as the search engine.

Chapter 5 summarizes the findings of this dissertation. It also highlights some exciting potential research extensions for future investigation.