FUEL OPTIMIZATION

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ABSTRACT

This paper describes the methods used by Southwestern Public Service Company (SPS) to optimize the use of approximately 90,000,000 MCF of natural gas and 2,000,000 tons of coal each year.

The fuel that is purchased by SPS comes from five different suppliers and is covered by thirteen contracts, each contract containing one or more take-or-pay constraints.

Optimization is applied at two levels:

1. Take-or-pay provisions of all contracts are met on monthly, annual or other basis as specified in the contracts.
2. Minute-by-minute use of gas and coal is adjusted to provide the lowest instantaneous overall cost of generating the power demanded by SPS customers at that instant.

The optimization methods used at both levels are described. Presented are the advantages and disadvantages of the techniques that are used. An assessment is made of the overall success of the optimization system.

BACKGROUND

What is an electric utility?

Some of you very likely know more about the operation of an electric power system than your author. For the benefit of the others and to make certain that all of us are together in our thinking, I am going to describe, very briefly, the elements of a central station, interconnected power system.

Let us begin at the power source. The electric utility is not an energy producer. The electric utility consumes primary energy as a raw material and delivers electrical energy as a manufactured product. The utility also usually performs the service of delivering the electric energy directly to the customer and collects its pay after the product has been consumed. The utility is responsible to accurately measure the quantity of power delivered, to compute the bill and collect its payment.

The elements of the power system are, a source or sources of primary energy, one or more power plants, usually a transmission system, a distribution system and several customers. Whenever the power plants are built in sizes large enough to take advantage of the economy of scale and the number of customers is large, the power system is classed as a central station system. If, in addition to connecting its own customers to the power plants, the transmission system is also connected to the transmission systems of neighboring utilities the power system is said to be interconnected.

The combination of power plants and transmission system is called the utility's bulk power system.

An electric utility with a problem

Southwestern Public Service Co. (SPS, for short, from now on) is a stockholder owned electric utility serving about 280,000 customers scattered over 45,000 square miles in the states of Texas, New Mexico, Oklahoma and Kansas. SPS operates ten major power plants (central stations) and has an eleventh under construction. It is interconnected with Public Service of Oklahoma, Central Telephone and Utilities, West Texas Utility, New Mexico Electric Service Company and Lea County Electric.

SPS's primary source of energy (fuel supply) is natural gas and coal. A small amount of No. 2 fuel oil may be used during emergencies.

Natural gas is obtained from five suppliers under twelve contracts. Coal is supplied by one supplier with one contract. Every contract contains a take-or-pay constraint.

Four thousand miles of high voltage transmission lines are assembled into a power grid to supply 177 transmission substations. Thirteen thousand miles of distribution lines supply 337 distribution substations which deliver the power to the customers' premises.

The problem

The most expensive fuel that can be purchased is take-or-pay fuel that is paid for but not taken. The second most expensive fuel is fuel that is purchased and wasted. All fuel optimization efforts are directed at eliminating or minimizing these two expensive items.

The problem, in a nut shell, is to devise a method of operation that will schedule the use of all take-or-pay quantities and minimize the cost of all fuel in excess of the take-or-pay quantities. Oh yes! Part of the optimization problem is to maximize the power produced by the take-or-pay fuel.

APPLICATION OF FUEL OPTIMIZATION AT SPS

Overview

A problem in two parts

The fuel optimization problem at SPS can be divided into two parts. First, how should the bulk power system be operated to assure the use of all take-or-pay quantities? Second, how should the bulk power system be operated to minimize the expense of nontake-or-pay fuel?

Take-or-pay optimization

The first problem, the problem of the take-or-pay use, is best handled on a rather long term basis. Most take-or-pay periods are of one month to one year in length. The operation of the bulk power system must be optimized over a length of time at least as long as the longest take-or-pay period.

Nontake-or-pay optimization

The second problem, the problem of the nontake-or-pay fuel, is of very short term duration. The span of time over which the operation of the bulk power system is optimized is from six seconds to ten minutes. If this optimization problem is solved correctly, a secondary result will be the optimum use of the take-or-pay quantities.

Fuel optimization -- Take-or-pay

The plan

The take-or-pay optimization problem is solved with the use of a fuel supply, bulk power system model. At the beginning of a year, one year of operation is planned. The model is developed in sufficient detail to yield a set of reasonable estimates of monthly fuel quantities at each delivery point for each month. The solution must result in the meeting of all take-or-pay contraints as imposed by each contract.

To add zest to the problem, some take-or-pays can be taken at either of two power plants. Some take-or-pay is monthly, some for periods of five months, seven months and twelve months. One take-or-pay period is for twelve months starting May 1, and ending with April 30 of the following year.

Next month

The estimated quantities planned for each power plant from each supplier for the first month, January, are used to develop daily quantities. The resulting schedule is given to the system operator as a guide to January's operations. The plan never works. Electrical use is weather sensitive and the weather is not normal for January. A routine overhaul takes a week longer than was planned. There are many unexpected reasons that can prevent the plan from working. At the end of the first month, the actual fuel quantities taken from each supplier are entered into the system model.

The remaining eleven months of the year are planned so that the take-or-pay quantities are again scheduled. Once again the next month's plan, this time it is February, is used to develop daily quantities and the resulting schedule is given to the system operator. And once again, the plan does not work. The actual quantities taken from each supplier in February are entered into the model and a new plan developed for the rest of the year.

Year end

The procedure is repeated for each successive month through the year. As the year end approaches, those suppliers whose take-or-pay quantities have not been satisfied receive more and more attention. The pressure is increased to schedule those supplies that are furtherest from their take-or-pay targets. The scheduling of the take-or-pay quantities becomes a pursuit curve problem. As each target is missed, the next schedule redirects the system operators efforts toward the targets from the latest actual positions of targets and pursuers.

Short term optimization

The nature of system load

Every electric power company must provide a balance between customer demand or load and total generation on a continuous basis. There is no line pack in an electric system. After a customer turns on or off a switch, the generation-load balance is upset. Within a second or two the total fuel input to the system must be readjusted to restore the generation-load balance.

The problem is made somewhat simplier than it may appear as it has just been stated because of a very fortunate circumstance. A utility such as SPS has so many customers that almost all of the time someone, somewhere on the system is switching on or switching off a power consuming load. Diversity is the name given to the fortunate fact that all of the customers never turn on all of their electrical equipment at the same time or, for that matter, never turn it all off at the same time. The existance of diversity allows the power company to treat the combined, ever changing demand of its customers as a continuous variable.

A mathematical model of the power system is used to guide the control of the fuel input. Included in the model are the details of each fuel supply, each generating unit and each segment of the electrical transmission system.

The next six seconds

Fuel input is controlled by adjusting the output of each generator. Control is directed by a digital computer. The computer takes a "stop action" look at the bulk power system, compares the state of the system that it sees now with the state of the system that it saw six seconds ago. A comparsion of the state of the system now with its state six seconds ago forms the basis of a prediction of the state of the system six seconds in the future. Control action is taken to attempt to zero the generation-load unbalance that is predicted for six seconds from now. The computer sends the indicated control signals to the governor control on each generator.

Once each ten minutes or for each ten megawatt change in system load, whichever comes first, economic targets for each generator are calculated. As control action is taken as described above the amount of load change allocated to each generator is biased to cause the outputs of all generators to adjust toward the economic targets.

Economic targets

As each day passes, the actual generation of each generator, month-to-date, is compared to the planned quantities. As the actual moves away from the planned (and it always will) the fuel cost used in scheduling the economic distribution of loads between the generators is modified to reduce the effective cost of generators lagging behind the plan and raise the effective cost of the generators that are running ahead. The effect of the adjusted costs is to cause the control system to move the generator outputs to levels that will optimize the fuel use.

Putting it all together

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How effective?

The system is very effective in controlling take-or-pay quantities. SPS has paid take-or-pay charges only once in thirty years. In that case some claims for force majeure relief claimed by SPS was denied by the supplier.

Short term scheduling based on the short term fuel optimization methods is less effective. The actual loss resulting from ineffective scheduling cannot be measured. The system operation cannot be replayed using other strategy. All that SPS can do is apply the correct method and trust in the results. One thing is evident, the effectiveness of the method can be no better than the accuracy of the system model used in the control system.

An indication of accuracy of the model is gained by comparing the actual annual electrical output to the predicted annual output. The comparison usually shows that very good predictive methods were used. Errors of less than one percent are usually realized.

The reigns tighten

The problem is becoming more complex with each passing day. More and more agencies are looking into the way that SPS conducts its business. They are sometimes representative of conflicting aims. Some would minimizing SPS's total energy use, never mind the cost. Some would reduce polution even if energy is wasted in the process. Others, looking out for the interest of the customer, call for minimizing fuel costs by all means available. For these reasons SPS has a continuing program of evaluating its optimization techniques and adding improvements whenever they are developed.

OPTIMIZATION TOOLS

Linear programming

SPS bulk power system is modeled, in a simplified fashion, in a linear programming formulation. Although a computer is not a requirement for the application of linear programming techniques, when the problem grows as large as SPS's, a computer is essential.

The linear programming formulation developed to model the annual operation of SPS's bulk power system requires the solution of the equivalent of 955 simultaneous equations containing 4331 variables. Remember that, whenever there are more variables than equations, there can be many solutions, sometimes an infinite number. Any solution that satisifies the equation is called a feasible solution. The linear programming method calls for an iterative search for the optimum solution. SPS's problem usually takes about 25,000 iterations requiring about 24 seconds of IBM 370/158 time. SPS uses IBM's MPSX/370 program, a general purpose linear programming package.

CPM -PERT

All planning of generating unit maintenance is done by building a generator unit available/unavailable network in which the maintenance activities are represented as CPM activities forming part of the project that might be called "Provide the Generating Capacity Required for One Year of Operations". Such a formal name is not actually used but it does describe the essence of the problem to be solved. The annual overhaul plan for each generating unit is described to the system model with the resources required. Each unit's capacity is a resource as well as the men and equipment to be used in its overhaul. After scheduling adjustments are made to levelize the total system resource requirements, the schedule is established. SPS uses an IBM product called PROJACS/370 to do the resource scheduling.

Incremental loading

Incremental loading is a short term resource optimizing technique that is based on the theory that there is a value, called the incremental cost, for every level of output of a production process. The incremental cost is the cost of any additional resources to produce one more unit of output. Or, stated in another way, incremental cost is the cost of producing the next unit of output. The theory states that the overall cost will be minimized when every production unit is operating at the same incremental cost. As applied to a bulk power system the resources are the fuel supplies, the unit of output is the kilowatt, and the production processors are the generating units. SPS uses an IBM 1800 process control computer to calculate the allocation of loads between the various units in operation.

The incremental cost of each of the generating unit is determined by multiplying the amount of heat input needed to produce the next kilowatt of output by the scheduling fuel cost. The incremental cost is modified by a penalty factor that is a function of the amount of electrical losses associated with the power produced at a generator.

CONCLUSION

The preceding is a very rough, much simplified description of fuel optimization techniques used by SPS. The opportunity to share these techniques with you is appreciated. Any suggestions for improvements will be welcomed. It is the hope of the author that the ideas presented here will be of some use to those reviewing them. If not of use, perhaps they will at least be of interest.