POWER Engineering

Define Then Achieve Fleet Optimization

Using continuous improvement to make assets perform at their peak

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The term "optimization" has been used so much, for so many things, that by now it has almost no meaning. Recently, the term "fleet optimization" has been bandied about, with the implication that by installing a lot of computer networking and information management, fleet optimization will be enabled.

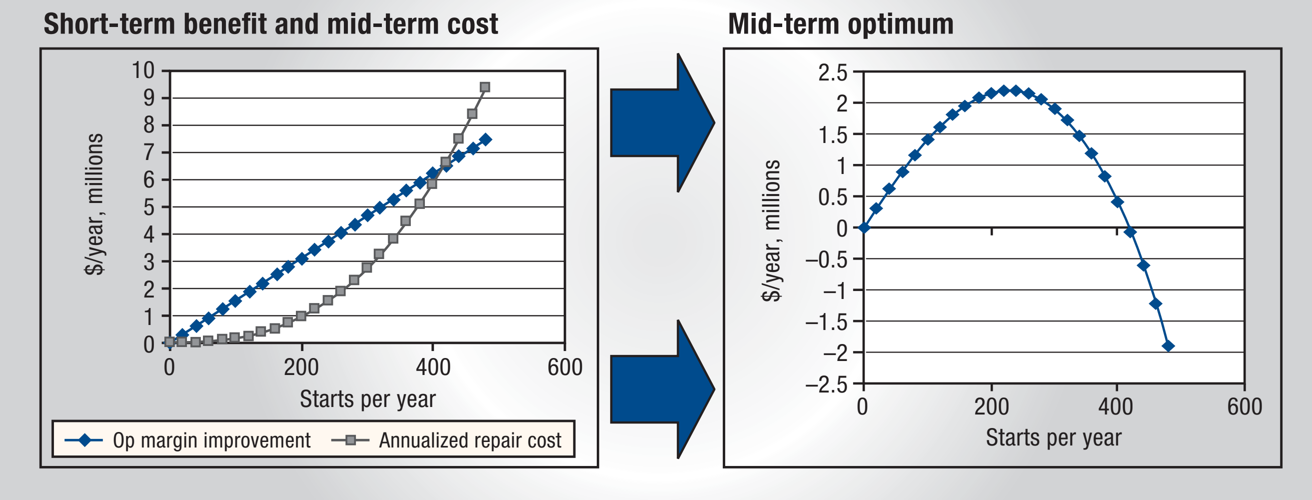
While it's true that fleet optimization may be enabled with networking and information management (IM) infrastructure, that infrastructure will not be used and useful without a clear understanding and vision of what it means to optimize. The industry is in need of a straightforward definition of fleet optimization and a straightforward perspective on achieving it.

Fleet Optimization Defined

Optimization is the process of minimizing or maximizing some quantity, given a set of relationships between variables and a set of constraints that must be satisfied. The set of relationships and the set of constraints together are called an optimization problem.

This is a somewhat theoretical definition, but it is a very powerful tool. It means that if you are not seeking to minimize or maximize some quantity, then you are not optimizing. This turns out to be important in every optimization problem because of the trade-offs inherent in the set of relationships between variables. The dollar is the conversion factor that points to the sweet spot in the trade-offs.

Figure 1 CYCLING LOAD PROFILE ANALYSIS



Regardless of the kind of generation company, all generators want to minimize costs. An extensive set of relationships exists between variables that ultimately resolves all the costs associated with making electricity. An extensive set of constraints also must be satisfied. Fleet optimization is the minimization of cost or maximization of earnings while satisfying all regulatory and business constraints. A fleet may be optimized using mathematical techniques when the relationships between variables and constraints have been defined. A pretty daunting task, but as has been pointed out, every journey begins with the first step.

Getting Started

In tackling the fleet optimization problem, it is beneficial to begin with a bottom-up approach that leverages one optimization tool that every fleet already utilizes—the energy management system (EMS). EMS is at the heart of all dispatching systems regardless of whether it's used in a non-merchant utility fleet or in a competitive wholesale market.

The EMS uses a rigorous methodology that guarantees least-cost dispatch of the fleet, given the relationship between cost and load for each generating unit and a set of constraints describing the minimum load, maximum load, emissions limits and a host of other constraints applicable to each unit. The fleet achieves the minimum cost of production when each unit has optimized to its minimum cost and the fleet as a whole can change its output as required to meet demand while maintaining a minimized cost dispatch solution. This requirement to keep the least-energy cost while changing the total output of the fleet is the source of the inherent value of unit operating flexibility. It is the requirement that produces value in ancillary services markets. The first important realization is that the fleet can be optimized only when each unit is optimized throughout its operating range.

The place to start is with individual unit short-term optimization. This involves defining all of the relationships between variables that have an effect on the total cost of production in terms of short-term "variable" costs, keeping all of the constraints in place.

For most units, the commodities that must be purchased and consumed to produce electrical energy are:

- Fuel
- NO_x allowances
- SCR or SNCR reagent (ammonia or another reagent)
- SO_2 allowances
- FGDS reagent (limestone, lime and so on.)

Some units have variable costs associated with the purchase of water used for cooling water and FGDS slurry water. As mercury limit regulations become applicable, reagents such as activated carbon may become a significant variable cost.

Remember that units in states that do not have tradable allowances do have limits of some sort placed on their emissions. An analysis of the incremental cost to replace power that cannot be generated by a unit that is running up against a limit is required to determine the virtual value of NO_x allowances.

An operator or a control system can make hundreds of adjustments to try to produce the lowest cost electrical energy possible. These include damper adjustments, fan speed adjustments and burner tilts, among others. In the language of optimization science, these are called manipulated variables. Changes in the manipulated variables result in changes to dependent variables such as flue gas oxygen content, steam temperatures, heat transfer surface cleanliness and so on. Changes in dependent variables result in changes to other dependent variables down a chain of relationships that ultimately result in changes to cost of production. Cost of production represents the ultimate dependent variable and the objective is its minimization.

Other disturbance variables such as ambient temperature, humidity and water in the fuel also produce effects on the dependent variables. Those effects must be characterized to achieve our optimization objective. The combination of all the mathematical relationships is called the objective function.

Many plant performance engineers who tackled unit optimization before about 1992 will testify that the multitude of functional relationships between variables is bewildering. Fortunately, the computing power now exists to gather all the data necessary to characterize the response of dependent variables to changes in the manipulated and the disturbance variables, develop the objective function as a set of mathematical expressions and perform the mathematics required to achieve total cost minimization.

The programs that collect the data and develop the characterizations are known as "neural networks" or more generically, "characterizers." The programs that solve for the minimum or maximum given the characterizations and constraints are called "solvers." Combining the functions of these programs produces a program called an "optimizer." The latest optimizers include the capability to recognize when something about the process has changed and develop new characterizations that are used to "immunize" the optimization problem against that change immediately and for the future.

Short-term Fleet Optimization

Even using state-of-the-art optimization computer programs, characterizing a unit and making its optimizer bullet-proof is not a trivial exercise. However, it is possible and even reasonably economical since effective tools are now available. Having characterized the settings (the manipulated variables) required to minimize real-time total cost of production for each unit, the characterization of cost as a function of unit load can be supplied to the fleet EMS so that it can optimize the fleet.

The cost of fuel across the load range has traditionally been the only commodity represented in this characterization. With the advent of emissions cap-and-trade systems and the cost of emissions reduction reagents used in SCRs and scrubbers, this is no longer adequate. The sum of the costs of the commodities mentioned above must be included in the characterization. The EMS then takes care of dispatching each unit at the load necessary to minimize the total real-time cost of the fleet.

The first challenge in fleet optimization, as distinct from unit optimization, is to update the EMS with fresh unit characterizations whenever appropriate. This means that each unit optimizer must be able to recognize when something about its objective function has changed enough to cause a change in the unit characterization used by the EMS. Almost any performance change of a piece of power plant equipment will cause the unit's objective function to change. Also, any change in the price of variable-cost commodities causes the objective function to change. Because these quantities change frequently, the EMS must have near real-time updates of each unit's cost characteristics in order to achieve an optimized fleet.

Mid-term Fleet Optimization

Having successfully achieved short-term fleet optimization, we turn our attention to optimization in the mid-term. The goal here is to understand how short-term optimization or changes in operating procedures might change a unit's objective function for the better, or might change some operating constraint in a way that produces a lower-cost result from the EMS. Sometimes these sorts of changes result in a change in the cost of maintaining a unit.

Operating with a cycling load profile, for instance, can result in added boiler maintenance costs and replacement power costs when compared to those resulting from a base-loaded profile. However, at the same time, operating with a cycling profile can save money during off-peak hours. In Figure 1 on page 116 an analysis of the benefit of cycling during off-peak pricing hours versus the added cost of maintenance shows a maximum net benefit of $2.2 million at 220 cycles a year. Mid-term fleet optimization is an exercise in balancing the economic benefit of the operating procedure change or short-term optimization against any resulting added cost of maintenance and replacement power, to minimize the total cost.

Some companies have rejected short-term optimization, fearing that resulting mid-term costs might become too high. Decisions based on knowledge, or at least reason, are preferable to decisions made on fear. Therefore, companies that have rejected short-term optimization on this basis are well advised to re-examine that decision.

The major difficulty with mid-term optimization is that it takes time to measure the rate at which maintenance costs increase as a result of the changed operating procedures or short-term optimization. The key is to start with a well-thought-out hypothetical characterization to use in the objective function. As time progresses, measurements of equipment degradation are taken and used to adjust the hypothetical characterization. This makes it progressively more representative of reality. Such a process is the essence of a continuous improvement program, approached from a perspective that combines business and engineering sciences. It is applicable to any number of operations vs. maintenance trade-off situations including reduction of minimum load, unit load ramp rate and cycling operations.

With a clear understanding of mid-term cost characteristics, the variable cost curves or constraints of each unit in a fleet are adjusted to reflect both short and mid-term costs, ensuring the appropriate dispatch to minimize fleet cost of production over the midterm. This addresses one of the most difficult issues between plant management and dispatch or trading management. Commonly, either the plant gives the dispatcher whatever he wants and then blames "erratic dispatch" for a high forced-outage rate, or the plant constrains dispatch in an effort to minimize mid-term costs, but leaves big money on the table in terms of the ability to minimize fleet-wide aggregate cost of production. Mid-term fleet optimization offers the mechanism through which the lowest total cost set of constraints and operating settings can be approached.

Optimization Through Investment

The next essential component to consider in a continuously improving optimization program is investment in the existing units with the goal of further reducing costs while satisfying all regulatory and business constraints. In other words, finding ways of changing the objective functions of the existing units by investing in new equipment or control software that enables the optimizers to resolve to an even lower total cost of production.

A case can be made for using optimization as a means for determining the number and nature of investment projects that should be implemented on the existing units of a fleet. The optimization problem uses investment in each project as the manipulated variable and maximized earnings as the objective. The problem solution indicates the level of investment necessary to maximize earnings; in essence pinpointing the investment level where further investment becomes dilutive to earnings.

Formal fleet optimization is best accomplished using a rigorous mathematical construct that minimizes the cost of production, maximizes earnings and satisfies all regulatory and business constraints. The form of the mathematical construct is well-established and useful. Its application is best accomplished from a bottom-up perspective starting with short-term unit optimization, moving to short-term and mid-term fleet optimization and finally optimization through investment. pe

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