

Using Visual MESA to Optimize Refinery Steam Systems

David Nelson, Gary Roseme - Nelson & Roseme, Inc. / Steve Delk, The MESA Company
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Abstract

Visual MESA[®] is a steam system optimization and management computer program that was originally developed at Chevron and now marketed by Nelson & Roseme, Inc. Visual MESA is currently used at refinery and chemical manufacturing sites to optimize the overall site steam system and the parts of the electrical system that economically trade off with the steam system.

This paper will explore significant optimization variables and constraints commonly encountered in refinery steam system optimization, the strategies Visual MESA uses to deal with them.

The key steam optimization problems to examine include:

- Boiler optimization including dual fuel boilers
- Gas turbine optimization
- Turbo generator optimization
- Spared pump optimization
 - Single turbine sparing a single motor
 - Multiple pumps with mixed drives in the same service (e.g. cooling tower drives)
- Extraction-condensing turbines (either drive turbines or turbogenerators)
- Steam production excess capacity constraints
- Fuel system constraints

Introduction

Steam systems at oil refineries and other large industrial complexes such as pulp and paper mills or large chemical plants are very large energy users that have many degrees of freedom. Manipulating these degrees of freedom with a cost based optimization program usually can result in significant savings in operating costs for a small investment.

This is particularly important with electrical deregulation in the United States. Since the electrical system is the main economic trade-off with a steam system, electrical deregulation provides many new challenges to operating the combined systems at minimum cost.

The extreme swings in electric price have resulted in the following operating scenarios that would rarely have been considered before:

- High incremental electric prices found during electric shortages have resulted in economics to shut down some plant production (of product) and replace that production at some other site (with lower incremental electric prices). This results in extreme savings in electric purchases or increases in electric sales.
- Low incremental electric prices can result in economics that suggest shutting down gas turbine cogeneration trains, especially at night.

In the this paper, Visual MESA will be described and then the meat of the paper will focus on the key optimization variables and constraints in steam system optimization and how they should be handled. This paper will not try to describe all the features of Visual MESA or fully explain on-line optimization technology.

What is Visual MESA

VISUAL MESA is a steam monitoring, modeling, optimization, auditing and accounting program used to manage steam and electricity in refineries, chemical plants and other large or complex facilities. Visual MESA was developed by Chevron Research and Technology in the early 1990's and deployed on-line at the three major domestic Chevron refineries. Visual MESA is now marketed worldwide by Nelson & Roseme, Inc. Visual MESA has four major sets of features:

- **VISUAL MESA for Monitoring.** Visual MESA helps manage your steam system by monitoring all variables and providing alerts on important changes. It tracks key operating parameters including economics. It helps in emergencies with directed load shed advice.
- **VISUAL MESA for Optimization.** Visual MESA finds how to run the steam system at minimum operating cost using SQP optimization. The optimization is customized to your facility so no infeasible or unsafe moves are recommended.
- **VISUAL MESA for "What If?"** Use Visual MESA to predict how your steam system will respond to a proposed change such as a new plant, a plant change, a shutdown or whatever YOUR facility needs to understand.
- **VISUAL MESA for Accounting and Auditing.** Using Visual MESA's data validation techniques, you can accurately account for steam use and track down waste and inefficiencies wherever they exist.

In the rest of this paper we will now focus on the optimization features within Visual MESA.

Visual MESA is built on the steam system modeling program MESA (Modular Energy System Analyzer) from the MESA companyⁱ. The SQP (Successive Quadratic Programming) optimizer from L. Lasdonⁱⁱ at the University of Texas at Austin is used for all optimization although it has been significantly tuned and customized for steam system optimization where there are many mixed integer problems.

Visual MESA has the required features implementing on-line optimization including:

1. Data validation
2. Steady-state detection
3. On-line model identification
4. Control system interfaces
5. Closed-loop model and control system reliability and feasibility checks

Optimization Variables

Optimization variables are those variables where you have a relatively free choice on what that value might be. For example, the rate a particular boiler operates is a free choice as long as the total steam production is satisfied, thus each boiler flow can be optimized such that the most efficient boilers production is maximized. There are two kinds of optimization variables that must be handled in optimizing a steam system:

1. Continuous variables such as steam production from a fired boiler or steam flow through a steam driven turbogenerator. It is also important to determine if the unit should be shutdown recognizing the minimum operating limit of the unit.
2. Discrete variables where the optimizer has to basically decide if a particular piece of equipment will operate or not. The most common occurrence of this kind of optimization in refinery steam system is spared pump optimization where you have to choose which of two pumps to operate, one of which is driven by a steam turbine and one by an electrical motor.

Constrained Variables

Constrained variables are those variables that cannot be freely chosen by the optimizer but must be limited for practical operation. There are two kinds of constraints to handle in steam system optimization:

1. Direct Equipment Constraints. An example of a direct equipment constraint is turbogenerator power output. In a turbogenerator you may optimize the steam flows through the generator within specified flow limits but there will also be a maximum power production limit.
2. Abstract Constraints. An abstract constraint is one where the variable is not directly measured in the system or a constraint that is not a function of a single piece of equipment. An example of this type of constraint is *steam cushion* (or

excess steam production capacity). Steam cushion is a measure of the excess capacity in the system. If this kind of constraint were not utilized then an optimizer would usually recommend that the absolute minimum number of steam producers be operated. This is unsafe because the failure of one of the units could shut down the entire facility.

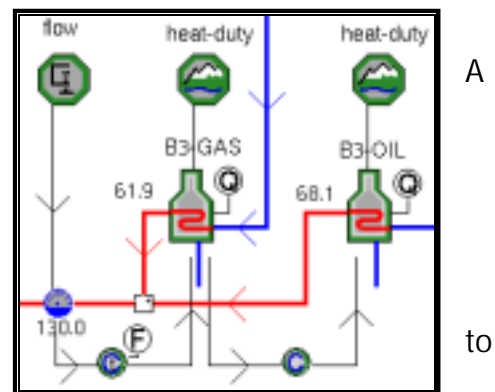
Optimization Examples

This section will describe and discuss several of the important optimizations found in refinery steam systems.

Boiler Optimization

Single and dual fuel boilers are optimized in similar ways. Here we will show an example of a dual fuel boiler.

To model a dual fuel boiler requires a single real boiler be broken up into two MESA boiler blocks. A dual fuel boiler that can fire both fuels at the same time is shown at the right. B3-GAS represents the gas burners and B3-OIL represents the oil burners. You are required to specify the duties for each set of burners independently so an on-line heat duty calculation is required. The steam flow is used to bias the efficiency of B3-GAS so the total predicted and measured steam flows match. The efficiency of B3-OIL is controlled to be a fixed percent of the efficiency of B3-GAS.



The two optimizers manipulate the *heat duty* of the respective fuel burners. The limits should represent the firing limits of the respective burners. The constraint on the meter limits the flow of the boiler within its normal operating range.

When optimizing dual fuel boilers the following factors are important to capture in the model:

1. An on-line method of measuring efficiency.
2. A method that independently measures the efficiency of each fuel.
3. Accurate costs of the respective fuels.
4. A constraint that accurately limits the total consumption of the respective fuels. These limits may be specified by a "*have to burn or fuel gas*" limit on the lower limit and an emission limit on maximum limit.

These factors are important to capture because dual fuel optimizations are not just controlled by the relative boiler efficiencies but also the costs of the fuels. They are limited by real constraints in the refinery, which specify that so much of a particular

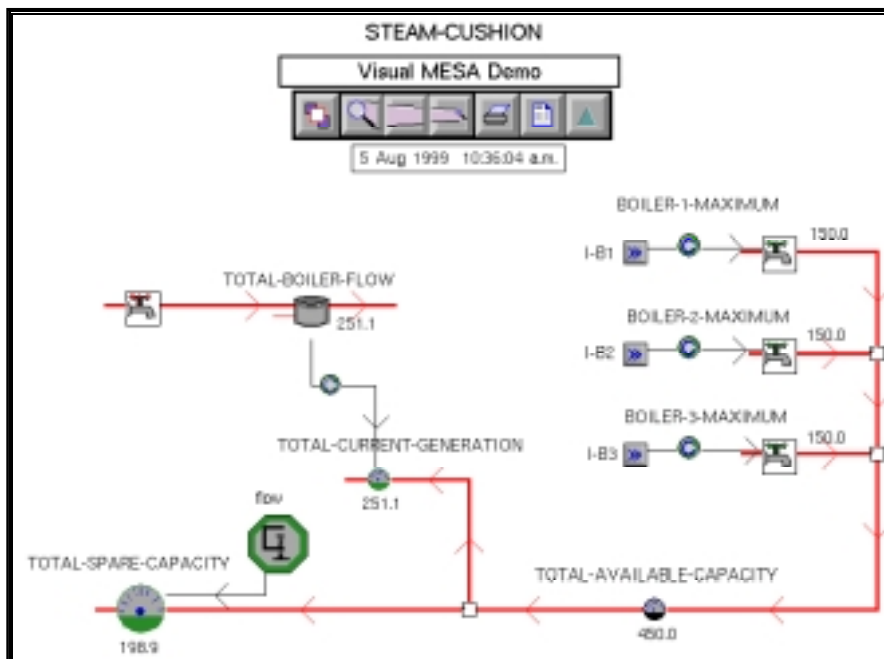
fuel must be burned in the refinery because there it is produced as a byproduct in the refinery and can not be sold. It must be burned. In the US refineries this is typically a fuel gas constraint. There may also be a total limit on a cheap internal fuel source as well. The intersection of all these variable provides a very complex optimization that can have very profound economics.

Steam Production Cushion

When a boiler optimization allows boilers to shut down you must deal with a constraint on the steam production spare capacity (sometimes known as steam cushion). If you don't deal with this constraint Visual MESA will tend to aggressively shutdown boilers until you will have very little spare capacity. This may be the minimum operating cost method to operate the steam system but it is not operationally robust. Without some spare capacity built into the system, a small steam failure could cascade into an entire facility shutdown. Here is how to deal with the steam production cushion constraint.

Create a Logic Drawing Using MESA Blocks

In most Visual MESA models, schematics are created that represent the real physical steam system. We can also use the MESA blocks to do logical and arithmetic calculations for other uses. The drawing below is a logic drawing that determines the total and spare steam production capacity for a steam system with three fired boilers.



1. In the upper left is a collector (or tank) component that adds up the total flow of all the boilers. In its specification is the name of each boiler.

- On the right side are three controller inlet pairs. These are the most important items in this problem. The purpose of these items is to calculate each boiler's maximum capacity. The capacity is determined by the flow of the boiler. For the boilers in this example, the minimum operating flow is 50 and the maximum is 150. The following table of values is used to translate the current flow into capacity:

Boiler Flow	Boiler Capacity
0.0	0.01
50	10
55	150

This table is utilized to provide the SQP optimizer derivative (slope) information. If we don't have a continuously increasing value, the derivative would be zero and the optimizer would not have any directional information on how to satisfy the constraint.

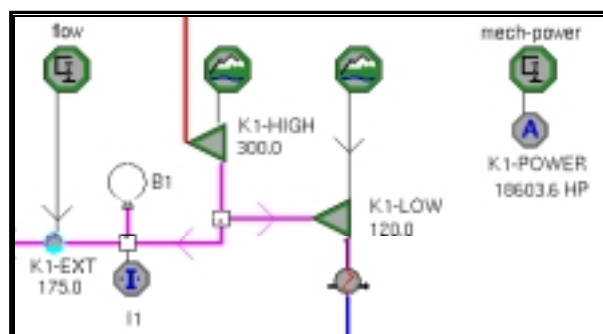
- The total available capacity is then added up.
- A meter block is used to subtract the current generation from the current capacity.
- The result is the *Total Spare Capacity*.
- A constraint is used to insist that the spare capacity be above some minimum value. Usually the constraint should allow the bounds to expand so the optimizer is not penalized for current operation outside the limit and also to prevent infeasible solutions when it is impossible to satisfy the minimum limit.

Here is how to select values for the minimum of the *Total Spare Capacity* constraint.

- This number is basically an insurance policy. The larger the number, the safer the operation. Higher values, however, cost money because it makes you run more equipment than absolutely necessary and typically there are large savings from shutting down your most inefficient steam producers.
- A value of 0.0 indicates no spare capacity. If any boiler trips, you cannot supply the steam required by the plant.
- A conservative number to use is the maximum capacity of the largest steam generator on-line. Then, if your largest generator fails, you will be insured that you have enough spare capacity on-line to service the facility.

Extraction/Condensing Drive Turbines

Optimizing extraction/condensing drive turbines is very common, especially in ethylene plants. The compressor drives are typically > 10,000 HP. On a drive turbine, the mechanical power of the turbine must



remain constant (the process is expecting a constant power output). Here is an example:

A single condensing extraction turbine models as two separate turbines. One from throttle pressure to the extraction pressure and one from the extraction to vacuum pressure.

The accumulator component on the far right calculates the total power from the drive turbine. The constraint above it is an *equality constraint* on mechanical power. This insures that the mechanical power of the unit remains constant at all times during optimization. The correct mechanical power is determined from the simulation results.

In many turbine optimization like this there are two degrees of freedom to optimize but we know all three flows. Selecting which flows to optimize is usually not important for the optimization. In this case we selected the optimization of the high-pressure turbine throttle flow and the low-pressure turbine exhaust flow. The extraction steam is determined by difference and is limited within its operating limits with the constraint block.

It is very important on condensing turbines like this to know the surface condenser pressure accurately. The amount of power produced in the low-pressure section of the turbine is extremely sensitive to this number.

Good efficiency curves are also important to have especially if there are multiple, parallel drives turbines in the system.

Spared Pump Optimization

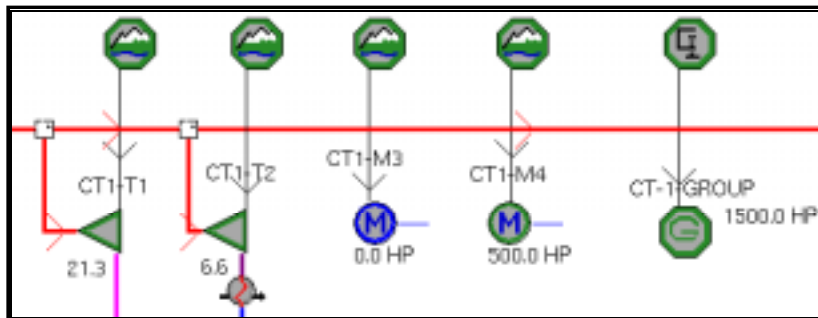
Spared Pump optimizations are mixed integer optimizations problems where you must decide which pump to operate for a predetermined process need. The simple and most typical cases is where you have a two identical spared drives, one driven by a steam turbine and one driven by a electric motor and you are trying to select the least cost option. This will not be described here. A more complicated case that will be described is when you have several drives, not necessarily the same size, in a shared service and you have to choose the optimal set of drives to operate. First some general comments about this problem:

1. The drives optimized typically will not be very large (> 100 HP but < 1000 HP) because large process driver like a compressor are too expensive to spare.
2. There will be lots of drives to optimize. An older refinery that has small turbine drives might have several hundred in the plant.

3. The turbine efficiencies will be pretty low (on the order of 35% isentropic efficiency) and be very hard to determine because of the size of the turbines
4. The process will dictate how many drives to operate and the optimizer will only need to select the correct ones.

Cooling Tower Drives Example

Here is an example of a set of cooling tower pump drives there are four 500 HP pumps. One is driven by a high pressure to medium pressure back pressure turbine, one by a high pressure to condensing turbine and two by motors. Currently, three of the pumps are running (the two turbines and one motor). The optimizer can manipulate the pumps but must maintain three in operation.



Optimizers are connected to each of the drives. These optimizer icons instruct the overall site optimizer to determine if the respective pumps operate.

The CT-1-GROUP icon on the far right is an optimization group accumulator. It is a special kind of accumulator that adds up the mechanical power of each of the drives and then controls the total power during optimization. It does the following:

1. Based on its specification, it specifies the mechanical power for each drive, the optimizer limits and the constraint limits connected to it
2. It also has the built in intelligence to simplify the optimization. For example if all the drives in a group were operating it would make the optimizers unavailable because there are no options. You must run all drives.
3. The constraint hooked to the CT-1-GROUP is either an equality or a minimum constraint on the total mechanical power of all operating pumps. In other words, it requires the optimizer to maintain at least as much total mechanical power from all pumps at the end of the optimization as current operation requires.

Conclusions

In this paper Visual MESA, an on-line steam management program was described. We also discussed several of the key optimization problems found in a typical oil refinery steam system such as boiler optimization, extraction-condensing turbine optimization and spared pump optimization and described how those problems are handled in Visual MESA.

ⁱ S. Delk, MESA Manual, The MESA Company , 1997

ⁱⁱ Y.Fan, S. Sarkar, and L. Lasdon, "Experiments with Successive Quadratic Programming Algorithms," Journal of Optimization Theory and Applications, Vol. 56, No. 3, March 1998.

NELSON & ROSEME, Inc.



Argentina: +54 (11) 45555703 - **Brasil:** +55 (11) 55332381
Venezuela: +58 (212) 2641873 - **México:** +52 (55) 5546-5440
Europe: +34 (93) 3753503
www.soteica.com - info@soteica.com