A Case Study:

Managing Cogeneration Systems

David Dietrich, P.E., M.E.
Dietrich Engineering

ABSTRACT

The small cogeneration plant manager* faces new challenges in that the cost of natural gas and electricity vary as never before. Time-of-day tariffs and deregulated markets require frequent balancing of thermal and electric costs and benefits. A simplified method allows a graphical solution that determines profitability based on fuel and electric rates. Whether this more frequent review is monthly, daily, or hourly depends on local conditions.

"PROFIT MAX FACTOR"

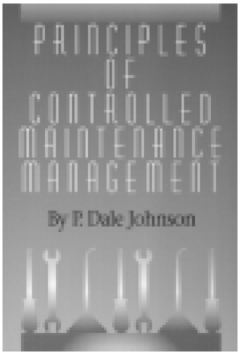
The options for cogeneration plant operation are many, but they are not infinite. Peltier and Ring noted that in order to maximize financial return, a plant may have to operate as baseload at some hours, to follow thermal load at others, and to follow electrical demand at still other times.[1]

Another option may be non-operation. Muschick and Toole developed a personal computer method to guide daily loading decisions for plant operators.[2] That model set a weekly target for energy production based on minimizing total cost.

---

*In this context, a small generator is anything smaller than the hundred-megawatt merchant class.

Streamline and economize your maintenance using easy to follow, step-by-step guidelines...



PRINCIPLES OF CONTROLLED MAINTENANCE MANAGEMENT

NEW

By P. Dale Johnson

An effective, well-managed maintenance program is crucial to the efficient and economical performance of any type of facility. This book presents a complete, step-by-step guide to systematically improving overall maintenance operations, covering maintenance organization, inventory, continuous inspection, planning, scheduling and program management. The presentation is structured in a manner which allows the reader to utilize basic guidelines in implementing a management system which can be customized to the specific requirements and goals of his/her plant or facility, regardless of size or type of operation.

ISBN: 0-88173-354-7

ORDER CODE: 0485B

6 x 9, 137 pp., Illus.
Hardcover, $88.00

CONTENTS

BOOK ORDER FORM

① Complete quantity, book title, order code, price and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Principles of Controlled Maintenance Management	**0485B**	**$88.00**	

② Indicate shipping address: **CODE: Journal 2001**

NAME (Please print) BUSINESS PHONE

SIGNATURE (Required to process order)

COMPANY

STREET ADDRESS ONLY (No P.O. Box)

CITY, STATE, ZIP

Applicable Discount	
Georgia Residents add 6% Sales Tax	
Shipping Fees	6.50
TOTAL	

MEMBER DISCOUNTS
A 15% discount is allowed to AEE members.
☐ AEE Member (Member No.____________________)

③ Select method of payment:

Make check payable in U.S. funds to:
AEE ENERGY BOOKS

☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

CARD NO.

Expiration date *Signature*

Send your order to:
AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

INTERNET ORDERING
www.aeecenter.org

TO ORDER BY PHONE
Use your credit card and call :
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.

The energy accounting method described here, called the "Profit Maximization Factor," combines the power of an hourly annual calculation with the simplicity of a spreadsheet. When compiled along with availability and capacity factor, the **profit max factor** tells a more complete story of plant performance.

The host facility is a 321-bed acute care medical center in the Pacific Gas & Electric (PG&E) service area of northern California. The cogeneration plant includes three 60-kWe Tecogen engines with induction generators in a topping cycle. Hot water from the engines is used to preheat boiler feedwater, heating hot water, and domestic hot water. Plant specifications are given in Table 1.

COSTS AND BENEFITS

Operation of the cogeneration plant incurs two costs. These are the natural gas fuel and maintenance. The facility experienced high natural gas costs during the winter months of 2001. For the year ended February 2001, natural gas varied from a low of $3.17 per million Btu ($0.317 per therm) to a high of $14.64 per million Btu ($1.464 per therm).[3] The his-

Table 1. Cogen Plant Description

C.O.D.	1991
Engines	3× internal combustion
Mfr.	Tecogen
Model	Chevrolet 454 cid V8
Cycle	Otto
Fuel	Natural gas
Cost ($/kW)	2,200
kWe (gross)	180
We (net)	177
Fuel flow	23.28 therm/hr (HHV)
Heat recovery	13.20 therm/hr (HHV)
Electrical efficiency	0.259 (HHV)
Thermal efficiency	0.567 (HHV)
Combined eff.	0.827 (HHV)
Generator(s)	3× induction

torical average had been $3.60 per million Btu ($0.36 per therm) for recent years.

The cost of maintenance under the initial third-party operating contract was $0.03 per kilowatt-hour (kWh). This rate may seem high but it included a performance guarantee as a benefit. More recently, the hospital staff have performed maintenance in-house at an estimated cost of $0.015 per kWh.

Benefits of the cogen plant are the electricity not purchased from the utility and the heat recovered from the engines.

Although wholesale electrical rates were at record highs for the period of study, utility retail rates were still capped at the tariff for regulated energy customers. Electricity transmission and distribution are purchased on a large commercial tariff at primary voltage (called E-20P).

The hospital had negotiated a favorable deregulated energy contract and received a further discount off the otherwise applicable tariff. The composite avoided cost varied from $0.046 per kWh off-peak to $0.152 per kWh on peak in the summer.

These numbers represent the marginal cost of avoided electric purchase. They include standby charge, demand charges, and energy charge, but not the fixed monthly customer charge nor other smaller items.

Thermal benefit recovered from the waste heat of the engines will reduce natural gas consumption of other hospital boilers. As given in Table 1, the cogen plant will recover 57 percent of the fuel input higher heating value as useful heat. The cogen plant also receives a lower transportation charge for fuel.

At low commodity rates for natural gas, the facility natural gas cost can actually go down with cogeneration if the avoided boiler efficiency is low enough, i.e., poor enough. At higher commodity rates for natural gas, the small transportation cost advantage is less of a factor. In any case, in order to compare like quantities, the avoided boiler efficiency must be considered.

FINANCIAL ANALYSIS

The above variables inform the decision on whether and how to operate the cogeneration plant. In the simple case presented by the hospital, all of the electricity is used on-site and valued at the avoided utility cost. Similarly, all of the recovered waste heat is used on-site and valued at the avoided boiler cost. The cogen plant was sized conservatively to achieve this efficient result. The plant is operated as baseload or shut down for maintenance.

All of the above inputs lead to constants and can be arranged in units of dollars per kWh. For any time and season then, the fuel and maintenance costs, and the electrical and thermal benefits, can all be expressed in units of dollars per kWh of generation. In the simplest annual analysis, there arc five combinations of time-of-day and season to be considered.[4] These five values are arranged in a matrix of the form shown in Figure 1. Engineers may prefer to think of this as a bin method calculation. Five bins are sufficient for the hospital.

Variable	Summer	Winter
Peak	($/kWh)	na
Part-peak	($/kWh)	($/kWh)
Off-peak	($/kWh)	($/kWh)

Figure 1. Typical Matrix

When the costs and benefits are expressed in like units, the series of matrices shown in Figure 2 can be added and subtracted, multiplied and divided, just like any other real numbers. More complicated examples with part-load operation present a challenge but always yield to the method.

Annual results for the case study are found in the two matrices at the bottom of Figure 2. These illustrate annual averages for each of the five combinations. It is still necessary to discuss whether annual averages are appropriate criteria, but the purpose of Figure 2 is to present the method.

From Figure 2 it is apparent that the five time-of-day periods have five different results. On-peak operation presents the greatest profit opportunity followed by part-peak operation. Off-peak operation is least profitable. All of these statements are intuitive and understood by facility managers, but quantification is much more helpful.

With regard to the electric rate matrix, the annual average in Figure 2 describes the entire year. That is, the matrix represents each hour of the

Figure 2. Costs and Benefits of Cogeneration—by Season and Time-of-day Interval.

Costs

Fuel	S	W	
PK	0.0600	na	(fuel$/kWh)
PP	0.0600	0.1086	(fuel$/kWh)
OP	0.0600	0.1086	(fuel$/kWh)

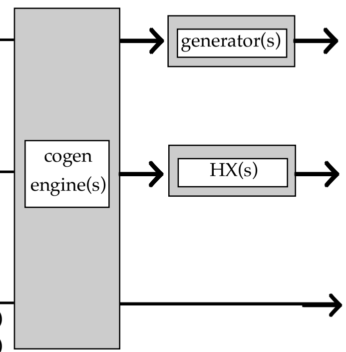
fuel >>>

Mtce.	S	W	
PK	0.0150	na	(mtce$/kWh)
PP	0.0150	0.0150	(mtce$/kWh)
OP	0.0150	0.0150	(mtce$/kWh)

maintenance >>>

Other	S	W	
PK	—	na	(other cost$/kWh)
PP	—	—	(other cost$/kWh)
OP	—	—	(other cost$/kWh)

other (if any) >>>



Benefits

elec	S	W	
PK	0.1515	na	(avoided elec$/kWh)
PP	0.0654	0.0655	(avoided elec$/kWh)
OP	0.0464	0.0472	(avoided elec$/kWh)

elec supply

heat	S	W	
PK	0.0487	na	(avoided gas$/kWh)
PP	0.0487	0.0831	(avoided gas$/kWh)
OP	0.0487	0.0831	(avoided gas$/kWh)

thermal supply

Other	S	W	
PK	—	na	(other benefit$/kWh)
PP	—	—	(other benefit$/kWh)
OP	—	—	(other benefit$/kWh)

other (if any)

Legend

S	Summer
W	Winter
PK	On Peak
PP	Part-peak
OP	Off-peak
na	Not applicable

SUMS OF ALL COSTS AND BENEFITS

Sum	S	W	
PK	0.1252	na	net benefit $/kWh
PP	0.0391	0.0250	net benefit $/kWh
OP	0.0200	0.0067	net benefit $/kWh

heat	S	W	
PK	22.15	na	net $/hr benefit for 177 kWe
PP	6.92	4.43	net $/hr benefit for 177 kWe
OP	3.55	1.19	net $/hr benefit for 177 kWe

thermal supply

year correctly. For the natural gas cost and benefit, use of an annual average would not be appropriate for the entire year, since the cost varied on a monthly basis. Monthly inputs are needed to draw correct conclusions.

Thermal benefit is linked to the fuel cost. Thus, the monthly calculation necessary for natural gas cost will suffice for thermal benefit analysis. Finally, maintenance is considered a constant per kWh for all hours.

Given the above discussion, a monthly analysis is both necessary and sufficient for the hospital in the case study. This monthly analysis shows that the benefits "went negative" for off-peak operation during some winter months, that is, when gas costs were four times the historic rate.

Wholesale electric prices were ten times their historic levels in California[5] but were not generally passed on to consumers. The combination brought about an outcome that was not intuitive. The hospital lost money in trying to do the right thing by running the cogeneration plant as bascload capacity. When the net benefit went to zero or negative the plant should have been shut down.

Another use of the "max factor" is quantification in the accounting sense. The monthly results when compiled yield a family of indices presented in Table 2. Availability is the percentage of hours that the plant was available to run. Capacity factor is the kWh that the plant generated of the maximum possible energy. The max factor is the percentage of profits that the plant earned compared to its ideal.

Table 2. Results of Performance Analysis

Availability	0.891	89% of the time
Capacity factor	0.860	86% of the power
Max factor	0.813	81% of the profit

The cogeneration plant earned approximately $36,000 in profits for the medical center, the great majority of the maximum. There were two winter months where the operating benefit went negative off-peak. Had the plant been shut down for those hours, the profit max factor would have improved.

DISCUSSION

At the other extreme of detail is an hourly calculation. If the California utilities successfully implement the proposed "price responsive load management program,"[6] then an hourly or daily calculation will be needed in order to know whether and how best to run each plant. The small cogenerators up to and including the ten-megawatt class may find assistance from on-line real-time services such as Silicon Energy,[7] Powerweb Technologies,[8] or Teldata Solutions.[9] Each of these could provide part of the data and others may be available.

One reviewer warned that "a lot of software, much of which could provide some pretty spectacular results, languishes on the shelf due to data input demands."[10] That is true but perhaps soon the demand-side technology will catch up with the supply-side technology. Until that time the small generators and cogenerators will continue to improvise. The creative energy manager can put max factor results into a graphical form that shows a family of payback curves as a function of fuel and electric rates.[11] This graphical form allows the user to determine profitability and simplifies decision-making.

Some cautions are necessary. The energy manager must understand the tariff or rate schedule in effect for his or her facility. In particular the demand charge calculation is often complex. In the tariff for the case study, there are three components to the demand charge and a stand-by charge. Further, if a demand charge has been incurred for the month-in-progress, then a recalculation may be in order. For additional guidance on the construction of the max factor, see end notes.[12,13]

The max factor method also has a role in conservation. Energy conservation measures (ECMs) affect site energy usage just as cogenerated power used on-site. Both reduce the amount of power to be purchased. The method described above should be applied to ECMs in facilities on time-of-day rates. The use of an average electricity price in payback calculations may be proper in some cases, but in general will not yield a correct result.

CONCLUSION

The profit max factor offers guidance to cogeneration plant managers faced with variable fuel and electric rates. In energy conservation, it offers a better alternative to use of average electric price in payback calculations. It combines the precision of an hourly annual calculation with the simplicity of a spreadsheet. When employed along with availability and capacity factor, the max factor provides a more meaningful description of cogeneration plant performance.

References and Notes[14]

1. Peltier, Robert V., and James F. Ring, "Managing Cogeneration Systems," *Energy Engineering*, **86**, 5, pp. 626, 1999.
2. Muschick, Russell P., and Loren G. Toole, "Simplified Operator's Guidance for a Cogeneration Plant," *Cogeneration and Competitive Power Journal*, **14**, 2, pp. 64-73, Spring 1999.
3. Natural gas price may not be determined until after the fact, at the end of the billing month. Use of a range or a worst case estimate can still reduce risk to the facility.
4. There is no winter on-peak rate in the Pacific Gas & Electric service area. Part-peak rates apply.
5. Wrote FERC Commissioner William L. Massey, "Prices have not been just and reasonable… the transfer of wealth from purchasers of power to sellers has been absolutely staggering and completely defies the public interest," Concurring opinion on FERC Order dated December 15, 2000, 93FERC61294.
6. California Energy Commission, "Price Responsive Load Management," presented to an AEE conference, San Diego, by Arthur Rosenfeld, Commissioner, May 9, 2001.
7. http://www.siliconenergy.com/
8. http://www.epoweralert.com/
9. http://www.teldalasolutions.com/
10. Personal communication.
11. With electric cost on the x-axis and fuel cost on the y-axis, plot curves for simple payback from, say, two years up to break-even. For the plant in the case study, these "curves" are actually straight lines.
12. D. Dietrich, R. Spitzka, D. Jones, "Case Studies of Small Cogeneration," presented at 22d AEE Conference in Atlanta, October 22, 1999. Published in proceedings and in *Cogeneration and Competitive Power Journal*, **15**, 2, pp. 37-49, Spring 2000.
13. D. Dietrich, "Case Studies of Cogeneration: Ten Megawatt Gas Turbine," presented at West Coast Energy Management Confer-

ence, San Jose, CA, June 22, 2000. Published in proceedings and in *Cogeneration and Competitive Power Journal*, **15**, 3, pp. 2841, Summer 2000.

14. Manuscript dated July 15, 2001 presented at the Integrated Energy Efficiency Congress, Cleveland, Ohio, August 29-30, 2001.

ABOUT THE AUTHOR

Dave Dietrich, P.E., M.E., is proprietor of Dietrich Engineering, Cool, California. He has been a consulting mechanical engineer for 20 years and has experience in both the supply and conservation sides of energy. His experience includes large commercial and institutional facilities on behalf of engineering, accounting, and property management firms in the U.S., Mexico, and Europe.

Dietrich Engineering, P.O. Box 7, Cool, CA 95614.
(t) 530-887-0100; (f) 530-887-0012; dxd1@earthlink.net