Optimizing Steam Turbine Generator Output: Identifying Opportunities

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Abstract
In an effort to maximize steam turbine generator output, Montenay Power Corp. (MPC), operator of the Miami Dade County Resources Recovery Facility (DCRRF) undertook a systematic approach to analyze various turbine and steam cycle issues affecting performance. Several low cost methods were used to identify opportunities for increased megawatt generation.

Shortfalls within the actual steam path through the turbine blading and internals were quantified with a steam path audit and computerized modeling of the blade path. This audit identified a shortfall of 2.5 megawatts (MW) from the original design and almost a full 1 MW gain through work done during the regular maintenance overhaul. The audit proved to be a valuable tool for making good economic decisions on what seal packing to replace/repair during the TG overhaul.

The plant had previously explored re-blading options with the Original Equipment Manufacturer (OEM). This brief study showed turbine internal changes would be capital intensive and carry megawatt improvement claims that were questionable due to various steam cycle issues.

Four major operational parameters that affect turbine performance were examined and quantified. Deviations from design steam flow, throttle temperature, back pressure, and throttle pressure accounted for a loss of 24 megawatts (MW) in generation.

The three low cost methods used to quantify these losses/opportunities were: 1) Acoustic valve leak detection surveys which identified not only low cost MW gain improvement opportunities but also safety and reliability issues; 2) Helium tracer gas leak detection, used to identify vacuum leaks and confirm the leaks were sealed properly; and 3) A complimentary steam trap survey, which also helped identify lost steam and potential risk to equipment.

Preliminary measures were taken to improve steam throttle flow, throttle temperature, back pressure and throttle pressure with a net gain of 7 MW so far. This paper details the methods used and results of the optimization program thus far.

Background
The Miami-Dade County Resources Recovery Facility (DCRRF) is a 4,200 ton (3,810 tonne) per day combined waste to energy and waste processing plant. The plant services the greater Miami – Dade County Florida area by processing approximately one third of the 3.5 million tons (3.2 million tonnes) of waste generated.

The 40-acre (16.2 hectares) site began operations in 1979 and has been retrofitted three times. The first retrofit completed in 1989, involved changing the waste processing system to a dry process and a rebuild of all 4 boilers. [1] See Fig. 1 for a site plan.

The second retrofit completed in 1997 involved upgrading the trash processing system, boosting the facility processing capabilities to over 1.2 million tons (1.1 million tonnes) per year, making it the largest in the world. [2]

The third retrofit completed in 2000 involved complying with the Clean Air Act Amendments (CAAA) of 1990
and meeting more stringent air emissions limits. It involved upgrading the air quality control system and some boiler combustion modifications.

The first retrofit left the facility steam limited as the new boilers had lower steam flow and temperature ratings than the original boilers. The original turbine, condenser, feed water heaters, and cooling tower were left unchanged. An interim fuel feed system design change in 1998 necessitated the removal of the top feed water heater from the turbine cycle.

Steam Cycle Description
The facility had 4 identical boilers, originally supplied in 1977 with a steam rating of: 187,700-lbs/hr (85,141 kg/hr)-steam flow at 625 psig (43.1 bar) and 750° F (399° C) each. The output of the 4 boilers feeds into a plant main steam header of which 2 identical steam turbines draw their steam from. The turbines are rated at 382,791-lbs/hr-steam flow at 614.5 psia and 750.2 degrees F each. The new rating for the boilers after completion of the first retrofit was changed to and remains: 180,000 lbs/hr (81,648 kg/hr) steam flow at 625 psig (43.1 bar) and 721 degrees F(383 Deg C). See Fig. 2.

The original turbine cycle contained 2 identical 'modules' each consisting of a 3-extraction steam turbine, the condenser, a steam jet air ejector set, a gland steam condenser, a low-pressure condensate heater, an open deaerator, a high pressure feed water heater, and a steam driven boiler feed pump turbine. For a detailed description of the original turbine cycle see the heat balance diagram, Fig. 2. This heat balance diagram does not show the steam driven boiler feed pump turbine.

Main steam from the boilers is also intermittently used for augmenting steam to the deaerators, to supply 56 steam sootblowers (14 per boiler), and to drive the steam driven boiler feed pump turbines. The exhaust from the steam driven boiler feed pump turbine is fed into the 2nd or mid point extraction line from the turbine to the deaerator. There is no steam use for heating at this outdoor plant.

Turbine Specifications
Brown Boveri Corporation (BBC) supplied the 2 steam turbine generators in 1979. They are 24 stage once through condensing turbines with 3 uncontrolled extractions. The first stage contains impulse blading and the remaining 23 stages contain reaction blading. The last row blading is an 18” freestanding blade. The extractions are positioned after stages 10, 17 and 21. The 100% load rating is 382,791-lbs/hr-steam flow at 614.5 psia and 750.2° F each with a design back pressure of 1.227 psi and producing 40,546 kw and a heat rate of 10,702 Btu/kwh. See the turbine cross-section diagram Fig. 3.

Proposal from the OEM
In July 2002 MPC contracted the Original Equipment Manufacturer (OEM) representative Alstom to perform an upgrade study. The aim of the investigation was to determine how to achieve maximum power output of the turbine using Asltom’s new state of the art MRB internals (new blading). The conclusion of the survey recommended complete replacement of the steam path (new rotor, blade carriers and new balance piston) The predicted gain would range from 7.1 MW to 2.9 MW over the existing estimated conditions for current output. [3]

Since the new blading would require an all new rotor and internal blade carriers the option was deemed capital intensive. Power output gains stated were also requiring more steam, which was not available at the time. Since power output predictions were based on current operating conditions, which were known to be less than original design, this option for increased MW was not pursued further.

Management decided instead to undertake a systematic approach to analyze and quantify existing shortfalls and employ low cost methods available for boosting output.

Quantifying Losses - Identifying Opportunities
Various methods used (discussed in detail in the following sections) resulted in several areas being identified as opportunities for increased power output. Note: For the work described in this paper, only gross Mw generation was considered. The facility is on a 40- acre site and includes parasitic loads of a metal processing plant, the municipal solid waste (MSW) processing plant, as well as a wood waste/biomass processing plant.

Note: Turbine performance or turbine cycle efficiency is normally measured and stated as unit Heat Rate (HR). Heat rate describes the amount of heat required to produce power and is usually expressed in units of Btu/ kWh. The heat added to the cycle comes from the boilers. In utility operations, where the fuel used to produce the heat is purchased, this is a key parameter. In the waste to energy industry, the fuel used to produce the
heat is obviously not purchased, causing heat rate to not carry as much importance in most facilities. However, if the plant does not have enough fuel/MSW or is limited by turbine for producing the heat capacity, heat rate acquires more importance. For the work described in this paper, only improvements in power output were considered, not heat rate improvements.

**Steam Path Audit**

For the first opportunity identifying and quantifying the internals of one steam turbine were examined during the maintenance overhaul. By developing a computerized model of the design internals and comparing actual conditions with the design, the steam path audit identified 5.0 MW of power loss due to degradation (2.5 MW per turbine). See Fig. 4 for the Opening (and Closing) Power loss by Category. Under operational parameters, the first to be examined was steam flow to the turbines.

### Steam Flow Shortfall

The initial 4-boiler steam flow total was 750,800 lbs/hr and the steam turbine inlet capability is 765,582 lbs/hr total. This leaves a shortfall of 14,782 lbs/hr prior to steam soot blower use or any of the other augmenting uses listed above. The current rating for the 4 boiler steam flow total is 720,000 lbs/hr resulting in a base short fall of 45,582 lbs/hr again prior to any other augmenting steam use.

The current historical data for plant performance shows actual steam flow averaging around 159,000 lbs/hr for the 4 boilers equaling 636,000 lbs/hr or a short fall of 129,582 lbs/hr. This short fall equates to approximately 14 MW.

A check of the delta between the boiler steam production and the steam entering the turbine, using low accuracy station instruments shows an additional steam loss of 41,000 lbs/hr. See Fig. 5 and 6. This short fall is equal to 8(E) MW. This additional generation capability of the TG set was not being used.

Methods used to help identify these opportunities, especially in regards to the delta between steam produced by the boilers and not making it to the turbine included the steam trap survey and the acoustic valve leak detection methods. Figure 6 was developed to correlate low steam flow with loss MW.

### Low Throttle Steam Temperature

The next parameter examined was steam temperature entering the turbine, also known as Throttle temperature. Using the performance correction curves from the OEM, a simplified approximation was developed to correlate the power loss attributed to running low steam temperatures. See Fig. 7.

The plant had struggled in the past with soot blower maintenance and fouling conditions and getting the boilers clean during outage. The plant began using a rotary cable swivel tool to get the boilers exceptionally clean during outages, which helped recover this loss. The cleaning process is described in previous conference proceedings [4]. This throttle temperature in the range of 700(E) F correlated to approximately 2.4 MW of power output loss, (1.2 Mw per turbine).

The methods used to help identify this parameter, was again the acoustic valve leak detection survey. In checking the attemperator /desuperheater valves, they were found leaking by exacerbating the low temperature condition.

### High Condenser Back Pressure

Another key parameter in steam to power efficiency is the turbine back pressure. Using the performance correction curves from the OEM, another simplified approximation was developed to correlate the power loss attributed to running high back pressures. See Fig. 8.

The design back pressure for the unit is 1.227 psia or 27.4 in Hg vacuum. Due to various in leakages, extra steam loading on the condenser from leaking valves and cooling tower inefficiencies, the plant was running at approx. 1.9 psi which also varied slightly from summer to ‘winter’ This parameter accounted for 2.0 Mw power loss. (1.0 Mw per turbine)

Methods used to help identify and improve this parameter included the Helium leak detection and sealing services for in-leakage as well as the acoustic valve leak detection survey finding various valves leaking.

### Low Throttle Steam Pressure

The last operational parameter examined was steam pressure to the turbine, or throttle pressure. Although this parameter according to the OEM correction curves, yields very small power losses it was still graphed in Figure 9. Failing superheater tubes leading to temporary plugging of the tubes until the replacement could be scheduled led to a higher then normal pressure drop. This parameter only accounted for 200 Kw of power loss, (100 Kw per turbine).

Table 1 shows the average lost megawatts as a summary as well as some of the gains made.

### Methods used to Quantify – Target Losses

Steam path audit

During the regularly scheduled turbine overhaul a steam path audit was conducted. The objective of the audit was to assess the condition of the turbine steam path to
identify degradation in thermal performance of the unit
and to point out the cause and location of power and
efficiency losses. [5] The audit works by first submitting
turbine details to the vendor who then builds a
computerized thermal model of the turbine blade path
using a proven program.

Upon opening of the turbine, an on-site turbine
inspection team gathers data, which is inputted, to the
thermal model. The program calculates the resulting
power loss and heat rate degradation for each loss
category, independent of other losses at each turbine
stage. The specific areas of concern addressed by the
audit are Leakages, Surface finish degradation, flow
blockages, and flow path modifications. The results of
solid particle erosion, foreign object damage and
deposits are combined however to best represent the
condition of the unit at the time of the audit.

The modeling allows power loss and resultant annual
costs to be assigned to each part or condition found on
the turbine internals. The information is available while
the unit is in the beginning stages of the overhaul, and
allows plant staff to make educated good economic
decisions as to what repairs to have completed. As an
example, if a certain stage of packing is costly to replace
and has little power loss recovery associated with it, (and
no other operational effects or risks), that work can be
foregone, keeping extra work in check.

On the other hand if a certain set of packing is found
in need of repair and has a major impact on power
output, the work can proceed with a Return on
Investment (ROI) showing a quick payback to justify the
extra work.

Steam Trap Survey
A major trap manufacturer conducted a complimentary
steam trap survey in August 2004. The steam traps are
located, identified, and tagged with a stainless steel tag
and clip. Each trap is tested to determine its operating
condition. The method used included ultrasonic listening
and visual inspection, and where possible atmospheric
discharge. Temperature alone can be misleading. A
temporary red and white paper tag is attached to each
failed trap in addition to the stainless steel tag.

Notes are made of specific problems such as
water hammer, poor or improper insulation, steam
leaks in piping or valves, improper installation or
application of the wrong style trap. Traps are
classified into one of the following categories: OK,
Blow Through, Leaking, Rapid Cycling, Plugged,
Flooded, out of service or not tested. [6] The
manufacturer uses data supplied and the results of
testing to estimate the amount of steam lost from
the traps.

Acoustic valve leak detection
Originally developed by the U.S. Navy for use
aboard submarines in the late 70's, this technology
detects whether valves are holding or leaking. Leaks
usually are in the turbulent flow regime, particularly
at the pressures found around a steam cycle. The
turbulence produces ultrasonic signals in the 10 to
100 kHz frequency range, which are detected at the
outside of the valve and measured by the analyzer.
Recorded signatures are similar to those used in
vibration analysis. The signatures are analyzed to
determine if the valve is leaking internally. The
signals are detected by special accelerometers
temporarily place in contact with the valve.

Typically temperatures of the valves exceed the
temperature limits of the transducers so a standoff 
or extension device is used [7]

Three basic test procedures can be used. Where
block valves can be closed to relieve the differential
pressure across the valve being tested, the Signature
Comparison method can be used. In cases where
there are no block valves, or the block valves cannot
be closed, the Differential Signature method is used.
This involves background signatures taken up and
downstream of the valve and at the valve itself. The
third method, the Direct Comparison method,
involves recording only the Pressure signatures at
the valves on essentially identical valves to compare
which valves are leaking the worst in the set. [8]

When the leak signal plus background noise is
subtracted from just the background signal the
determination can be made whether the valve is leaking
or not. See Fig. 10

This testing has been found to benefit in several
ways. It finds the valves that are leaking steam back
to the condenser. These valves not only cause a loss
in power MW by not going through the blade path,
but also put an additional load on the condenser,
which causes it to operate at a slightly higher back
pressure resulting in additional power loss.

Attemperator or de-superheater block valves and
control valves can also be checked. These valves leaking
by can exacerbate low steam temperatures costing
further power loss. By conducting the survey prior to a
planned outage, valves can be targeted for repair. Again
with estimates from the valve survey, return on
investments for the valve can be calculated to show very
short payback and justify the expense.
**Helium Leak detection and sealing**

Venting equipment must be installed on a steam condenser to prevent non-condensable gases from accumulating in the vapor space. Small amounts of non-condensable gases inhibit heat transfer and adversely affect unit performance by increasing back pressure. Large amounts can virtually block the condensation process. [9] Although some of these gases are released from solution and some arrive with the exhaust steam, the major non-condensable component is air. Most plants use steam jet air ejectors or vacuum pumps for evacuating these non-condensable gases.

Although precautions are taken to make the system vacuum-tight, leaks do exist. Most of the air finds its way into the sub-atmospheric condenser system as leakage. Older initial methods employed shaving cream sprayed around flanges and valve stems to try and identify vacuum air in leakage sources.

The use of tracer gas testing has been more widely accepted as a method to help identify air in leakage sources. Tracer gases such as Helium or SF6 are sprayed intermittently around the sub-atmospheric portions of the turbine cycle, while a mass spectrometer detects low concentrations of the gas at the outlet of the extractor. Helium is normally sufficient to identify leaks but SF 6 can be used if higher sensitivity is required. Once the Helium is detected, areas are re-sprayed to confirm the leak source. The time it takes for the Helium to be detected, the number of divisions on the scale of the mass spectrometer and the time it takes to clear the monitor all indicate the severity of the leak.

Once identified the leaks can be resolved. At Dade, we have found that repairing the leaks while the mass spec and helium is still set up allows us to re-test right away and confirm the leak has been addressed.

**Optimizing the Output**

The steam path audit helped identify turbine physical degradation, and document exactly which components contributed to what degree of the power loss. In addition, the closing audit documented the power gain from the seals and packing that were replaced.

Turbine power loss went from 2.5 Mw lost at the opening audit, to 1.6 Mw lost at the closing, a gain of .9 Mw per turbine or 1.8 total. This gain was confirmed once the unit came back on line. See Fig. 4 for the results of the audit broken down by category.

The steam trap survey helped identify the gap seen between the boiler output steam and the turbine inlet by finding an estimated 6,390,000 lbs/year of lost steam from defective traps. These traps were earmarked and replaced during subsequent outages for a power gain of 50 KW per unit or 100 KW total.

In addition to finding small power gain opportunities, and perhaps more importantly, the steam traps survey also helped in reducing risk to plant equipment. Water damage to the boiler tubes from water in the steam sootblower lines was prevented by pointing out traps on that system that were non functional. Also non-functioning traps on turbine extraction lines were found and corrected preventing turbine internal damage.

The acoustic valve survey found several opportunities for power gain. The superheater attemperator block valves were found leaking. By repairing these during subsequent outages, an estimated increase of 20 degrees F superheated steam correlates to a power gain of 0.2 Mw per turbine or .4 Mw for both.

Another valve identified was the wrong application of the hogger jet from the steam jet air ejectors. Valves in this service should be at least a class IV and preferred to be a class VI tight sealing valve by IPC standards. This valve replacement is estimated at improving back pressure and increasing power output by 0.1 Mw. Main steam and turbine automatic drain valves were found leaking, attributing to further power gain opportunities of 0.1 Mw. In addition several leaks to atmosphere off the sootblowing system identified and additional 0.2 Mw gain. Many of the valves and leaks identified work toward increasing steam flow to the turbine and further reducing the delta between the boiler to turbine steam flow.

The Helium tracer gas testing works well for the plant. Once the leakage area is identified, a special flexible sealant is used to seal up the leaks while the unit is on line. This sealant was specially formulated for the purpose of sealing air in-leakage and is drawn into the leaking flange. It remains flexible through several thermal cycles, normally lasting to the next overhaul (5 years). The plant seals the leaks as soon as they are identified. This allows subsequent testing the same day to confirm the leaks are sealed.

When the turbine shaft sealing glands have been found as a source of air in leakage, the gland steam pressure is varied (increased) to eliminate the leak. Again re-testing at various pressures allows optimizing the air in-leakage and improving back pressure. Gains from this method have totaled .6 MW in the past and are seen the very next day. Note: When raising gland steam pressure settings caution must be observed. Water in the lube oil must be monitored as too much gland steam leakage can affect lube oil quality.

Communication with the operations group also helped optimize the output. By posting several of the key figures in the control room, the operations group could get a grasp on the effect off design
conditions had on the output. This caused them to look harder for items affecting the performance.

Another area addressed was the surface area on the superheaters. By quantifying the effect temperature had on output, an ROI could be calculated for a slightly longer superheater pendant style. The larger surface area will be installed this year on superheaters to improve throttle temp. This gain is estimated at .7 Mw’s.

Ongoing sootblower refurbishment program expenditures can also be justified based on the gain in throttle temperature expected.

Regular condenser cleaning can improve and/or maintain the condenser efficiency and optimize turbine back pressure. If required ROI calculations with before and after condenser cleaning back pressure readings can help justify this program.

Other resources
Some other resources available include the US Department of Energy, Energy Efficiency and Renewable Energy program. The Industrial Technologies division has a Best Practices program that works with industry to identify plant-wide opportunities for energy savings and process efficiency.

Through the implementation of new technologies and systems improvements, companies across the US are achieving immediate savings results. Solicitations are available where government funding can be awarded to help you with energy improvements. The web site for more information is: http://www.oit.doe.gov/bestpractices.

Planned – Further Investigate
To help better assess actual temperatures and pressures around the unit, a handful of high accuracy test instruments were purchased. The plant plans on installing temperature and pressure transmitters and Resistance Temperature Devices (RTD’s) to verify plant instrumentation and more accurately assess shortfalls. The key parameters to be examined are steam throttle temperature, back pressure and first stage pressure, (an indication of flow).

In close proximity to the Dade facility, an MSW landfill has landfill gas available, which is currently being flared off. An investigation has begun into the economics of bringing the landfill gas to the site and used in a small package boiler rated at the same conditions of the existing boilers, to take advantage of the extra turbine generator capacity.

Cooling tower upgrades exist and are under investigation whereby new design fill material and drift eliminators have shown performance improvements at other facilities. Cooler condenser water can be estimated with its impact on back pressure and again a return on investment can be calculated.

Consideration is being given to replacement of the steam jet air ejectors. Replacing them with a mechanical extractor (vacuum pump) would result in less steam consumption there and more steam available for power output. There are reports that the mechanical exhauster can increase in removal capacity as air in-leakage increases resulting in better back pressure and increased power output over a steam jet air ejector. [9]

The facility currently quarter’s whole tires on site in preparation for land filling. Independent of the landfill package boiler option above, the facility is also investigating a small package boiler fired on tires or tires derived fuel (TDF). If the economics of compressing and cleaning the landfill gas from above do not prove the project feasible, perhaps the TDF boiler will.

With the removal of the top feed water heater during a fuel feed modification, temperatures run well below the design point of 350 degrees F. The ROI is being calculated for a project to install a replacement heater, possibly in the flue gas stream.

Consideration is also being given to re-piping the unused first extraction steam line to augment the deaerator heater. This would allow for additional mega watt output through out the first section of the turbine blading rather than using main steam.

Summary - Conclusions
When the new blading proposal from the OEM required extensive capital including a new rotor, and had power gains based off existing conditions, the plant staff decided to look more closely at the operating conditions. By correlating the OEM turbine correction curves to actual conditions, the plant was better able to understand where opportunities existed for improved optimized power output without re-blading.

Operating at off design conditions made up significant challenges as well as opportunities. Steam flow, steam temperature, and back pressure were the largest areas identified for improvement and totaled 22 Mw’s. The internal blading of the turbine itself was identified with a 2.5 Mw shortfall from original design due to degradation. Maintenance on the turbine internals gained back almost a full 1 Mw.

By using Acoustic Valve leak detection surveys, steam trap surveys, Helium tracer gas techniques and turbine steam path audits, the plant was able to pinpoint and quantify factors affecting the steam to power efficiencies. Gains made so far in the program total close to 7 Mw’s recovered.

Communicating the effect of operating off design conditions to the operations group also helped raise awareness and improve power output. Placing copies of
simplified correction curves in the control room helped
them focus on the various parameters affecting power
output.

The plant staff is working on further opportunities for
increased power output. These include more superheater
surface area for improved temperature and possible
sources for additional steam flow. The turbines have a
reserve capacity that can be capitalized on.

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**Table 1 – Summary of Power Losses and Gains**

**Miami-Dade County Resources Recovery Facility**

**Site Plan**

![Site Plan](image)
Figure 2 – Heat Balance
Montenay Power Corp
Miami 77 – Unit 2

Opening Audit Power Loss by loss Category

Closing Audit Power Loss by loss Category

Figure 4 – Blade Path Degradation and closing audit
Figure 5 – Boiler vs. Turbine Steam Flow

Figure 6 – Steam Flow to Power correlation
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Figure 8 – Back Pressure to Power Loss
Annual Losses due to Low Throttle Pressure

**Figure 9** – Throttle Pressure to Power Loss

**Figure 10** – Acoustic valve survey basic principal