Fourth CNS International Conference on CANDU Maintenance
November 1997, Toronto, Canada

THERMAL EFFICIENCY IMPROVEMENTS - AN IMPERATIVE FOR NUCLEAR GENERATING STATIONS

Dr. Sal Hassanien, P.Eng
Technical Superintendent, Bruce B, Ontario Hydro
Bruce B, B01, Box 2000, Tiverton, Ont. NOG 2TO
Tel: 519-361-2673 ext. 5651, Fax: 519-361-7790

Scott Rouse, P.Eng
In-House Account Executive, Genco, Ontario Hydro
700 University Avenue, H10 F18, Toronto, Ont. M5G 1X6
Tel: 416-592-8044, Fax: 416-592-4841, Email: srouse@hydro.on.ca

Abstract

A one and a half percent thermal performance improvement of Ontario Hydro's operating nuclear units (Bruce B, Pickering B, and Darlington) means almost 980 GWh are available to the transmission system (assuming an 80% capacity factor). This is equivalent to the energy consumption of 34,000 electrically-heated homes in Ontario, and worth more than $39 million in revenue to Ontario Hydro Nuclear Generation.

Improving nuclear plant thermal efficiency improves profitability (more GWh per unit of fuel) and competitiveness (cost of unit energy), and reduces environmental impact (less spent fuel and nuclear waste).

Thermal performance will naturally decrease due to the age of the units unless corrective action is taken. Most Ontario Hydro nuclear units are ten to twenty years old. Some common causes for loss of thermal efficiency are:

- fouling and tube plugging of steam generators, condensers, and heat exchangers.
- Steam leaks in the condenser due to valve wear, steam trap and drain leaks.
- Deposition, pitting, cracking, corrosion, etc., of turbine blades.
- Inadequate feedwater metering resulting from corrosion and deposition.

This paper stresses the importance of improving the nuclear units' thermal efficiency. Ontario Hydro Nuclear has demonstrated energy savings results are achievable and affordable. Between 1994 and 1996, Nuclear reduced its energy use and improved thermal efficiency by over 430,000 MWh.

Efficiency improvement is not automatic — strategies are needed to be effective. This paper suggests practical strategies to systematically improve thermal efficiency.

Introduction

Business today is expected to achieve more with less. Better performance and reduced environmental impact with decreasing resources are now the norm in North America's competitive electricity industry. Ontario Hydro Nuclear is no exception. In the foreseeable future, competition will be based on the cost per kWh to the customer. The lower the price – the better the profit.

Improving nuclear plant thermal efficiency is the fastest means to improve profitability (more GWh per unit of fuel) as well as competitiveness (cost of unit energy). Looking at it another way, the same output can be achieved with less reactor power. This translates into an increased life span of the major generating equipment, for example, pressure tubes, steam generators, and condensers.

Thermal efficiency is also a good indicator for measuring operation and maintenance quality.

The average thermal performance for an Ontario Hydro nuclear unit is 29-31% [Ref. 1]. This means that the reactor has to produce approximately 3 MW in order to deliver 1 MW to the transmission system. Comparing this situation with the automotive industry, it would mean that two out of every three cars produced would be left to rust at the back of the plant.

A one and a half percent increase in thermal performance for Ontario Hydro Nuclear's operating units (Bruce B, Pickering B and Darlington) is equivalent to 980,000 MWh or over $39 million. The average "all-electric" home in Ontario consumes 28,600 kWh annually. (Energy is assumed to be worth four cents per kWh, the average selling price to the transmission company. See attached table). A one and a half percent thermal efficiency improvement is feasible. The Electric Power Research Institute (EPRI) estimates that improvements of two to four percent are possible at most fossil and nuclear power plants.

In September 1996, at the EPRI Workshop on Plant Performance Improvement, it was reported that many U.S. nuclear plants had achieved a two to three percent improvement by implementing a specific program. In support of EPRI, the American Council for Energy Efficiency (ACEE) estimates that the heat rate of all fossil and nuclear plants can be improved by three percent [Ref. 2].

In 1994, Ontario Hydro's In-House Energy Efficiency Group spearheaded a corporate-wide program to improve thermal efficiency and reduce electrical consumption. The program achieved over a billion kWh annual savings in three years, worth more than $50 million per year [Ref. 3]. Nuclear contributed one third of the results – 431 GWh. Thermal performance improvements accounted for 59% of the energy savings achieved. The success of the In-House initiative demonstrates that a one and a half percent improvement is not only feasible, but affordable.

The contribution from Nuclear and from the Fossil generating units suggests the opportunities are too large to overlook. The opportunities are, in many cases, common between businesses, for example, improved monitoring technologies, maintenance practices, employee awareness, and adopting progressive business drivers that recognize and support energy efficiency improvement.

Most of Ontario Hydro's nuclear generating units are ten to twenty years old with fifteen to twenty-five year old designs. Due to age, these units will suffer varying degrees of loss of thermal performance. Most of the heat losses that reduce the thermal efficiencies occur in the secondary side (steam generators, turbine and condenser, and associated equipment). The reduction of heat transfer rates and the steam generation are caused by several mechanisms, e.g., plugging of leaking tubes, fouling and scale building in boilers and heat exchange tubes, etc. Thermal performance loss is gradual and can not be adequately monitored by the existing plant instrumentation, which is of the same vintage and not accurate. Typically, the thermal performance of the units is reduced by two to five percent after ten to fifteen years of operation unless a program is established to optimize operation and improve maintenance of the secondary side.

Although there have been several initiatives in Ontario Hydro nuclear units to reduce heat loss or improve equipment on the secondary side, these efforts have been fragmented. The initiatives suffered as they competed for resources and priorities due to a short-term focus on maintaining the unit's operation. In some cases, the decisions for implementing some of the programs to improve thermal efficiency were accepted based on the short-term impact on OM&A (as a cost) rather than as an investment. These decisions were made in spite of the fact that the typical return on investment for thermal improvement projects is 300% to 500% with short payback periods.

The Main Causes for Thermal Losses

All heat transfer equipment such as steam generators, condensers and heat exchangers suffer from reduction in heat transfer, steam generation, or energy extraction rates as the equipment ages. This loss is normally due to fouling, or loss of heat transfer area due to tube plugging, or flow rate reduction due to sleeving [Ref. 4,5,6]. Also, steam leaks develop, for example, to condenser, atmosphere, or lake due to valve wear, steam traps and drains leaks. All steam and hot water leaks contribute to thermal losses.

Another cause for loss of performance is deposition of corrosion material and impurities. For example, turbines experience loss in performance due to pitting, cracking, corrosion and erosion of the turbine blades. Also, inadequate metering contributes to reduced performance. Feedwater rates are typically measured by an orifice plate or a venturi. Deposition of corrosion products results in measured feedwater flow that is higher than the actual flows [Ref. 7,8,9,10]. Even at what appears to be steady-state condition, there are small transients. After the transient, the system may not go back to exactly its original condition for a period of time. This was evident at Bruce B when the power was measured with higher accuracy by means of real-time energy monitored at a two-minute frequency. In most existing units, the current installed flow, temperature and pressure measurements suffer from similar inaccuracies.

EPRI data supports the typical average performance loss of three to five percent for ten to twenty year old plants [Ref. 8, 10]. To illustrate, for a 1,000 MW pressurized water reactor (PWR) nuclear unit,

* 1 kg/s error in feedwater flow results in 1.85 MW error
* 1 deg C error in feedwater flow results in 7.7 MW error
* 1 PSI error in steam pressure results in 0.15 MW error.

Strategies To Improve Thermal Performance

As the existing stations age, the thermal performance will continue to decline. Hence, it is imperative to develop strategies and to implement systematic, long-term, continual improvement thermal performance programs. Strategies were developed based on work at Bruce B, communication with several U.S. nuclear plants that have established programs to improve thermal performance, and EPRI research (*Thermal Performance Engineer Handbook* (under preparation) [Ref.12]). Implementing the following seven strategies will ensure improvement to thermal efficiency.

1. *Establish Continual Improvement Program*

   A program with specific goals, objectives, targets and plans needs to be developed. The critical success factors are:

- Visible commitment and support from the station senior management.
- Develop the thermal improvement program as a profit generator rather than as a short-term OM&A cost burden.
- Set clear and specific goals with measurable targets.
- Commit adequate resources.
- Raise energy efficiency awareness in the plant through orientation and training.
- Integrate the program into normal operation, maintenance, and procurement activities.

2. *Monitor Improvement and Optimization of the Operation*

- Develop an on-line, real-time heat and mass balance program (heat balance frequency of 10 minutes) to immediately tell the operators there are some missing MW's so that they can take corrective action. Many U.S. nuclear units have on-line mass and energy balances [Ref. 11].
- Improve the secondary system equipment surveillance to establish trends and detect loss of performance or equipment degradation early. For example, valve leak detection program, steam trap, heat exchangers, steam generators monitoring and inspection programs.
- Thermography program for insulation and heat loss reduction [Ref. 4,6].
- Optimize boiler blow down flows to reduce unnecessary heat losses while maintaining the impurities concentration below the allowable limits [Ref. 1].

3. *Improve Instrumentation (Advanced Measurements)*

- Replace existing critical flow temperature and pressure instrumentation with accurate, modern, digital instrumentation.
- Rely more on ultrasonic flow measurement for feedwater flows.
- Replace present RTDs with advanced temporary measurements (self-calibrating RTDs).
- Increase instrument's redundancy and calibration frequency and precision.

4. *Improve Control of the Secondary Side*

- Improve flow, pressure and temperature control through the use of distributed digital control systems and diligent operator monitoring and actions [Ref. 8,10].

5. *Improve Maintenance*

- Improve surveillance and monitor the equipment condition.
- Improve leak detection and time to repair leaking valves and steam traps expeditiously.
- Perform on-line condenser tube cleaning.
- Periodic turbine performance testing, steam trap leak and valve eradication.
- Use thermography to determine heat escape.
- Improve insulation.
- Frequently calibrate feedwater flow.

6. *Dedicate a Thermal Performance Group*

- Implement a dedicated "Performance Group" that looks after day-to-day monitoring, optimizing operations and looking for any "missing MW's". This follows the example of most of the excellent U.S. nuclear utilities.

Also, this group would be responsible for long-term enhancements of instrumentation and maintenance and design modifications specific to increasing output. Typically, the size of the group is from four to twelve persons. All the modifications are normally capitalized. The group is considered a profit centre not a cost centre [Ref. 2].

7. *Cost-effective Design Modifications*

- Replace inefficient equipment, or equipment that has reached the end of its useful life, with more efficient designs.
- Carry out some design modifications to the existing equipment to improve monitoring or its operation or control.
- Examine each design modification on its cost effectiveness, sustained savings and payback period [Ref.1,2].

Conclusions

The thermal performance of the existing stations will continue to decline because of aging. Hence, it is imperative to develop strategies and to implement systematic, long-term, continual improvement of thermal performance programs to regain and reduce degradation in thermal performance of the nuclear units.

Ontario Hydro's In-House initiative demonstrates the benefits of the program by saving over 1.2 billion kWh annually, with 703 GWh directly from thermal and conversion efficiency. Industry experts, including EPRI, believe a 2-3% savings is possible. Ontario Hydro Nuclear can realistically save at least 1.8%.

Benefits of thermal performance improvements to the existing nuclear stations are:

- Improved competitiveness (lower cost of unit energy).
- Increased profitability (more GWh to the grid).
- Reduced environmental impact (less spent nuclear fuel waste to store).
- Increased life span of key components (pressure tubes, steam generators).
- Earned emission credits as energy saved is converted to CO_2, NOx, and SOx credits.

We believe the seven-element thermal efficiency program can achieve at least a one and a half percent improvement to Ontario Hydro's nuclear units. The question is not whether we can afford to improve – but can we afford not to?

References

1. Hassanien, S., Ontario Hydro. *Thermal Efficiency (Performance Improvement) Imperative,* Thermal Efficiency Improvement Seminar, Tiverton, ONT, Nov. 1996

2. Eckert, T., EPRI. *EPRI Perspective,* EPRI Plant Performance Improvements Seminar, Asheville, NC ,Sep. 1996

3. Rouse, S., Ontario Hydro. *Ontario Hydro Report: Review of 1996 In-House Energy Efficiency Results*, Apr. 1997

4. Verdin, G., Babock and Wilcox. *Steam Generator Performance*, Thermal Efficiency Improvements Seminar, Tiverton, ONT, Nov. 1996

5. White, G., Dominion Engineering. *Causes for PWR Steam Generator Performance Degradation*, EPRI Plant Performance Improvements Seminar, Asheville, NC, Sep. 1996

6. Bell, R., Heat Exchangers Systems. *Power Plant Heat Exchanger Condition Assessment*, EPRI Plant Performance Improvements Seminar, Asheville, NC, Sep. 1996

7. Sullivan, C., IES Utilities. *Feedwater Venturi Fouling Study*, EPRI Plant Performance Improvements Seminar, Asheville, NC, Sep. 1996

8. Estrada, H., Caldon Inc. *An Assessment of the Integrity and Accuracy of Feedwater and Temperature Measurements*, EPRI Plant Performance Improvements Seminar, Asheville, NC, Sep. 1996

9. Zobin, D., Ontario Hydro. *Feedwater Flow Measurement Using UT*, Thermal Efficiency Improvement Seminar, Tiverton, ONT, Nov. 1996

10. James, R.W., EPRI. Lubnow, T., MPR Associate. Hauser, E., Caldon Inc. *EPRI Ultrasonic Flow and Temperature Measurement System for PWR*, Balance of the Plant Performance Monitoring Group Meeting, Asheville, NC, Sep. 1996

11. Woodword, R., IES Utilities. *Plant Information System*, EPRI Plant Performance Improvements Seminar, Asheville, NC, Sep. 1996

12. EPRI Plant Support Engineering. *Thermal Performance Engineer Handbook*, In Preparation, May 1997 draft, to be published by EPRI by Dec. 1997

Nuclear Business Unit Internal Energy Saving Program
1994 to 1996 Executive Summary

OH Saved - 1,270,000 MWh
Nuclear Saved - 34% of OH total, or:
431,230 MWh
144,919 MWh (SS) Station Service Saved
286,311 MWh (TE) Thermal Efficiency

Facility Information					**Station Service**			**Thermal Efficiency**[3]		
Facility & number of units	Oper. Units	Generator Output MW	Station Service[1] MWh	Comments:	Station Service Economic Potential [2] MWh^	**Reported Energy Saved: 1994-96** **MWh**	**%**	1.5% Assumed Improvement MWh	**TE Saved 1994-96** **MWh**	**%**
Pickering 8	4	2160	1,210,982		121,098	**9,792**	**8%**	227,059	**185,872**	**82%**
Darlington 4	4	3740	2,096,794		209,679	**0**	**0%**	393,149	**78,791**	**20%**
Bruce A 4	0	0	0		0	**33,666**		0	**11,959**	
Bruce B 4	4	3400	1,906,176		190,618	**34,356**	**18%**	357,408	**9,689**	**3%**
HWP						**65,226**				
Other						**1,880**				
Sub-totals			5,213,952		521,395	**144,920**		977,616	**286,311**	
Value of energy saved - at 4c/kWh					$20,855,808	**$5,796,800**		$39,104,640	**$11,452,440**	

Benefits of Nuclear's Internal Energy Saving Program:

Financial; Long Term Marginal Cost is $.04/kWh, e.g; **$17,249,240** per year, As a result of energy saved between 1994-96!
$59,960,448 per year, may be economically achievable

Nuclear Recovery Plan: Demonstrated Success;

Increase Productivity	**$11,452,440**	per year	Thermal Efficiency of 286,311 MWh
Decrease Cost	**$5,796,800**	per year	Station Service reduced by 144,920 MWh
Employee Involvement		Empower staff: 'Nuclear Excellence' Objectives! e.g. Supported by both Society & PWU	

Notes:

1 Station Service is estimated at 8% of output.
2 Economic potential is based on industrial experience, 10% (Scott Rouse 592-8044). Energy is MW*8,760 hrs*.8 (80% Capacity Factor)
3 Thermal Efficiency: (Peter Stern, x- 6668) economic potential assumed at 1.5%; (EPRI reports potential 2-3% savings).

95