

SIEMENS

A LARGE STEAM TURBINE RETROFIT DESIGN AND OPERATION HISTORY

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Abstract

A reliable source of low-cost electricity is fundamental to a healthy economy. The current market supports both the development of new generating resources and the retrofitting of the existing infrastructure to meet the increased electrical demands.

While new green-field projects are an important part of the long-term expansion of the growing demand for electricity, they require a large capital outlay and a lengthy approval process involving numerous government agencies including Siting Councils, Environmental Agencies (State and Federal), and Utility Commissions. On the other hand upgrading existing infrastructure with modern technology can occur in a shorter timeframe, provide improved unit performance, increased reliability and longer operation between inspections – all with less capital investment.

These technology retrofit solutions represent an opportunity for generating companies to quickly and cost-effectively improve their competitive position by improving the operation, performance and reliability of existing equipment.

This paper describes the design and the results of the Steam Turbine Replacement Components that were supplied by Siemens Power Generation to Dairyland Power Cooperative.

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1.0 INTRODUCTION

Dairyland Power Cooperative and Siemens Power Generation (Siemens PG) successfully retrofitted the High Pressure / Intermediate Pressure (HP/IP) and Low Pressure (LP) turbine steam paths of Dairyland Power Cooperative's (DPC) J. P. Madgett Unit #1. This is a coal-fired sub-critical steam plant which entered into commercial service in 1979, has a nominal rating of 365 MWs. The turbine-generator set is a tandem-compound design with a combined high pressure and intermediate pressure section and one double-flow, low pressure section (figure 1). The goals of the upgrade program included: improved efficiency at all loads, increased maximum capacity and prolonged maintenance intervals.

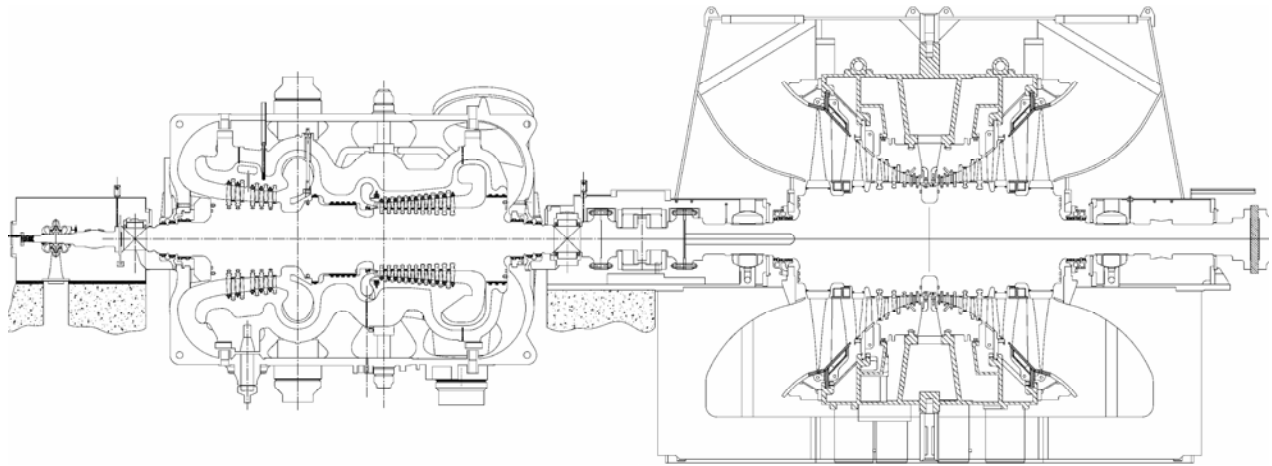


Figure 1 – Madgett Unit #1 Longitudinal

Although many factors influence the development of an effective turbine upgrade program, the key factors considered by DPC during the evaluation process were performance improvement, proven technology and reliability.

Additional criteria that were evaluated by DPC with respect to each of the potential turbine suppliers were:

- Performance Guarantee and Testing Criteria
- Hardware Scope of Supply
- Material Selection
- Turbine Upgrade Experience
- Installation Scope and Duration
- Equipment Warranty
- Design Alternatives Incorporating Current and Potential Future Station Upgrades (in essence, Strategic Planning)

Based on these considerations, DPC Madgett Unit 1 personnel made the decision to upgrade the existing unit through the installation of modern Siemens HP/IP and LP turbine components. The Siemens PG retrofit design packages included new rotors, inner casings, and high efficiency stationary and rotating blades. In addition to the hardware, this project included turnkey engineering, installation services and major service work on the generator. The 50-day retrofit outage occurred during the fall of 2004, and the unit was successfully returned to service as scheduled.

Several major maintenance projects, aside from the turbine upgrade, were also performed at the station during the outage. These projects included significant boiler maintenance, upgrade of the original plant control system to a modern DCS type, replacement of the main unit transformer and upgrades of the generator and transformer protection relays. In addition, a complete generator maintenance inspection was performed and the stator winding support system was upgraded, to ensure trouble-free operation with the anticipated higher loads. Considering the many different projects scheduled for the one outage, it was critical that each program have a detailed schedule that was closely adhered to in order for the plant to be ready for start-up on time.

Relevant project experience and the structured use of analysis learned from similar projects prepared project stakeholders for potential contingencies and contributed to meeting the planned outage duration. Stakeholder teams carried out multiple planning forums to discuss the modification work needed to install the new turbines and review installation process improvements learned from similar projects. The outcome was improved quality and reduced outage duration. The operation and performance of the retrofitted unit continues to meet or exceed DPC's defined goals.

1.1 BACKGROUND

In 2003 the originally installed turbines at the Madgett station had been in service for 24 years. The unit was experiencing maintenance issues and performance levels expected from hardware designed and manufactured in the 1970s. At the same time, DPC was experiencing an increase in electricity demand.

Market conditions made it necessary for DPC to find a way to increase its generation capacity, yet still remain competitive from a cost standpoint. New construction was considered as too expensive and the necessary implementation schedule was too long.

The Madgett station is a major generating facility for DPC and the long-term plan was to continue operating this plant for at least 30 years. Reducing the maintenance costs by replacing the turbine components was an attractive solution; however, it would be necessary to justify this project with additional generation revenue.

An engineering specification was developed that targeted performance improvements for the unit, and addressed the existing reliability concerns. In response to the published specification, the utility received competitive bids from major turbine manufacturers.

DPC performed technical and economic reviews of the proposals received and awarded the contract for upgrading Madgett Unit 1 to Siemens PG in (2003). Some of the key order agreements included:

- DPC was guaranteed a delta performance improvement. Testing was conducted using procedures from the ASME Performance Test Code PTC6-1996.
- A six-week installation schedule.
- A 10-year inspection interval for the new HP/IP and LP components.

This paper will discuss the turbine upgrades to provide insight regarding the magnitude and extent of this project.

2.0 BB44FA – HP/IP TUBINE DESIGN

2.1 INTRODUCTION

The BB44FA (Full Arc) turbine retrofit design targets existing Westinghouse Building Block (BB) 44, sub-critical fleet, operating at inlet conditions up to 2,400 psig and 1,000°F. Currently, these machines are operating between a nominal range of 350 to over 680 MWs. This design solution offers the highest efficiency and reliability for those customers who operate their BB44 machines as base loaded units. There is also a BB44PA (Partial Arc) design solution that offers the highest efficiency and reliability for those customers who operate their BB44 machines over a wide load range.

The BB44FA design incorporates the latest design advancements, philosophies, features, and technologies developed within the Siemens PG family. Figure 2 illustrates the differences between the existing BB44 and the new BB44FA designs.

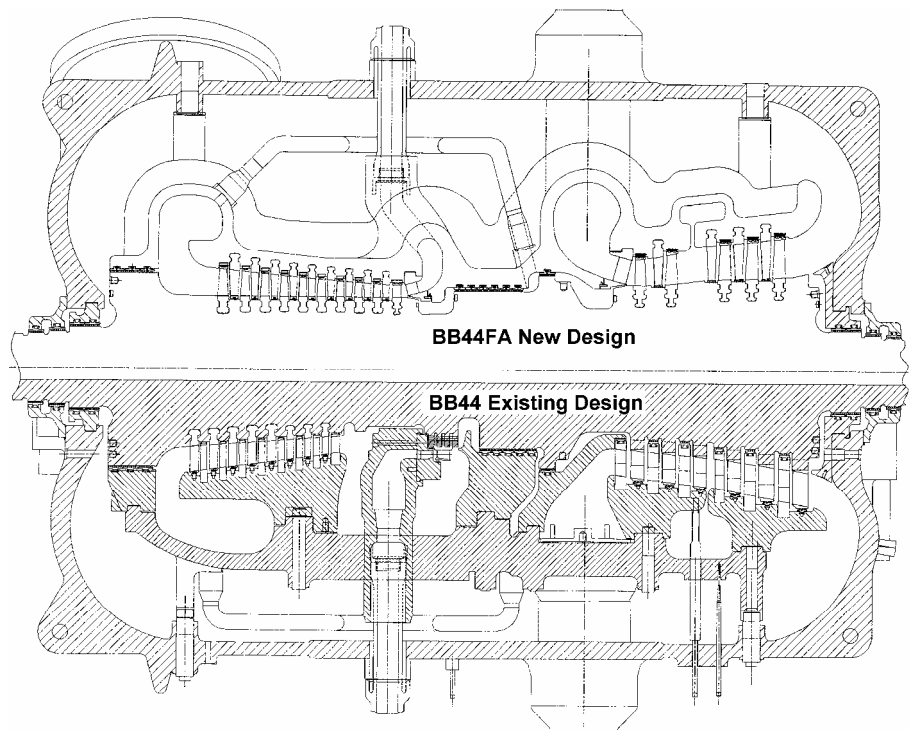


Figure 2 – Comparison of BB44 and BB44FA Turbines

The following list is a brief summary of the strategy that was implemented to achieve higher efficiencies and world class reliability:

- Full Arc of Admission Inlet Section, improved with 3D Computational Fluid Dynamics (CFD) technology
- Eliminated the Separate Nozzle Chambers & Nozzle Blocks
- Eliminated the 180° steam turn around to the HP Blade Path
- Eliminated the Impulse Control Stage
- Implemented the latest in 3D Blading Technology
- Designed a Fully Integral Inner Casing
- Implemented Advanced Sealing Technology throughout the turbine

Siemens PG has all of the existing “as built” records, the original design knowledge and calculations on all of the original BB44 machines in the Siemens PG fleet. Therefore no additional field measurements were required at Madgett, prior to the outage. Madgett’s actual outer casing dimensions were used to ensure that the inner casing would properly assemble into the outer casing. There were no interferences during the installation of the BB44FA, and as a result, there were no increases in outage duration. Complete solid models of all components were created and assembled to ensure that all parts fit properly together and can be properly installed. These solid models are used in designing the components and are used directly in creating all manufacturing and installation drawings. Figure 3 shows the solid model assembly of the BB44FA inner and outer casings.

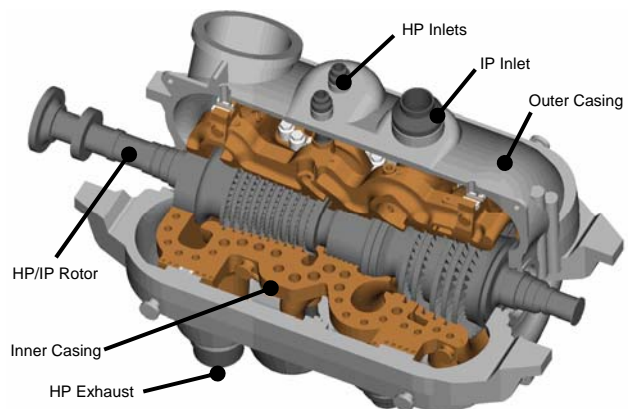


Figure 3 – BB44FA 3D Assembly Model

2.2 BB44FA CASING DESIGN

A full-arc admission turbine design provides optimal efficiency for variable-pressure operation and results in low thermal stressing due to low steam velocities and forces at the first-stage blading [1]. The pressure drop in the 360° inlet duct is an important parameter that is factored into the HP efficiency calculation. A detailed CFD calculation was performed on the inlet feature (figure 4) to obtain the highest possible HP efficiency. Siemens PG worked with casting suppliers, during the design process, to ensure that the inlet feature designed



Figure 4 – BB44FA 3D Inlet Feature

could be cast and resulted in optimal contours and surface finishes to achieve minimal losses.

All internal stationary components are being removed and replaced with a single, fully integral casing. This design approach reduces the number of parts and significantly reduces the installation and outage time. The Madgett BB44FA utilizes the same mating features as the existing BB44 inner casing. This ensures that the new BB44FA inner casing will match up to all axial, vertical and transverse anchor points in the outer casing. The outer casing is re-used with all of the existing outer casing connections. The BB44FA is truly a “drop-in-place” replacement for the existing BB44.

The single inner casing was designed using the latest 3D Finite Element Analysis (FEA) technology. The unique features of this casing design (vertical ribs, flanges and the casing end rings) have all been sized and designed to control the inner casing’s thermal distortion (figure 5). Controlling the distortion means maintaining designed clearances and obtaining the highest possible efficiency at running speed.

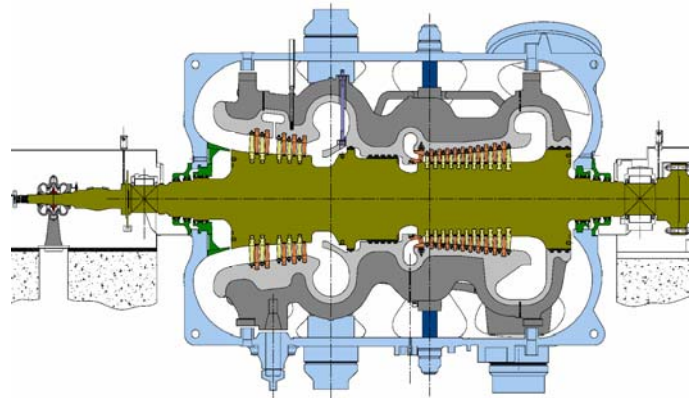


Figure 5 – BB44FA Longitudinal

An FEA solid model of the base and cover was used with all operating conditions applied for the analysis. Figure 6 shows the steady state temperature distribution of the BB44FA inner casing. Axial and radial clearances were calculated specifically for Madgett’s steam conditions and blade path configuration. This was done to ensure that once the inner and outer casings reach steady state operating condition, the optimal clearances are achieved at all locations within the machine (inner casing to rotor) and the inner to outer casing (including all connection points).

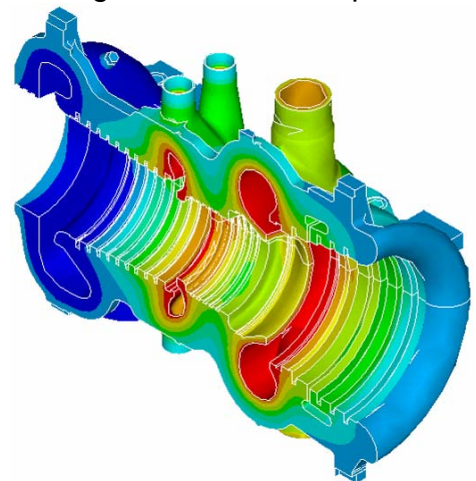


Figure 6 – BB44FA 3D Temperature Profile

A 3D contact analysis was also performed on this inner casing, which focused on the horizontal joint bolting. This design will maintain contact and a steam-tight joint for 10 years before needing to be re-tightened.

The BB44FA turbine re-uses the existing inner and outer glands. The seal segments are replaced with spring back seal carriers to restore these seals back to the original designed radial clearances. The inner gland ring was re-used, however the flow guide portion of the ring was machined with a new profile.

2.3 BB44FA SEALING DESIGN

The seals for the HP, IP and LP dummy pistons were comprised of a combination of both Spring Back and Retractable Seal Segments (figure 7). Retractable seals provide small radial clearances during operation (closed position) and large radial clearances in the open position. These types of seals minimize wear and optimize performance of the machine. Retractable seal technology has been successfully applied to steam turbines for more than 15 years [2, 3].

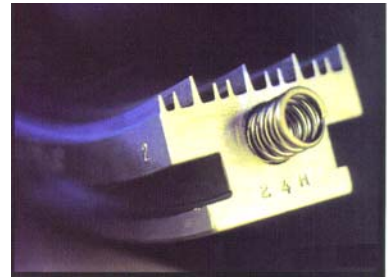


Figure 7 – Retractable Seal

2.4 BB44FA ROTOR DESIGN

The BB44FA HP/IP rotor consists of a monoblock, fully integral no-bore forging, which allows for quicker start-up times and long fatigue life. Coupling flanges are integral to the rotor body and all rotating blades utilize either single or double tee-roots. The BB44FA rotor weight is comparable to the original BB44 rotor, which allows the existing bearings to be re-used. The BB44FA rotor overhang geometry was machined to exacting standards, to greatly reduce the potential for field modifications. The journal diameters and the coupling bolt holes are machined to match up with existing equipment, again reducing cost, field scope and installation time.

An axisymmetric FEA was performed on this rotor geometry with all of the Madgett specific operating conditions. Low Cycle Fatigue (LCF), fracture mechanics, torsional and lateral vibration calculations were also performed on this rotor geometry. Figure 8 shows the final machined and assembled BB44FA rotor.



Figure 8 – BB44FA Fully Assembled HP/IP Rotor

2.5 BLADE PATH DESIGN

The HP and IP blade paths were designed specifically for Madgett to provide improved efficient performance for the available space. Many recent improvements in blade path design have been incorporated into the BB44FA design:

- Advanced airfoil design
- Overall blade path thermodynamic optimization
- Enhanced sealing

Drum Stage Blading

The drum-type HP/IP blade construction features an integrally shrouded blade design concept (figure 9). The integral shrouds provide two basic functions: First, they form a circumferential steam path boundary allowing efficient seal designs to be utilized; and second, they provide individual blade tip support between neighboring blades in each blade row. Siemens PG has more than 40 years of successful experience with integrally shrouded blade designs [4, 5, 6, 7].

HP & IP Blade Path Inlet – Low Reaction Diagonal Stage

The first stage of the HP and IP blade paths may utilize a low reaction design with a diagonal arrangement (figure 10) to reduce rotor inlet temperatures while providing favorable flow conditions where the radial steam flow enters the reaction blading axially. This first stationary row is supported in the casing at the base and tip of the airfoil to minimize leakage. Due to Madgett's operating conditions a diagonal stage was required for the HP blade path, but not for the IP blade path.



Figure 9 – Integrally Shrouded Tee-Root Blade

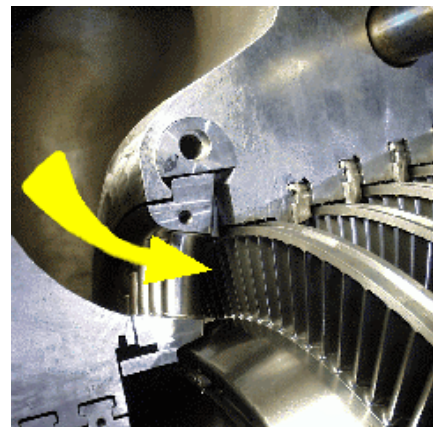


Figure 10 – Low Reaction Diagonal Stage

Advanced Airfoil Design

The blade paths for both the HP section of the turbine and the IP section are composed entirely of 3D airfoil construction. The benefits of this technology allow the airfoil shape to be enhanced to the varying steam conditions between the base and tip of the blade. This design is a considerable advantage over the previous generation of the typical parallel-sided airfoil.

In shorter blades, relatively large end-wall losses occur at the hub and shroud (secondary losses). Bowing the blades at the hub and shroud boundary improves the flow conditions at the end walls and minimizes losses. Longer blades are of twisted design depending on the hub-to-tip ratio, whereby each profile section is adapted to suit the local inlet and exit angle conditions. The blade profiles themselves have also been improved using numerical optimization methods to provide better flow and strength properties. A typical 3DS (low Secondary losses) blade is presented in figure 11.



Figure 11 – 3DS Blades

Blade Path Sealing

The HP blade path uses spring back seals for both the rotating and stationary blade rows. The IP blade path uses spring back seals over the rotating rows and staked-in seals under the stationary rows. Staked-in seals can be machined closer together thus allowing for more seal fins in the same axial length, increasing the sealing efficiency.

2.6 PERFORMANCE

DPC's BB44FA upgrade was successfully installed at the Madgett plant in the fall of 2004. This upgrade has improved HP element efficiency by 8-10% and IP element efficiency by 2-4%, with a 15-20 MW output increase. Two other B44FA upgrades were installed in the fall of 2004 with similar results. Degradation testing has been performed on Madgett's BB44FA and results show that this design is still performing with minimal degradation. Figure 12 shows the complete BB44FA inner casing and rotor assembled at the manufacturing facility.

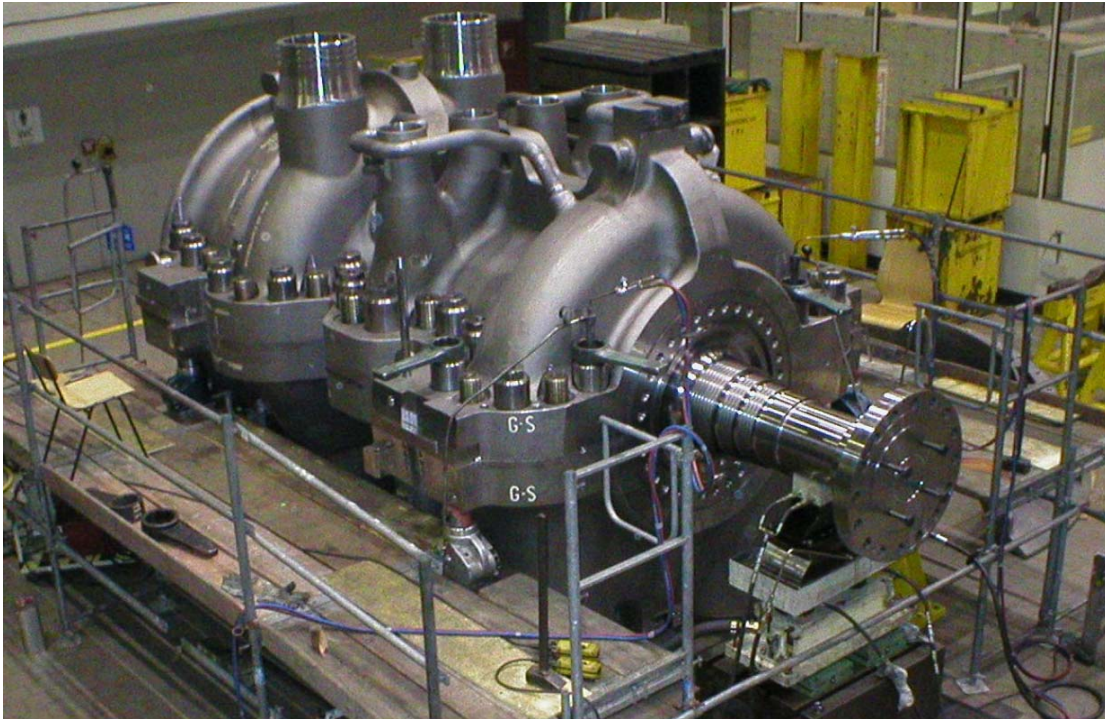


Figure 12 – BB44FA Inner Casing & Rotor Assembled

3.0 BB73-8.7M2 LP TURBINE DESIGN

3.1 INTRODUCTION

As part of the steam turbine retrofit upgrade at Dairyland Power Cooperative's J.P. Madgett Station, Siemens PG designed and successfully retrofitted the existing five-stage BB73 Low Pressure (LP) turbine with a new seven-stage BB73-8.7m² design. The cross-over steam conditions from the HP/IP turbine remained the same as the original unit design. The BB73-8.7m² retrofit product is based on many years of design experience with double-flow LP applications and incorporates the latest in technology improvements. Figure 13 shows the solid model assembly of the BB73-8.7m² upgrade product.

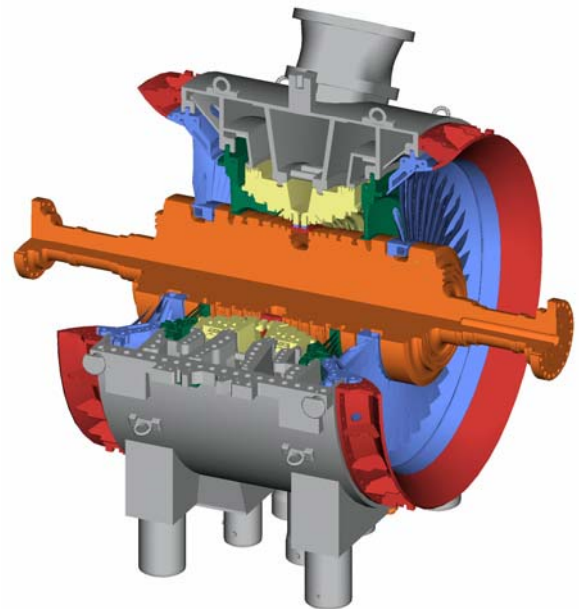


Figure 13 - BB73-8.7m² 3D Assembly

The first BB73 turbines were installed in 1967. During the fleet's 38 years of operation various reliability issues have developed as the design ages. This includes stress corrosion cracking, high cycle fatigue, low cycle fatigue,

lashing wire cracking, and back pressure limitation (5.5 inches HgA). Siemens PG continually studies these LP turbine issues and has incorporated a practical approach in the upgrade design to address performance, long-term operation and reliability.

The following list is a brief summary of the strategy that was implemented to achieve higher performance and world class reliability:

- Eliminate riveted shrouds on front-end blading
- Eliminate riveted shrouds and lashing wires on large LP blading
- Single inner casing with moisture removal features
- Increase resistance to stress corrosion cracking
- Increase resistance to high cycle fatigue
- 8.7 inches of HgA exhaust pressure limit at high loads
- 10-year inspection interval
- Torsional compatibility with existing generator rotor

This retrofit LP steam turbine design is intended to be a “drop-in-place” replacement, minimizing installation time and therefore outage duration. In an effort to achieve this goal, many of the existing inner-to-outer cylinder connection points are being re-used with the BB73-8.7m² upgrade.

The design features included in the LP upgrade are many. It has a monoblock rotor forging without thru-bore. The front-end stages are reaction type with integral shrouds. The last-stage rotating blades are freestanding design. The inner casing is a fabricated single inner cylinder design with an improved exhaust diffuser. The blade path sealing includes tip to tip inter-stage and shaft seals. Figure 14 shows the BB73-8.7m² longitudinal section.

While reliability and availability are the primary goals of an LP turbine replacement, the upgrade design offers significant performance improvements as well by employing the latest design and manufacturing techniques. Proper material selection and conservative design criteria ensure a long and reliable operating life for the replacement components.

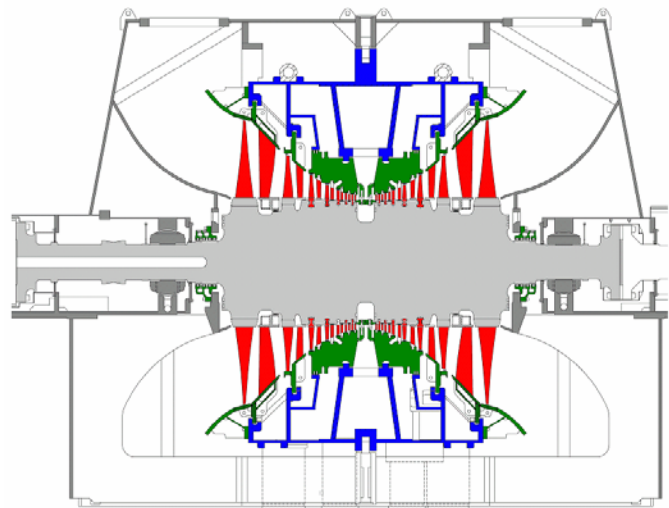


Figure 14 - BB73-8.7m² Longitudinal Section

3.2 BB73-8.7m² CASING DESIGN

The inner cylinder design is a fabricated single casing construction with a separate upper and lower half and a bolted flange at the horizontal joint. In each flow direction the casing supports and aligns three separate blade path stationary components: 1) guide blade carrier for front-end drum stages, 2) segmental assembly for L-1C row, and 3) L-0C segmental and exhaust diffuser.

The LP turbine inner casing has improved stiffness as a result of using advanced finite element methods during the design process. The rigid casing maintains proper alignment between stationary and rotating components to maximize inter-stage seal efficiency and eliminate rubbing. The casing's high degree of rigidity also minimizes steam leakage along the horizontal joint. Low pressure turbine casings are prone to high thermal stresses due to their functional requirements. The Siemens BB73-8.7m² design takes this into account by keeping the expected thermal stresses well below the crack initiation limits. The differential expansion calculation was also performed to verify that no seal rubs would occur during transient conditions. A horizontal joint bolting analysis was also performed for the inner casing and guide blade carriers with proper operating loads. The graphic in Figure 15 shows the complete inner casing solid model of the assembled cover and base halves.



Figure 15 - Inner Casing Solid Model

3.3 SEALING DESIGN

Tip to tip seals have been adopted for the inter-stage sealing of this upgrade design. This type of seal arrangement allows large relative axial displacements without rubs, thus improving the cycling ability and sustained efficiency of the unit. As can be seen in figure 16, there is a large range of relative axial movement possible while still maintaining 100% of the sealing effectiveness. In addition, Siemens PG uses different seal strip spacing for the mating seals, so that in case there is a rub (tip to tip), only one or two seal strips will be affected while the remaining strips are untouched.

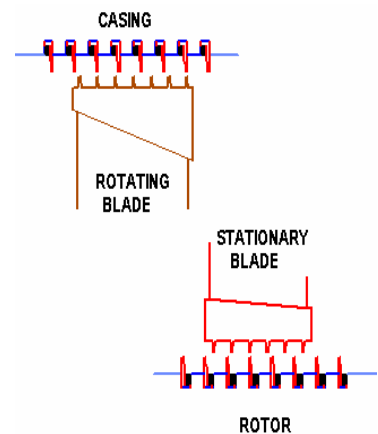


Figure 16 - BB73-8.7m² Double-Strip Seals

3.4 BB73-8.7M2 ROTOR DESIGN

The BB73-8.7m² rotor consists of a monoblock, fully integral, no thru-bore forging. Both coupling flanges are integral to the rotor body and all rotating blades utilize either a tee root or side entry root. The Madgett BB73-8.7m² rotor is approximately 20% heavier than the original rotor. The decision for constructing modern turbine rotors with no thru-bore was based on many design advantages. Obviously, without a rotor bore, it is no longer a long-term maintenance requirement to perform bore inspections. The operating stresses of a no-bore rotor are lower compared to a similar design with an axial thru-bore.

The BB73-8.7m² rotor overhang geometry is a duplicate of the existing rotor overhangs, which enables the new rotor to be installed without any modifications to the existing equipment. The journal diameters and the coupling bolt holes are machined to match up with existing equipment, again reducing cost, field scope and installation time.

A 3D solid model of the BB73-8.7m² rotor was created to ensure that all components fit properly. An FEA analysis was performed on this rotor geometry with all of the Madgett specific operating pressures and temperatures applied. Figure 17 shows the blade path area with steady state temperature distribution.

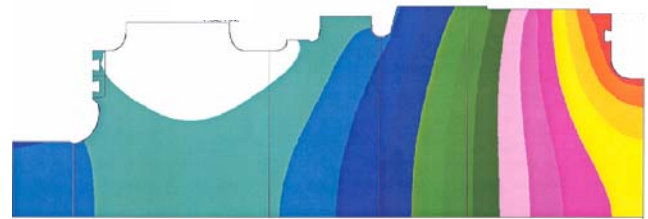


Figure 17 – BB73-8.7m² FEA Temperature Plot

Fracture mechanics, torsional and lateral calculations were performed to evaluate and analyze the complete rotor train for Madgett specific static and dynamic loadings. Rotor dynamic calculations were performed with both the existing and replacement turbine rotors. Torsional integrity of the upgraded rotor train was evaluated to address single- and double-line frequency responses, and it was confirmed that the existing torsional characteristics of the turbine-generator system has not been impacted. Lateral dynamic analysis confirmed that rotor stability and high-cycle fatigue requirements are met.

Stress corrosion cracking prevention was addressed through the use of selecting favorable material properties, applying residual compressive stresses and by reducing stress concentrations in the blade attachment areas.

The machined BB73-8.7m² rotor in the cylinder base during the final assembly checks of the Madgett LP in the manufacturing facility is shown in figure 18.

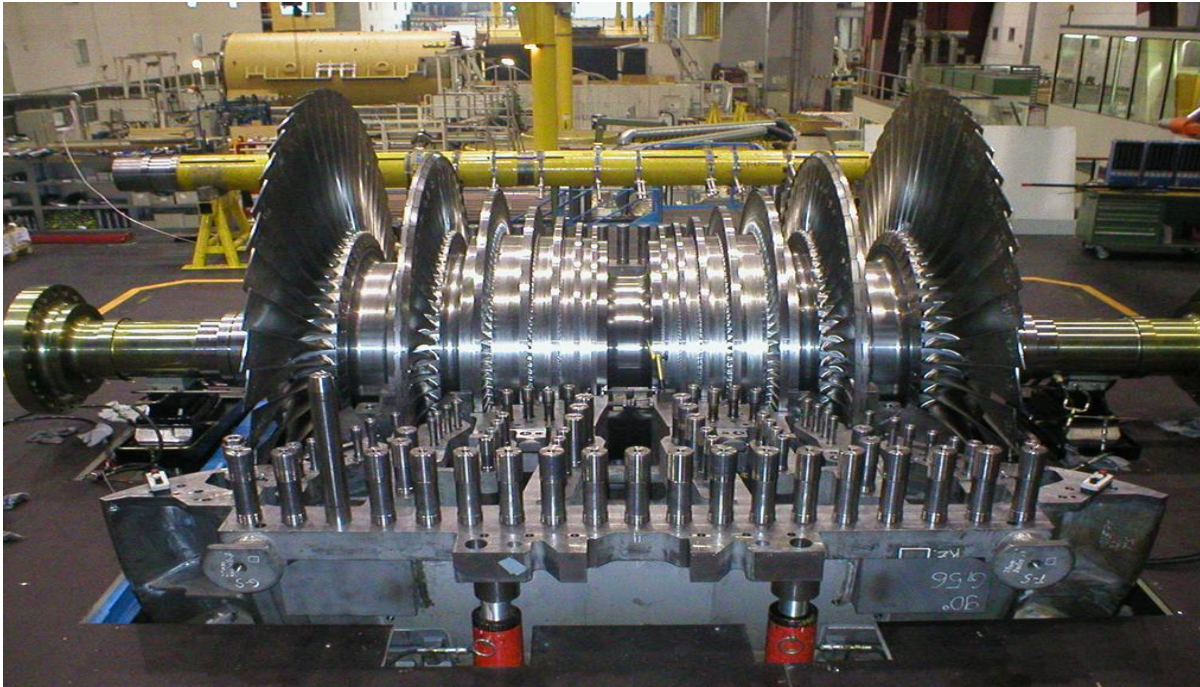


Figure 18 – BB73-8.7m² Rotor Assembly with Cylinder Base

Bearing Oil Lift System

The existing bearings are re-used with some field alterations to accommodate the installation of bearing oil lift for use during turning gear operation. The independent oil lift systems are mounted directly to the LP bearing pedestals to prevent the requirement for high pressure piping runs in the power plant. The oil lift system was implemented to prevent stick-slip of the rotor during turning gear, which would potentially damage the bearing babbitt material.

3.5 BLADE PATH DESIGN

The Madgett BB73-8.7m² LP blade path has been designed with seven stages per flow utilizing Siemens PG's standard 37.7-inch free-standing L-0R row, interlocked L-1R row and integrally shrouded L-2R row. The four front-end stages (drum stages) are of Siemens PG integrally shrouded tee-root blade design with customized 3D blade profiles that match the existing cross-over and extraction pressures. The entire blade path is made from 12% Cr and 13% Cr stainless steel with the exception of the last rotating blade, which is made from 16% Cr (16-4 PH).

Using Siemens proprietary design tools, the drum stage blade path has been designed for Madgett specific steam conditions to optimize the thermal performance of the turbine

upgrades. The performance and mechanical advantages of the drum stages are similar to the HP/IP designs as described in the BB44FA sections.

Free-Standing Last Row Blade

The Madgett BB73-8.7m² has free-standing 37.7-inch last row blades. Siemens PG's free-standing blades are of heavy-duty design with a maximum permissible back pressure of 8.7 HgA at high loads. The blade design has curved side-entry roots and both rows use a mixed-tuned assembly sequence to provide for increased natural frequency separation (figure 19).

The blade attachment area is the most highly stressed part of the rotor. The root size has been enlarged with generous fillet radii in critical areas, and hence the stress concentrations have been reduced significantly.

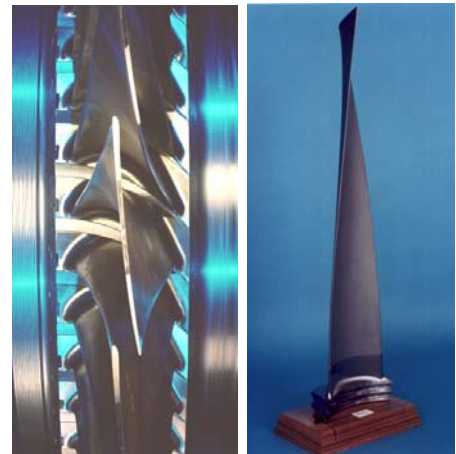


Figure 19 – BB73-8.7m² Last Row Blade

Moisture Erosion Protection

The effects of moisture erosion on the LP turbine at Madgett were a concern regarding long-term operation. Addressing this concern was one of DPC's requirements.

There are different methods for protecting against erosion, depending on the moisture content of the steam in the blade path. The standard BB73-8.7m² design uses laser hardening on the last rotating blade leading edge. For higher levels of moisture, suction slots can be machined into the last-stage stationary airfoils, and the moisture is removed from the blade path and drained to the condenser. In applications with very high levels of moisture, Siemens PG employs a 'steam heating' system which is unique to our turbine designs. For the Madgett station, it was decided to implement the steam heating system as an extra precaution against moisture erosion of the last-stage rotating blades.

Steam Heating

High temperature steam is supplied from an upstream LP extraction. This feature is integral with the new inner casing design. This supply steam is connected to the L-0 stationary blade row and piped thru the interior of the hollow vanes to supply heat energy to evaporate the heavy water droplets back into steam before passing to the rotating row. The supply steam is then drained to a feed-water heater. A basic schematic of the system is shown in figure 20.

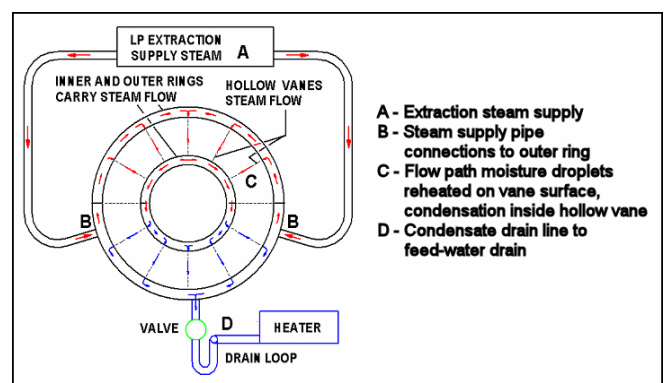


Figure 20 – BB73-8.7m² Steam Heating System

3.6 PERFORMANCE

The improved performance of the new BB73-8.7m² comes from improved front end (drum stages) blade design, the 25% increased annulus area and the more efficient last three LP stages. Additionally, exhaust losses are reduced with the use of an improved exhaust flow guide.

The boiler supplied steam conditions at the Madgett station were not changed as part of the turbine upgrade program. For units of similar size to Madgett, it would be expected to gain approximately 7 to 8 MWs by upgrading the original LP turbine to modern technology.

4.0 SUMMARY OF BB44FA AND BB73-8.7M2 ADVANTAGES

BB44FA HP/IP Turbine Upgrade

Siemens PG has successfully designed, manufactured and installed three BB44FA style machines in the US market, including Dairyland Power Cooperative, J. P. Madgett Station. All three of these machines have met or exceeded contractual requirements. The advanced technology and techniques described in this paper are being implemented into all of Siemens PG's modernization products. Following is a summary of the features and benefits of the BB44FA turbine upgrade.

Features and Benefits

- Single-piece inner casing design which:
 - Enhances reliability
 - Controls casing ovality during operation, maintaining desired radial clearances for maximum efficiency
 - Reduces the number of parts and installation time (align one component vs. eight in original design)
 - Maintains all existing inlet/exhaust connection points and inner casing support locations (axial, transverse and vertical), without any modifications
 - Maintains existing operation and controls hardware
- Full-arc admission design provides optimal efficiency for variable-pressure operation and results in low thermal stressing due to low steam velocities and forces at the first-stage blading
- No-bore rotor designs for fast start-up and flexible operation
- Fully integrally shrouded blade design with tee-roots, allowing efficient seal designs to be utilized and pre-stressed blades display excellent damping behavior
- Three-dimensionally designed blades, offering the highest efficiencies possible
- Use of spring-back and retractable sealing technologies to further enhance performance and reliability.
- Designed for ease of maintenance and 10-year inspection intervals
- Proven designs based on over 30 years of design, manufacturing, and operating experience
- Re-use of existing outer casing with minimal alterations

BB73-8.7m² LP Turbine Upgrade

Siemens PG has successfully designed, manufactured and installed five turbines with BB73-8.7m² upgrades in the US market, including Dairyland Power Cooperative, J. P. Madgett Station. These machines have incorporated Siemens PG's advanced technology LP blades for improved reliability and increased power generation. The design features as described in this paper are being implemented into all of Siemens PG's LP upgrade products to address all fleet issues such as SCC, moisture erosion and long-term performance. Following is a summary of the features and benefits of the BB73-8.7m² turbine upgrade.

Features and Benefits

- Improved blade path output, heat rate
- Monoblock rotor to reduce operational stresses and eliminate bore inspections
- Rotor surfaces and profiles specifically contoured to minimize stress risers
- Integrally shrouded blades to eliminate rivet inspection and long-term maintenance issues
- Freestanding L-0R blades for optimum performance
- Mix-tuned L-0R blade row reduces installed flutter potential
- 8.7 in. HgA backpressure at high loads
- Rigid inner casing design to prevent routine fatigue cracking
- Single casing simplifies installation / alignment
- Improved horizontal joint and bolting arrangement to prevent steam leakages and material loss on the joint surface

COMBINED UPGRADE ADVANTAGES

There are inherent cost advantages to upgrading both turbine elements at the same time. While the hardware cost for each turbine component is not affected; there are cost savings associated with project support, transportation, mobilization, installation and program management. DPC and Siemens PG spent considerable efforts coordinating the tasks to ensure issues were addressed and redundancies were eliminated.

The new turbine hardware for both the HP/IP and LP elements has recommended intervals between major inspections of 10 years. By upgrading both turbines at the same time, the number of turbine maintenance outages is significantly reduced, and the turbine outages can be coordinated more easily.

5.0 CONCLUSION

As with most major purchase decisions, the key issues are product features, price, and performance. Siemens PG's advanced design LP and HP turbines provide the reliability and performance improvement that DPC required, with features that addressed their long-term maintenance concerns.

A turbine retrofit project is a major undertaking for both the plant owner and the turbine vendor. The Madgett Turbine Retrofit/Generation Upgrade project began as a project evaluation program and transformed into a strategic planning initiative for DPC. Long-term maintenance issues were considered as well as current and future electric power market conditions. Turbine retrofit decisions had to consider the long-term operation, including potential uprate plans, for the life of the station.

From a project evaluation standpoint, DPC took a global perspective to ensure that all alternatives were properly assessed and considered and all bidders were evaluated fairly.

From a long-term reliability standpoint, the Madgett station project goal is to address on-going maintenance issues and provide significant performance improvements using the latest design turbine technology. Through a team approach and flexibility, the project is poised to provide excellent value to all the project stakeholders. The increased asset value of the project has not gone unnoticed by the member-owners of DPC as well.

IN MEMORIAM

This report is dedicated to **David Rybarik**, Dairyland Power Cooperative Director, Generation Support Services, who died Sunday, June 5, at age 59. David joined Dairyland on Oct. 1, 1980, as a mechanical engineer. Throughout his career at Dairyland, he was a key contributor to the design and implementation of many key projects, including the retrofit project highlighted in this report. He was an exceptional person and engineer who was constantly striving to initiate improvements at Dairyland. He was passionate about his work and became a friend to the many people he came into contact with in the industry. Known to be cheerful, enthusiastic, and active in his church and community and an avid downhill skier and bicyclist, Dave lived life to the fullest. His annual ski trip out West with his sons was always a highlight of his year.

David is survived by his wife, Fran and two adult sons, Brian Rybarik (Madison, Wis.) and Scott Rybarik (Denver, Co.).

6.0 REFERENCES/BIBLIOGRAPHY

- [1] Termuehlen, Variable-Pressure Operation and External Turbine Bypass Systems to Improve Plant Cycling Performance, ASME/IEEE/ASCE Power Generation Conference, October 8-10, 1979, Charlotte, NC.
- [2] Foley, M: Retractable Brush Seals Allow Sweeping Improvements in Steam Turbine Efficiency, Modern Power Systems, July 2000, p. 37-39.
- [3] Little, N., Sulda, E., Terezakis, T., Efficiency Improvement on Large Mechanical Drive Steam Turbines, Proceedings of the 30th Turbomachinery Symposium.
- [4] Pfitzinger, E.W., Deckers, M., de Lazzer, A. (2003). Standardized Flexibility in Advanced Blading Technologies for Highly Efficient Steam Turbines, Proceedings of "XXXV. Kraftwerkstechnisches Kolloquium 2003", Dresden, Germany.
- [5] Hoffstdadt, U., Klauke, U., Hinz, H., Boxberg – A New Benchmark for High Efficiency, Modern Power Systems, October 2001.
- [6] Simon V., Stephan, I., Bell, R.M., Capelle, U., Deckers, M., Schnaus, J., Simkine, M. (1997). Axial Steam Turbines with Variable Reaction Blading, Advances in Turbine Material, Design and Manufacturing, Proceedings of the 4th International Charles Parsons Conference, pp. 46-60, London.
- [7] Hurd, P., Thamm, N., Neef, M., Truckenmueller, F., Pollak, H., Deckers, M. - Modern Reaction HP/IP Turbine Technology Advances & Experiences, ASME Power Generation Conference, April 5-7, 2005, Chicago, Illinois.

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