LG&E/KU – Mill Creek Station

Phase II Air Quality Control Study

Draft System

February 15, 2011
Revision B – Issued For Client Review

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Tables

1.0 Introduction

As a part of the draft system analysis of the conceptual design process for Mill Creek, the flue gas draft system requires evaluation to determine if modifications or replacements of the existing fans and other draft system components will be required. This is due to the installation of additional draft system equipment to control, or enhance the control of, certain flue gas emissions. For Unit 1, the major modifications and additions to the draft system being considered include a new selective catalytic reduction (SCR) system, new pulse jet fabric filter (PJFF) system, and the refurbishment and upgrading of the existing wet scrubber. Demolition of the Unit 1 ESP would be required to make room for the new SCR system. The Unit 1 ESP would not be replaced. Unit 2 would be similar to Unit 1. Added to Unit 3 would be a new PJFF system and new ductwork to utilize the existing Unit 4 wet scrubber. The Unit 3 wet scrubber would be demolished to make room for the new PJFF. Unit 4 would have a new PJFF system and a new Wet Flue Gas Desulfurization (WFGD) system. For more detail on the AQC equipment modifications, additions, etc. discussed here and others for each Mill Creek unit refer to Section 5.0.

Following this introductory section for the Mill Creek draft systems, the draft system of each unit will be analyzed on an individual basis based on the draft system additions and changes previously discussed. First, there will be an overview of the layout of each existing draft system, existing boiler and draft system characteristics, existing fans, and design pressures. Next, an overview of the future draft system layout and expected operating characteristics will be discussed. The existing fans will be evaluated first against the future draft system performance requirements. Then, if new fans may be needed, the required maximum continuous rating (MCR) performance requirements will be presented for the new fans. A recommended Test Block fan performance will be indicated as well. The analysis of each unit will conclude with a look at estimates of the recommended draft system design pressures.

For the sizing of any new fans for the Mill Creek site, the standard Black & Veatch fan sizing philosophy for developing Test Block conditions as additional margin on MCR conditions is recommended and has been utilized. This philosophy includes the application of the following items to the required MCR conditions for new or modified fans:

- 10 percent margin on flue gas flow exiting the boiler
- 50 percent margin on leakages throughout the draft system
- 50 percent margin on air heater differential pressure
- 25^{o}F temperature increase at the fan inlet

- Adjustments of draft system pressure drops to correspond with increased Test Block flow rates
- 1.0 inch of water (inw) control allowance

2.0 Unit 1

2.1 Existing Draft System

2.1.1 Layout

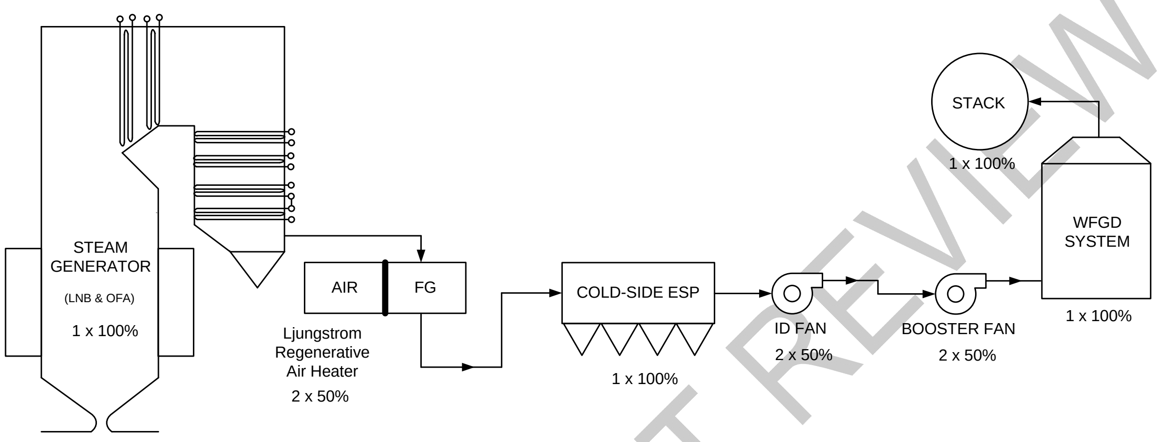

Figure 2-1
Mill Creek Unit 1 Existing Draft System

The flue gas draft system begins at the outlet of the boiler, or economizer (from this point forward in this draft system analysis section the flue gas draft system will be referred to as just the draft system). From there the flue gas travels directly to two 50 percent capacity ljungstrom regenerative type air heaters. The air heaters transfer a large amount of energy in the flue gas to the combustion air entering the boiler. Once through the air heaters, the flue gas travels through ductwork and into one 100 percent capacity electrostatic precipitator (ESP) where particulate is removed. Two 50 percent capacity induced draft (ID) fans then draw the flue gas out of the ESP. After the ID fans, a set of two 50 percent capacity booster fans, coupled in series with the ID fans, send flue gas to the wet scrubber. Once the majority of the sulfur dioxide in the flue gas is removed by the wet scrubber, the flue gas then exits to the atmosphere through the stack. An illustration of the Unit 1 existing draft system based on this description is shown in Figure 2-1.

2.1.2 ID and Booster Fans

The existing draft fan system consists of two ID fans and two booster fans coupled in series as previously discussed. The Allis-Chalmers electric motors for each ID fan are single-speed motors that operate nominally at 720 rpm. The nameplate horsepower rating of the ID fan motors is 2,500 horsepower with a service factor of 1.15. They operate at a nominal voltage of 4000 volts. Primary, flow control of the ID fans is accomplished by the use of fluid drives (American Standard Gyrol drives size 497, class 4) in between the fans and motors. The ID fans are double inlet centrifugal fans with a maximum speed capability of approximately 685 rpm due to the fluid drives. The ID fans are the original ID fans for Mill Creek Unit 1 and are an American Standard design, size 1231AF 4200BE.

The booster fans are driven by Siemens-Allis single-speed electric motors that operate nominally at 900 rpm. The nameplate horsepower rating of the booster fan motors is 3,000 horsepower with a service factor of 1.15. They operate at a nominal voltage of 4000 volts. Primary flow control for the booster fans is accomplished by the use of fluid drives (American Standard Gyrol drives size 427, class 5) in between the fans and motors. The booster fans are double inlet centrifugal fans with a maximum speed capability of approximately 850 rpm due to the fluid drives. The booster fans are an American Standard design, size 1143AF 3600B.

2.1.3 Boiler and Draft System Characteristics

Currently, the major performance characteristics of the Unit 1 boiler and existing draft system at MCR are as follows in Tables 2-1 and 2-2.

Table 2-1
Unit 1 Boiler Characteristics at MCR

Boiler total heat input	3,224 MBtu/hr (based on net plant output of 303,000 kW and heat rate of 10,639 Btu/kWh)
Boiler excess air	20 % or 3.25% oxygen – wet basis (estimated)
Loss On Ignition (LOI)	2 % (estimated)
Ambient conditions	
Dry bulb temperature	77 ^{o}F
Relative humidity	60 %
Barometric pressure	29.49 inHg

Table 2-2 Unit 1 Existing Draft System Characteristics at MCR	
Air heater leakage	10 % (estimated)
ESP leakage	5 % (estimated)
Flue gas temperatures	
Boiler outlet	760 ^oF
Air heater outlet	375 ^oF
ESP outlet	340 ^oF
ID fan outlet	~350 ^oF (calculated)
Booster fan outlet	~355 ^oF (calculated)
WFGD outlet	~130 ^oF (calculated)
Furnace pressure *	-0.5 inches of water gauge (inwg)
Draft system differential pressures *	
Boiler	4.5 inw
Air heater	5.0 inw
ESP	5.0 inw
ESP outlet to ID fan inlet	1.0 inw
WFGD	10.0 inw
Stack	1.0 inw
* Note that throughout this document gauge draft pressures will be listed with units of “inwg” and differential draft pressures with units of “inw”. This is similar to the difference between the units of “psig” and “psi”	

Based on the layout of the existing draft system in Figure 2-1 and the boiler and the draft system characteristics listed in Tables 6-1 and 6-2, the estimated performance requirements of the existing ID fans are shown as the MCR point in Figure 2-2. Note that the flue gas outlet pressure of the existing ID fans is assumed to be atmospheric or 0.0 inwg.

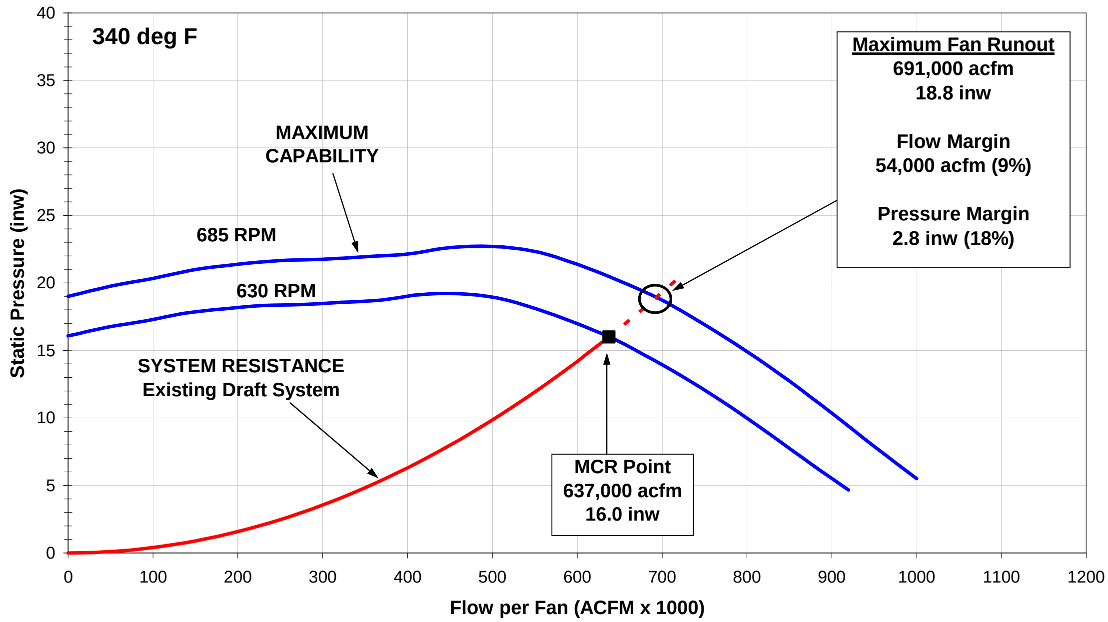

Figure 2-2
Unit 1 Existing ID Fan Performance with Existing Draft System

Based on the MCR point shown in Figure 2-2, it appears that the ID fans operate at approximately 630 rpm and have flow and pressure margins of approximately 9 and 18 percent, respectively. These margins are below the ranges of flow and pressure margins that are typically recommended by Black & Veatch for fans in either new or retrofit applications. The recommended Black & Veatch Test Block fan sizing philosophy, outlined at the beginning of this section, would typically result in flow margins in the range of 20 to 30 percent and pressure margins in the range of 35 to 45 percent.

The booster fan performance curve was unavailable and, therefore, their current MCR point in relation to the maximum fan runout, like the one shown in Figure 2-2, cannot be shown at this time. However, the need for further analysis of the existing booster fans is not anticipated. With the expected installation of both an SCR system and a PJFF system, the overall draft fan horsepower demand at MCR is expected to require close to what the combined 5,500 nominal horsepower that each existing ID and booster fan combination can deliver. This includes the consideration of removing and not replacing the ESP. This would not allow for a suitable amount of margin if the existing ID and booster fans were to be reused with no modifications.

Additionally, the existing ID fans are located directly below the outlet of the ESP and ductwork entering the existing fans would complicate routing of ductwork through the area once the ESP is removed. The fans may also interfere with new superstructure required to support the SCR module above. Moreover, removal of the heavy fans and motors will make available additional load-carrying capacity in the existing foundation that may be taken advantage of in supporting the new SCR system. Therefore, it is expected that the existing Unit 1 ID and booster fans would be replaced with a single set of new ID fans.

Lastly, the existing draft system equipment and ductwork transient design pressures are listed in Table 2-3. These will be used in determining the amount of stiffening that would be required, if any, in support of the proposed AQC upgrades. These design pressures are unknown for some of the equipment and portions of ductwork of Unit 1. These may need to be determined during detailed design depending on their location in the draft system.

Table 2-3
Unit 1 Existing Draft System Equipment and Ductwork Transient Design Pressures

Furnace/Boiler	+13 / -6.6 inwg
Boiler Outlet to Air Heater Inlet	Unknown *
Air Heater	Unknown *
Air Heater Outlet to ESP Inlet	± 25 inwg
ESP	± 25 inwg **
ESP Outlet to ID Fan Inlet	± 25 inwg
ID Fan	Unknown (typically more conservative than connecting duct)
ID Fan Outlet to Booster Fan Inlet	± 12 inwg
Booster Fan	Unknown (typically more conservative than connecting duct)
Booster Fan Outlet to WFGD Inlet	Unknown
Wet scrubber	Unknown
Wet scrubber Outlet to Stack Inlet	Unknown

* The design pressures of the air heaters and upstream flue gas duct would not be affected by the installation of a PJFF system. However, if an SCR system is installed in the future, these design pressures would need to be confirmed to allow the SCR system installer to apply the proper amount of stiffening to existing equipment if required.

** Estimated – The ESP design pressure would not be affected by the installation of a downstream PJFF system. Additionally, with an SCR installation this design pressure would not need to be confirmed due to the expected demolition of the ESP.

2.2 Future Draft System

2.2.1 Layout

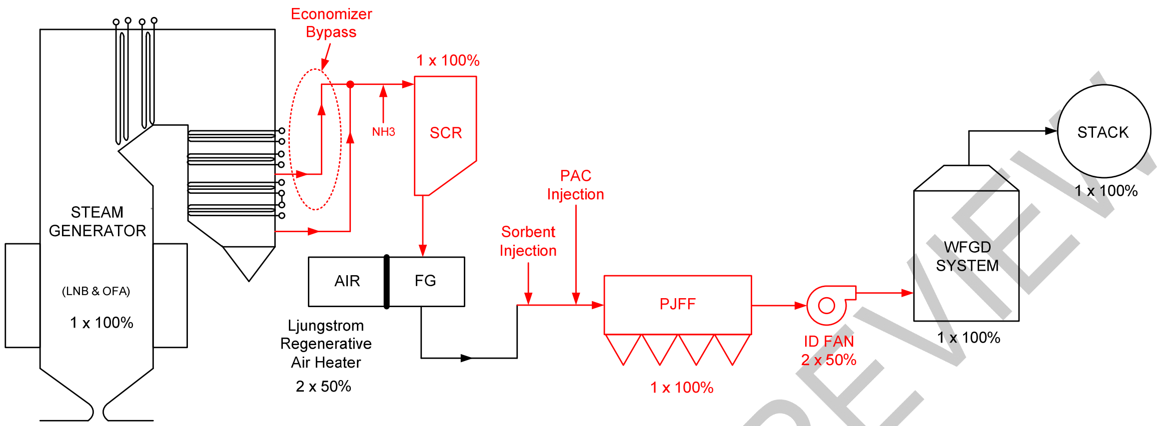

Figure 2-3
Unit 1 Future Draft System

Based on the additions to the Unit 1 draft system previously discussed and the expectation that the existing fans will be replaced by a single set of new ID fans, the flue gas would be redirected through the draft system as follows. At the outlet of the boiler, or economizer, the flue gas would travel to the new SCR system allowing for the removal of NOx emissions before entering the air heaters. As the flue gas travels through the boiler, a portion of it may bypass all, or part of, the economizer. The economizer bypass would allow a minimum flue gas temperature entering the SCR to be maintained. Once the flue gas is through the air heaters it would enter the new PJFF system allowing for the removal of particulate. The demolished ESP, allowing room for the SCR system, would not be replaced. The new ID fans would then draw the flue gas out of the PJFF system and send it to the wet scrubber system. In addition, the wet scrubber system would be refurbished and upgraded to improve performance; however, the draft system layout in this area is not expected to change significantly. An illustration of the Unit 1 future draft system based on this description is shown in Figure 2-3.

2.2.2 Draft System Characteristics

The major performance characteristics of the Unit 1 future draft system at MCR are as follows in Table 2-3. Note that the items in bold in Table 2-3 are new.

Table 2-4 Unit 1 Future Draft System Characteristics at MCR	
SCR system leakage	**2 %**
Air heater leakage	10 % (estimated)
ESP leakage	**(demolished)**
PJFF system leakage	**3 %**
Flue gas temperatures	
Boiler outlet	760 °F
SCR outlet	**760 °F**
Air heater outlet	375 °F
ESP outlet	**(demolished)**
PJFF outlet	**375 °F**
New ID fan outlet	**~400 °F**
Booster fan outlet	**(not replaced)**
Wet scrubber outlet	~130 °F
Furnace pressure	-0.5 inwg
Draft system differential pressures	
Boiler	4.5 inw
SCR	**10.0 inw**
Air heater	5.0 inw
ESP	**(demolished)**
Air heater to PJFF inlet	**1.0 inw**
PJFF	**6.0 inw**
PJFF outlet to ID fan inlet	**1.0 inw**
Wet scrubber	**12.0 inw (refurbished & upgraded)**
Stack	1.0 inw

2.2.3 Analysis of Existing ID Fans with Future Draft System

To further demonstrate the affect the additional draft system resistance of the SCR and PJFF, shown in Table 2-4, has on the existing draft fans and that a new draft fan system should be installed, a new system resistance curve is shown in Figure 2-4. First, note that this system resistance curve for the ID fans does not include the wet scrubber and stack resistance as the booster fans would be expected to overcome these. Secondly, note that the chart is based on a higher ID fan inlet temperature (the existing air heater gas outlet temperature) which decreases the maximum capability of the existing ID fans. This is due to the expectation that the new PJFF would have less air in-leakage. The MCR point of this new system resistance curve in Figure 2-4 is clearly outside the capabilities of the existing ID fans. Although the booster fans may have enough additional capacity to allow the ID and booster fan combination to reach the new MCR point, margin would be needed on top of this which would be extremely limited.

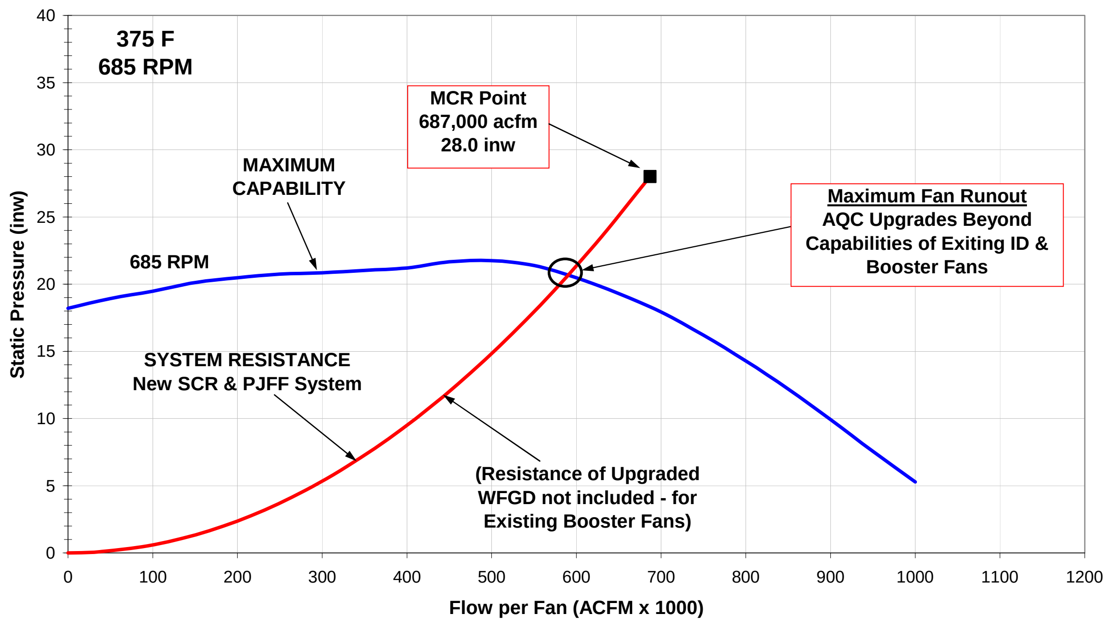

Figure 2-4
Unit 1 Existing ID Fan Performance with Future Draft System

2.2.4 New ID Fan Design Conditions

Based on the layout of the future draft system in Figure 2-3 and the future draft system characteristics in Table 2-4, the estimated performance requirements of the new ID fans at MCR are shown in Table 2-5. Also in Table 2-5 are the recommended Test Block conditions developed using the standard Black & Veatch fan sizing philosophy previously outlined. Note the flow and pressure margins of 25 and 40 percent, respectively.

Table 2-5
Unit 1 New ID Fan MCR and Recommended Test Block Conditions

	MCR	Test Block
Fan Speed (rpm), maximum	------	900
Inlet Temperature (°F)	375	400
Inlet Density (lb/ft^3)	0.0444	0.0419
Flow per Fan (acfm) *	687,000	858,000
Inlet Pressure (inwg)	-28.0	-38.4
Outlet Pressure (inwg)	13.0	19.1
Static Pressure Rise (inw)	41.0	57.5
Shaft Power Required (HP) **	5,300	9,200
Efficiency (%) **	85	85
Number of Fans	2	2
Flow Margin (%)	---------	25
Pressure Margin (%)	---------	40

*Per fan basis with both fans in operation
**Estimated – assumes variable speed operation

2.2.5 Operating and Transient Design Pressures

With a pressure margin of 40 percent listed in Table 2-5, the new ID fans would be expected to operate the future draft system with the Test Block pressures listed in Table 2-6. The normal operating, or MCR, pressures have been shown in Table 2-6 as well for reference.

Table 2-6
Unit 1 Flue Gas Draft System Pressures at MCR and New ID Fan Test Block

	MCR Pressure (inwg)	Test Block Pressure (inwg)
Furnace/Boiler	-0.5	-0.5
Boiler/Economizer Outlet	-5.0	-6.0
SCR Outlet	-15.0	-18.3
Air Heater Outlet	-21.0	-28.9
PJFF Outlet	-28.0	-38.4
ID Fan Outlet	13.0	19.1
Wet scrubber Outlet	1.0	1.4

With the future draft system Test Block operating pressures defined in Table 2-6, the future draft system potential minimum transient design pressure requirements can be determined and are shown in Table 2-7. The Black & Veatch philosophy for calculating the minimum required transient design pressures is based on the draft system being designed to 66 percent of its yield stress for maximum continuous operating (Test Block) pressures and 95 percent for short durations, or transient conditions. This results in a 44 percent increase in the allowable stress throughout the draft system for short durations without resulting in permanent deformation or buckling of any structural components. For example, the air heater gas outlets are expected to be exposed to negative draft pressures of -28.9 inwg (see Table 2-6) when the ID fans are operating at Test Block conditions. The calculated negative transient design pressure in this case would be 44 percent higher or -42 inwg. The positive transient design pressure would still be +35 inwg (see Table 2-7).

The transient design pressures in Table 2-7 would be used in determining the amount of stiffening of existing and new equipment that would be required, if any, in support of the proposed AQC upgrades. Since National Fire Protection Association (NFPA) 85 requires that new flue gas ductwork and equipment between the boiler outlet and the ID fan inlet be designed for transient pressures of ± 35 inwg, calculated transient design pressures below ± 35 inwg are disregarded and the ± 35 inwg is used as the design transient pressure for that draft system component or section of ductwork. For calculated transient design pressures over ± 35 inwg such as in the previous example, the calculated pressure is used.

Table 2-7
Unit 1 Future Flue Gas Draft System Potential Transient Design Pressure Requirements

Furnace/Boiler	± 35 inwg *
Boiler Outlet to SCR Inlet	± 35 inwg
SCR	± 35 inwg
SCR Outlet to Air Heater Inlet	± 35 inwg
Air Heater	+35 / -42 inwg
Air Heater Outlet to PJFF Inlet	+35 / -42 inwg
PJFF	+35 / -56 inwg
PJFF Outlet to ID Fan Inlet	+35 / -56 inwg
New ID Fan	(Determined by Manufacturer)
ID Fan Outlet to Wet Scrubber Inlet	+28 / -10 inwg **
WFGD	+28 / -10 inwg **
Wet Scrubber Outlet to Stack Inlet	± 10 inwg **

* Further research is needed to determine whether this would be required.

** Estimated – Ductwork and equipment downstream of the ID fans up to the stack inlet was assumed to have a minimum transient design pressure rating of +10/-10 inwg, typical of ductwork in that section of a draft system. If the actual design pressures in this section are different, stiffening would likely not be required except for the minimum positive design pressure greater than +10 inwg from the ID fan outlet through the wet scrubber. NFPA 85 does not specifically call out a minimum design pressure requirement for ductwork downstream of ID/Booster fans.

The AQC equipment additions and changes to all of the Mill Creek units will likely be considered major alterations or extensions to the existing facilities per the NFPA 85 code - Section 1.3 (2007 Edition). The code, in this instance, would imply that the boiler and flue gas ductwork from the boiler outlet (economizer outlet) to the ID fan inlet be designed for transient pressures of ± 35 inwg at a minimum per Section 6.5. Further research is needed to determine whether the remaining portions of the existing Unit 1 boiler and draft system meet this criteria or if they would require stiffening. This further research would be required during detailed design.

2.2.6 Additional Items

It is expected that the economizer bypass previously mentioned during the layout discussion would be in operation when flue gas temperatures entering the SCR drop to approximately 615^{o}F. This minimum ammonia injection temperature is expected to occur at plant loads between 225-200 MW gross and below and is based on SCR catalyst that Black & Veatch would typically procure.

A gas-side economizer bypass has been determined to be a plausible solution. Therefore, for conceptual design purposes this type of economizer bypass will be used. A total of four 2ft x 2ft bypass ducts could potentially fit across the back pass just before the economizer within the existing boiler steel. Two 2ft x 2ft additional bypass ducts could fit by modifying some of the boiler steel in that area. If designed and installed properly, gas-side bypasses are effective but require that the dampers, in a hot and particulate intensive environment, be properly maintained. Additionally, the Mill Creek site is familiar with gas-side bypasses as the SCR systems on Units 3 and 4 utilize this type. Other means of maintaining a minimum SCR flue gas inlet temperature consist of water-side economizer bypasses and water-side economizer recirculation systems. These systems can be effective as well but also have their own disadvantages. The most appropriate SCR catalyst with its own specific minimum temperature, as well as the most effective means of maintaining that minimum inlet temperature, would be further evaluated during detailed design.

Concerns of ammonium bisulfate (ABS) and other deposits are also important when considering SCR systems for NOx control. These deposits are caused by reactions between acid gases and excess ammonia (ammonia slip) from the SCR system. They form in the air heaters as the flue gas cools, typically in difficult to clean areas of older air heaters that were not designed for SCR operation. Black & Veatch recommends that the air heaters incorporate the proper modifications at the time of the SCR system installation which will require a separate study to be performed by the air heater manufacturer during detailed design. These air heater modifications typically include, but are not limited to, the following:

- Replacement of baskets with enamel coated baskets.
- Reduction of the number of basket layers from three to two deeper layers.
- Installation of higher energy and/or multimedia (steam or compressed air / high pressure water) sootblowers with improved controls.

3.0 Unit 2

3.1 Existing Draft System

3.1.1 Layout

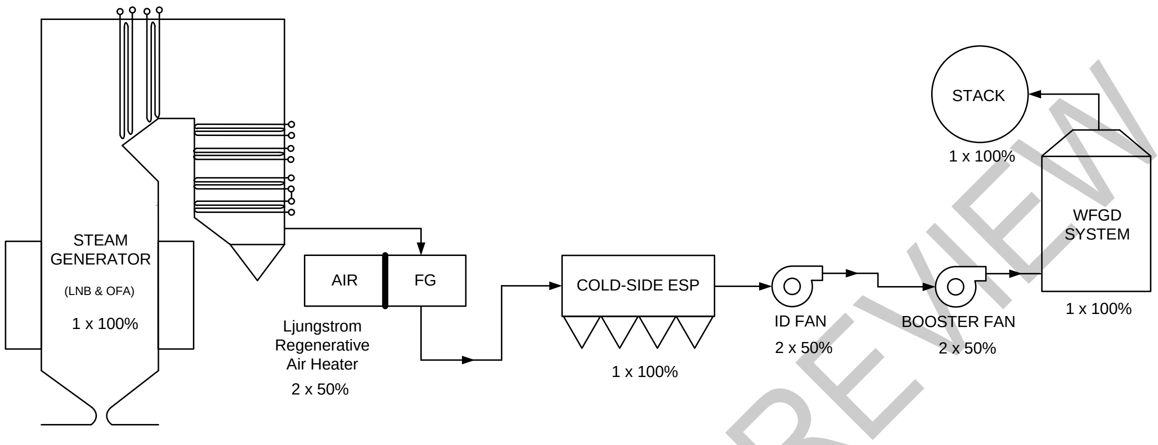

Figure 3-1
Unit 2 Existing Draft System

The draft system for Unit 2, shown in Figure 3-1, and the existing ID and booster fans are very similar to Unit 1. For a description of the Unit 2 draft system layout and ID and booster fans refer to the Unit 1 discussion on these items.

3.1.2 Boiler and Draft System Characteristics

Currently, the major performance characteristics of the Unit 2 boiler and existing draft system at MCR are as follows in Tables 3-1 and 3-2.

Table 3-1 Unit 2 Boiler Characteristics at MCR	
Boiler total heat input	3,311 MBtu/hr (based on net plant output of 303,000 kW and heat rate of 10,929 Btu/kWh)
Boiler excess air	20 % or 3.25% oxygen – wet basis (estimated)
Loss On Ignition (LOI)	2 % (estimated)
Ambient conditions	
Dry bulb temperature	77 ^{o}F
Relative humidity	60 %
Barometric pressure	29.49 inHg

Table 3-2
Unit 2 Existing Draft System Characteristics at MCR

Air heater leakage	10 % (estimated)
ESP leakage	5 % (estimated)
Flue gas temperatures	
Boiler outlet	760 °F
Air heater outlet	375 °F
ESP outlet	340 °F
ID fan outlet	~350 °F (calculated)
Booster fan outlet	~355 °F (calculated)
Wet scrubber outlet	~130 °F (calculated)
Furnace pressure	-0.5 inwg
Draft system differential pressures	
Boiler	4.5 inw
Air heater	5.0 inw
ESP	5.0 inw
ESP outlet to ID fan inlet	1.5 inw
Wet scrubber	10.0 inw
Stack	1.0 inw

Based on the layout of the existing draft system in Figure 3-4 and the boiler and the draft system characteristics listed in Tables 3-5 and 3-6, the estimated performance requirements of the existing ID fans are shown as the MCR point in Figure 3-1. Note that the flue gas outlet pressure of the ID fans is assumed to be atmospheric or 0.0 inwg.

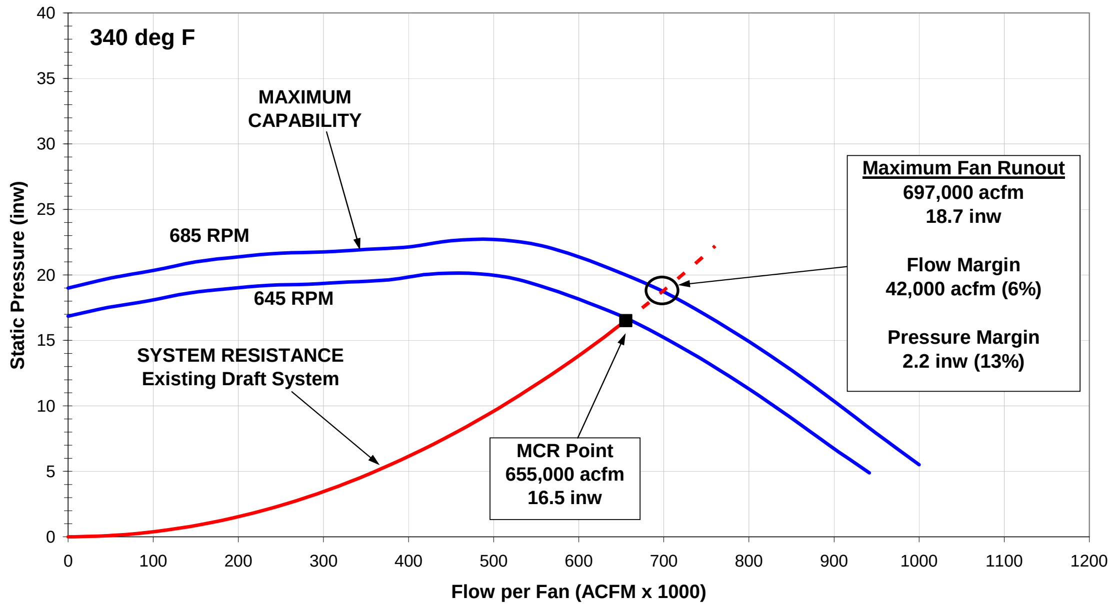

Figure 3-2
Unit 2 Existing ID Fan Performance with Existing Draft System

Based on the MCR point shown in Figure 3-2, it appears that the ID fans operate at approximately 645 rpm and have flow and pressure margins of approximately 6 and 13 percent, respectively. As with the Unit 1 existing ID fan margins, these are below the ranges of flow and pressure margins that are typically recommended by Black & Veatch.

The booster fan performance curve for Unit 2 was unavailable as well and, therefore, their current MCR point in relation to the maximum fan runout, like the one shown in Figure 3-2, cannot be shown at this time. However, the need for further analysis of the existing booster fans is not anticipated. With the expected installation of both a new SCR system and a new PJFF system as with Unit 1, the same reasons for the replacement of the Unit 1 existing ID and booster fans applies to Unit 2 due do the similarity between the units. It is expected that the existing Unit 2 ID and booster fans will be replaced with a single set of new ID fans.

Lastly, the existing draft system equipment and ductwork transient design pressures for Unit 2 are similar to those listed in Table 3-3 for Unit 1. These will be used in determining the amount of stiffening that would be required, if any, in support of the proposed AQC upgrades.

3.2 Future Draft System

3.2.1 Layout

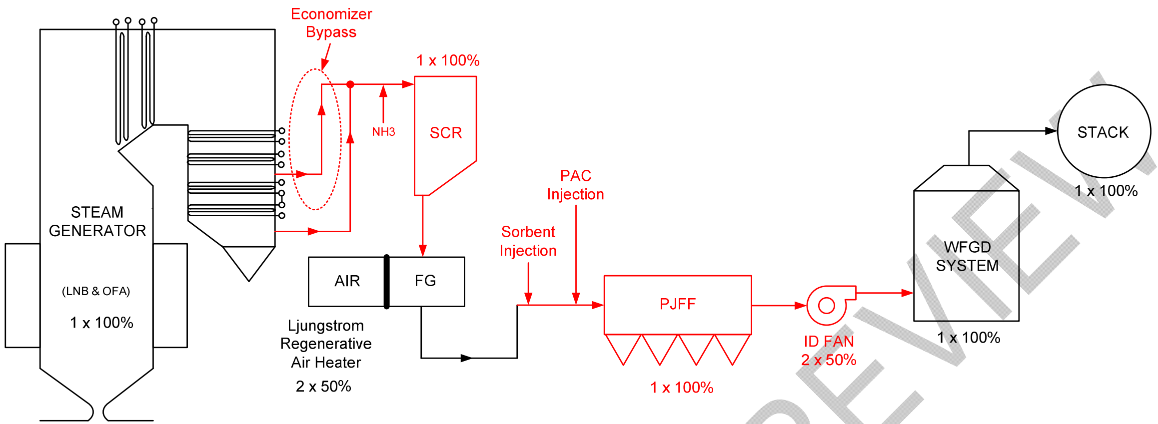

Figure 3-3
Unit 2 Future Draft System

The future draft system for Unit 2, shown in Figure 3-3, is similar to Unit 1. For a description of the Unit 2 future draft system layout and flow path refer to the Unit 1 discussion. An illustration of the Unit 2 future draft system based on this description is shown in Figure 3-2.

3.2.2 Draft System Characteristics

The major performance characteristics of the Unit 2 future draft system at MCR are as follows in Table 3-3. Note that the items in bold in Table 3-3 are new.

Table 3-3 Unit 2 Future Draft System Characteristics at MCR	
SCR system leakage	**2 %**
Air heater leakage	10 % (estimated)
ESP leakage	**(demolished)**
PJFF system leakage	**3 %**
Flue gas temperatures	
Boiler outlet	760 °F
SCR outlet	**760 °F**
Air heater outlet	375 °F
ESP outlet	**(demolished)**
PJFF outlet	**375 °F**
New ID fan outlet	**~400 °F**
Booster fan outlet	**(not replaced)**
Wet scrubber outlet	~130 °F
Furnace pressure	-0.5 inwg
Draft system differential pressures	
Boiler	4.5 inw
SCR	**10.0 inw**
Air heater	5.0 inw
ESP	**(demolished)**
Air heater to PJFF inlet	**1.0 inw**
PJFF	**6.0 inw**
PJFF outlet to ID fan inlet	**1.0 inw**
Wet scrubber	**12.0 inw (refurbished & upgraded)**
Stack	1.0 inw

Based on the layout of the future draft system in Figure 3-3 and the future draft system characteristics in Table 3-3, the estimated performance requirements of the new ID fans at MCR are shown in Table 3-4. Also in Table 3-4 are the recommended Test Block conditions developed using the Black & Veatch fan sizing philosophy. Note the flow and pressure margins of 25 and 40 percent, respectively.

Table 3-4
Unit 2 New ID Fan MCR and Recommended Test Block Conditions

	MCR	Test Block
Fan Speed (rpm), maximum	---------	900
Inlet Temperature (°F)	375	400
Inlet Density (lb/ft^3)	0.0444	0.0419
Flow per Fan (acfm) *	706,000	881,000
Inlet Pressure (inwg)	-28.0	-38.4
Outlet Pressure (inwg)	13.0	19.1
Static Pressure Rise (inw)	41.0	57.5
Shaft Power Required (HP) **	5,400	9,400
Efficiency (%) **	85	85
Number of Fans	2	2
Flow Margin (%)	---------	25
Pressure Margin (%)	---------	40

*Per fan basis with both fans in operation
**Estimated – assumes variable speed operation

With a pressure margin of 40 percent listed in Table 3-4, the new Unit 2 ID fans would operate the future draft system with pressures similar to Unit 1 in Table 3-6. Furthermore, the Unit 2 future draft system potential minimum transient design pressure requirements are similar to Unit 1 as shown in Table 3-7.

3.2.3 Additional Items

Discussions and recommendations regarding the economizer bypass for SCR flue gas temperature control and concerns over ABS deposits in air heaters from SCR operation for Unit 2 would be similar to Unit 1.

4.0 Unit 3

4.1 Existing Draft System

4.1.1 Layout

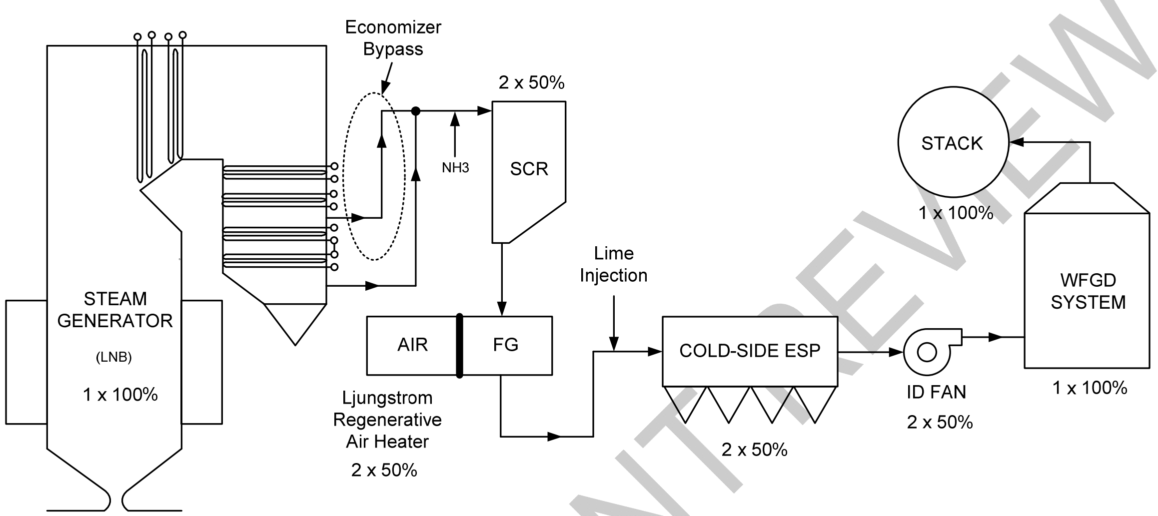

Figure 4-1
Unit 3 Existing Draft System

The description of the existing draft system for Unit 3, shown in Figure 4-1, is similar to Unit 1 except for the SCR system with an economizer bypass and a single set of ID fans. The SCR system is used to remove NOx emission and is located between the boiler outlet and the air heater gas inlet for the purposes of NOx removal. Additionally, the draft fans consist of a single set of ID fans instead of ID and booster fans. For a description of the rest of the Unit 3 draft system layout refer to the Unit 1 existing layout.

4.1.2 ID Fans

The existing Unit 3 draft fan system consists of two ID fans. The Electric Machinery electric motors for each ID fan are single-speed motors that operate nominally at 900 rpm. The nameplate horsepower rating of the ID fan motors is 9,000 horsepower and they operate at a nominal voltage of 4000 volts. Primary, flow control for the ID fans is accomplished by the use of fluid drives (American Standard Gyrol drives size 497, class 5H) in between the fans and motors. The ID fans are double inlet centrifugal fans with a maximum speed capability of approximately 865 rpm due to the fluid drives. The ID fans were recently modified from their original design with rotor replacements, motor rewinds, and fluid drive modifications around the year 2003. Even though the motors and fluid drives limit the ID fans to a maximum of 865 rpm, the new ID fan rotors are actually designed to operate up to a speed of 1000 rpm. The original ID fans for Mill Creek Unit 3 are an American Standard design, size 1430AF 3200BkD. The newer rotors are a Howden design L5N 3749.00.86 DBN6T.

4.1.3 Boiler and Draft System Characteristics

Currently, the major performance characteristics of the Unit 3 boiler and existing draft system at MCR are as follows in Tables 4-1 and 4-2.

Table 4-1
Unit 3 Boiler Characteristics at MCR

Boiler total heat input	4,209 MBtu/hr (based on net plant output of 397,000 kW and heat rate of 10,602 Btu/kWh)
Boiler excess air	20 % or 3.25% oxygen – wet basis (estimated)
Loss On Ignition (LOI)	2 % (estimated)
Ambient conditions	
Dry bulb temperature	77 ^{o}F
Relative humidity	60 %
Barometric pressure	29.49 inHg

Table 4-2 Unit 3 Existing Draft System Characteristics at MCR	
SCR system leakage	2 % (estimated)
Air heater leakage	10 % (estimated)
ESP leakage	5 % (estimated)
Flue gas temperatures	
Boiler outlet	690 °F
SCR outlet	690 °F
Air heater outlet	330 °F
ESP outlet	330 °F
ID fan outlet	~350 °F (calculated)
Wet scrubber	~130 °F (calculated)
Furnace pressure	-0.5 inwg
Draft system differential pressures	
Boiler	4.5 inw
SCR	8.0 inw
Air heater	5.0 inw
ESP	5.0 inw
Wet scrubber	10.0 inw
Stack	1.0 inw

Based on the layout of the existing draft system in Figure 4-1 and the boiler and the draft system characteristics listed in Tables 4-1 and 4-2, the estimated performance requirements of the existing ID fans are shown as the MCR point in Figure 4-2.

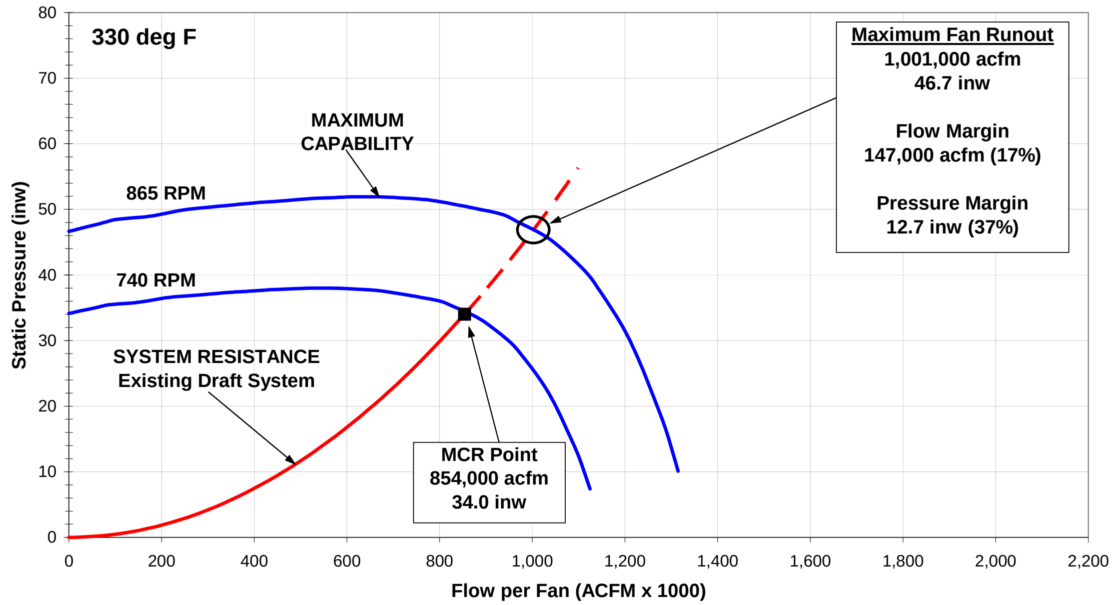

Figure 4-2
Unit 3 Existing ID Fan Performance with Existing Draft System

Based on the MCR point shown in Figure 4-2, it appears that the ID fans operate at approximately 740 rpm and have flow and pressure margins of approximately 17 and 37 percent, respectively. These margins are close to or within the ranges of flow and pressure margins that are typically recommended by Black & Veatch.

Lastly, the existing draft system equipment and ductwork transient design pressures are listed in Table 4-3. These will be used in determining the amount of stiffening that would be required, if any, in support of the proposed AQC upgrades. These design pressures are unknown for some of the equipment and portions of ductwork of Unit 3. These may need to be determined during detailed design depending on their location in the draft system.

Table 4-3
Unit 3 Existing Flue Gas Draft System Equipment and Ductwork Transient Design Pressures

Furnace/Boiler	+5 / -7 inwg
Boiler Outlet to SCR Inlet	Unknown
SCR	Unknown
SCR Outlet to Air Heater Inlet	Unknown
Air Heater	Unknown
Air Heater Outlet to ESP Inlet	± 22 inwg *
ESP	+10 / -20 inwg *
ESP Outlet to ID Fan Inlet	Unknown **
ID Fan	Unknown (typically more conservative than connecting duct)
ID Fan Outlet to Wet Scrubber Inlet	Unknown **
Wet Scrubber	Unknown
Wet Scrubber Outlet to Stack Inlet	Unknown

* With the SCR installation these design pressures do not appear adequate for normal operation. It is expected that these have increased and these values will need to be determined during detailed design of the PJFF installation.

** These pressures will need to be determined to allow the PJFF installer to apply the proper amount of stiffening to existing equipment if required.

4.2 Future Draft System

4.2.1 Layout

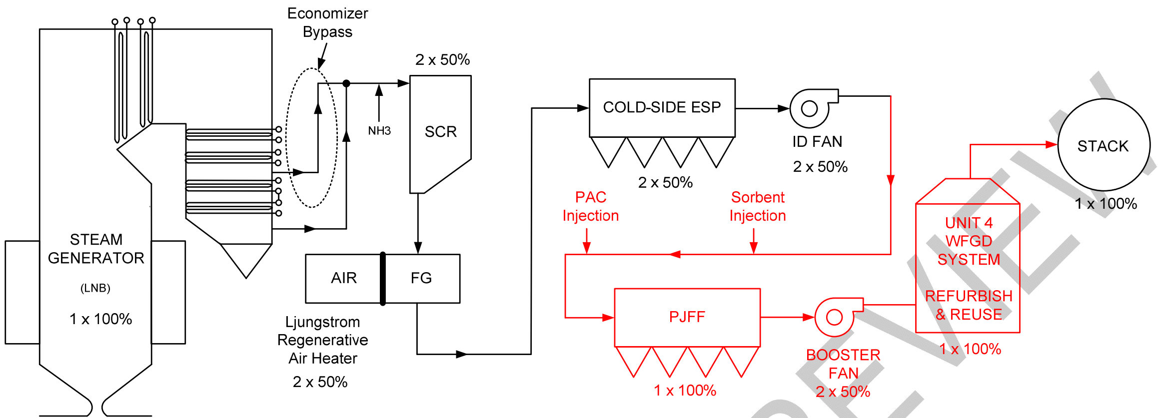

Figure 4-3
Unit 3 Future Draft System

Based on the additions to the Unit 3 draft system previously discussed, the flue gas would be redirected through the draft system as follows. At the outlet of the existing ID fans the flue gas would travel to the new PJFF system allowing for the removal of finer particulate. New booster fans would then draw the flue gas out of the PJFF system and send it to the refurbished Unit 4 wet scrubber system. The Unit 3 wet scrubber system would be bypassed and demolished to make room for the new PJFF. Temporary ductwork would be installed between the outlet of the existing ID fans and the refurbished Unit 4 wet scrubber system to allow operation of Unit 3 while demolition of the Unit 3 wet scrubber system and erection of the Unit 3 PJFF is completed. The use of new booster fans as opposed to continuing to only use the existing ID fans will be discussed later in this section. An illustration of the Unit 3 future draft system based on this description is shown in Figure 4-3.

4.2.2 Draft System Characteristics

The major performance characteristics of the Unit 3 future draft system at MCR are as follows in Table 4-4. Note that the items in bold in Table 4-4 are new.

Table 4-4
Unit 3 Future Draft System Characteristics at MCR

SCR system leakage	2 % (estimated)
Air heater leakage	10 % (estimated)
ESP leakage	5 % (estimated)
PJFF system leakage	**3 %**
Flue gas temperatures	
Boiler outlet	690 ^{o}F
SCR outlet	690 ^{o}F
Air heater outlet	330 ^{o}F
ESP outlet	330 ^{o}F
ID fan outlet	~345 ^{o}F (calculated)
PJFF outlet	**~345 ^{o}F (calculated)**
New booster fan outlet	**~355 ^{o}F (calculated)**
Wet scrubber outlet	~130 ^{o}F (calculated)
Furnace pressure	-0.5 inwg
Draft system differential pressures	
Boiler	4.5 inw
SCR	8.0 inw
Air heater	5.0 inw
ESP	5.0 inw
ID fan outlet to PJFF inlet	**1.0 inw**
PJFF	**6.0 inw**
PJFF outlet to booster fan	**1.0 inw**
Booster fan outlet to Wet scrubber	**1.0 inw**
Existing Unit 4 Wet scrubber	**12.0 inw (refurbished & upgraded)**
Existing Unit 4 Stack	**1.0 inw**

4.2.3 Analysis of Existing ID Fans with Future Draft System

There is the potential that the existing ID fans could provide the only motive force to move the flue gas through the draft system. However, new ductwork would need to be arranged to locate the ID fans downstream of the PJFF system as it is highly recommended to operate a PJFF under negative draft pressure.

With a PJFF addition upstream, the existing ID fans in their existing configuration would only have margins of approximately three percent on flow and seven percent on pressure as shown in Figure 4-4 by the "Current Maximum Capability" curve and the "Maximum Fan Runout" box. However, also shown in Figure 4-4, the fans have the potential to operate at speeds up to 1000 rpm as shown by the fan curve which Figure 4-4 is based on and confirmations from the manufacturer. Although the existing Unit 3 ID fan drive system is not design to operate beyond 865 rpm, it appears that the existing ID fans could support the installation of a PJFF system upstream and have ample flow and pressure margins if supplied with a suitable drive system. With a PJFF system installed the expected flow and pressure margins would be approximately 19 and 43 percent, respectively, as shown in the "Potential Maximum Fan Runout" box. These margins are more than adequate to warrant the reuse of the existing ID fans for Unit 3 provided the rest of the ID fan system is designed to handle the increased speeds such as the foundations, bearings, lube oil, etc. Note also that the existing Unit 3 ID fans have sufficient margin to allow temporary operation of Unit 3 with the refurbished Unit 4 WFGD while the existing Unit 3 WFGD is demolished and the new PJFF is erected.

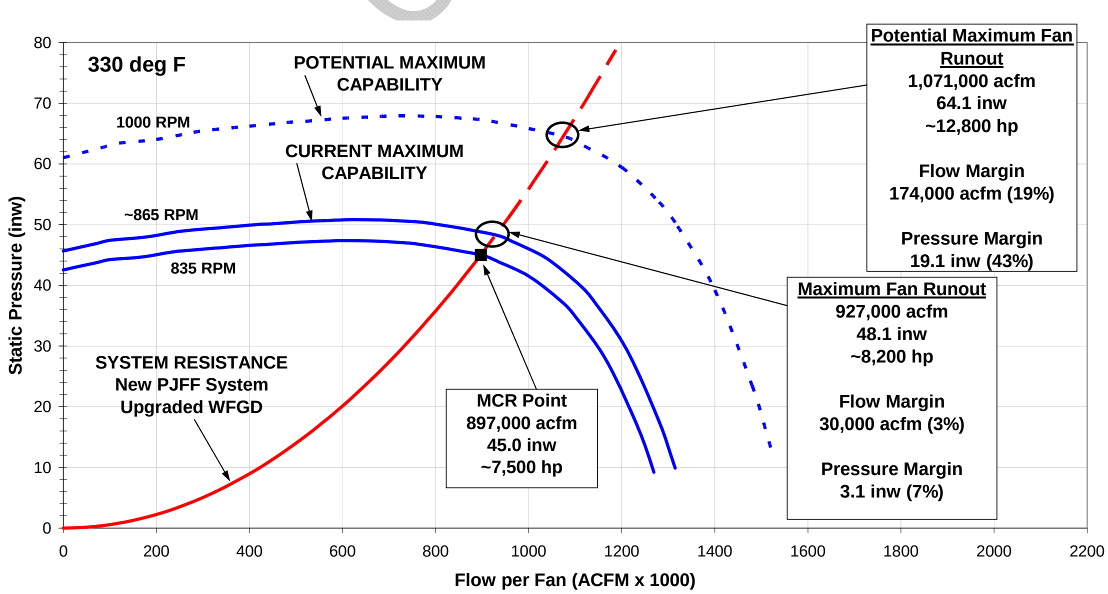

Figure 4-4
Unit 3 Existing ID Fan Performance with Future Draft System

Nevertheless, Black & Veatch recommends the use of booster fans at this time to compensate for the draft losses of the new PJFF system and the refurbished Unit 4 Wet scrubber. The unavailability of a detailed analysis of the speed capabilities of the entire existing ID fan system and the small margins that would be available with the ID fans in their existing configuration are the reasons for this decision. The estimated performance of the existing ID fans with booster fans downstream of a new PJFF system is shown in Figure 4-5. Note that the pressure rise required has lowered since the outlet pressure of the existing ID fans is expected to be reduced to approximately atmospheric pressure or 0.0 inwg. This will allow the PJFF system to be under negative draft pressures.

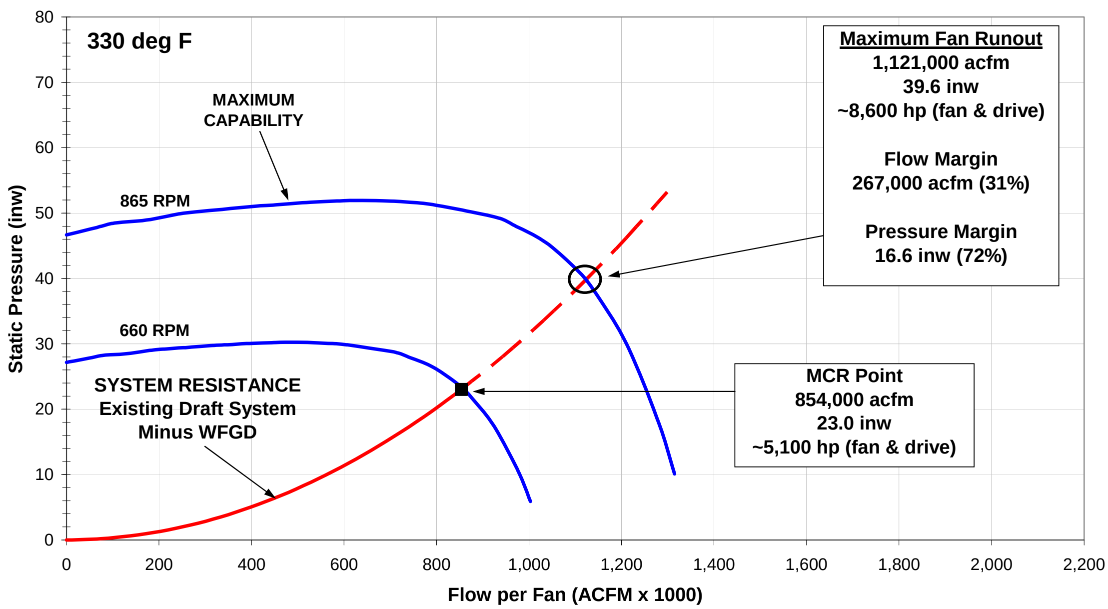

Figure 4-5
Unit 3 Existing ID Fan Performance with Future Draft System and New Booster Fans

4.2.4 Booster Fans

Based on the layout of the future draft system in Figure 4-3 and the future draft system characteristics in Table 4-4, the estimated performance requirements of the new booster fans at MCR are shown in Table 4-5. Also in Table 4-5 are the recommended Test Block conditions developed using the Black & Veatch fan sizing philosophy. Note the flow and pressure margins of 25 and 46 percent, respectively.

Table 4-5
Unit 3 New Booster Fan MCR and Recommended Test Block Conditions

	MCR	Test Block
Fan Speed (rpm), maximum	---------	900
Inlet Temperature (°F)	345	370
Inlet Density (lb/ft^3)	0.0485	0.0467
Flow per Fan (acfm) *	861,000	1,077,000
Inlet Pressure (inwg)	-8.0	-10.9
Outlet Pressure (inwg)	14.0	21.3
Static Pressure Rise (inw)	22.0	32.2
Shaft Power Required (HP) **	3,500	6,400
Efficiency (%) **	85	85
Number of Fans	2	2
Flow Margin (%)	---------	25
Pressure Margin (%)	---------	46

*Per fan basis with both fans in operation
**Estimated – assumes variable speed operation

4.2.5 Operating and Transient Design Pressures

With a pressure margin of 46 percent listed in Table 4-5, the new ID fans would be expected to operate the future draft system with the Test Block pressures listed in Table 4-6. The normal operating, or MCR, pressures have been shown in Table 4-6 as well for reference.

Table 4-6
Unit 3 Flue Gas Draft System Pressures at MCR and New ID Fan Test Block

	MCR Pressure (inwg)	Test Block Pressure (inwg)
Furnace/Boiler	-0.5	-0.5
Boiler/Economizer Outlet	-5.0	-6.0
SCR Outlet	-13.0	-15.8
Air Heater Outlet	-18.0	-25.1
ESP Outlet	-23.0	-31.8
ID Fan Outlet	0.0	0.0
PJFF Inlet	-1.0	-1.4
PJFF Outlet	-7.0	-9.5
Booster Fan Inlet	-8.0	-10.9
Booster Fan Outlet	14.0	21.3
Wet Scrubber Inlet	13.0	19.8
Wet Scrubber Outlet	1.0	1.5

With the future draft system Test Block operating pressures defined in Table 4-6, the future draft system potential minimum transient design pressure requirements can be determined and are shown in Table 4-7. The Black & Veatch philosophy for calculating the minimum required transient design pressures is the same method discussed for Unit 1.

The transient design pressures in Table 4-7 would be used in determining the amount of stiffening of existing and new equipment that would be required, if any, in support of the proposed AQC upgrades. In review, the National Fire Protection Association (NFPA) 85 requires that new flue gas ductwork and equipment between the boiler outlet and the ID fan inlet be designed for transient pressures of ± 35 inwg. Therefore, calculated transient design pressures below ± 35 inwg are disregarded and the ± 35 inwg is used as the design transient pressure for that draft system component or section of ductwork. For calculated transient design pressures over ± 35 inwg the calculated pressure is used.

Table 4-7
Unit 3 Future Flue Gas Draft System Potential Transient Design Pressure Requirements

Furnace/Boiler	± 35 inwg *
Boiler Outlet to SCR Inlet	± 35 inwg *
SCR	± 35 inwg *
SCR Outlet to Air Heater Inlet	± 35 inwg *
Air Heater	+35 * / -37 inwg
Air Heater Outlet to ESP Inlet	+35 * / -37 inwg
ESP	+35 * / -46 inwg
ESP Outlet to ID Fan Inlet	+35 * / -46 inwg
ID Fan	+35 * / -46 inwg
ID Fan Outlet to PJFF Inlet	± 35 inwg
PJFF	± 35 inwg
PJFF Outlet to Booster Fan Inlet	± 35 inwg
New Booster Fan	(Determined by Manufacturer)
Booster Fan Outlet to Wet Scrubber Inlet	+31 / -10 inwg **
Wet Scrubber	+31 / -10 inwg **
Wet Scrubber Outlet to Stack Inlet	± 10 inwg **

* Further research is needed to determine whether this would be required if lower than ± 35 inwg.

** Estimated – Ductwork and equipment downstream of the ID fans up to the stack inlet was assumed to have a minimum transient design pressure rating of +10/-10 inwg, typical of ductwork in that section of a draft system. If the actual design pressures in this section are different, stiffening would likely not be required except for the minimum positive design pressure greater than +10 inwg from the booster fan outlet through the wet scrubber. NFPA 85 does not specifically call out a minimum design pressure requirement for ductwork downstream of ID/Booster fans.

As mentioned earlier in the Unit 1 discussions, the AQC equipment additions and changes to all of the Mill Creek units will likely be considered major alterations or extensions to the existing facilities per the NFPA 85 code - Section 1.3 (2007 Edition). The code, in this instance, would imply that the boiler and flue gas ductwork from the boiler outlet (economizer outlet) to the ID/booster fan inlet be designed for transient pressures of ± 35 inwg at a minimum per Section 6.5. Further research is needed during detailed design to determine whether the remaining portions of the existing Unit 3 boiler and draft system meets this criteria or if they would require stiffening.

5.0 Unit 4

5.1 Existing Draft System

5.1.1 Layout

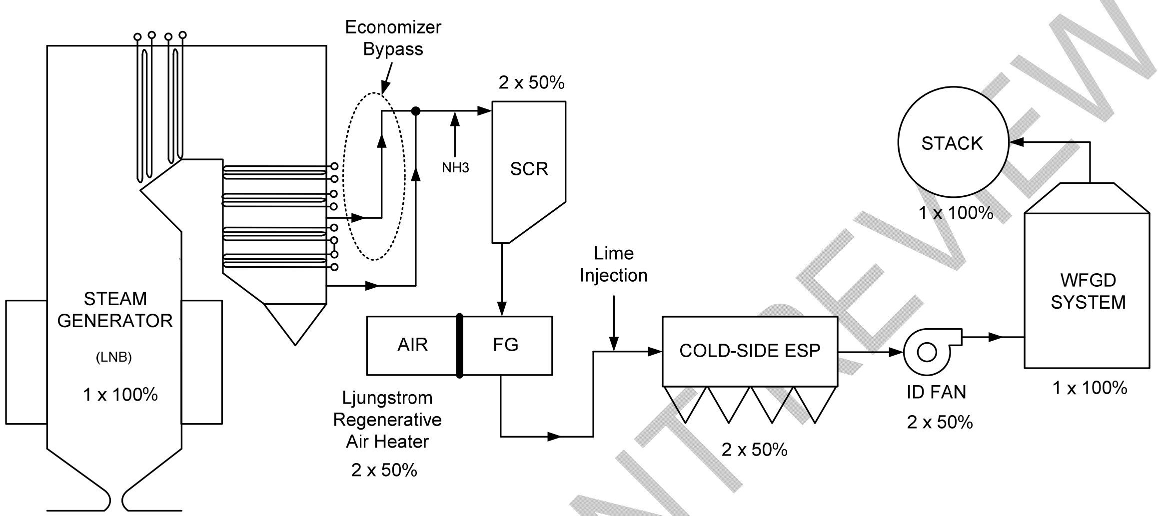

Figure 5-1
Unit 4 Existing Draft System

The description of the existing draft system for Unit 4, shown in Figure 5-1, is similar to Unit 1 except for the SCR system with an economizer bypass and a single set of ID fans. The SCR system is used to remove NOx emission and is located between the boiler outlet and the air heater gas inlet for the purposes of NOx removal. Additionally, the draft fans consist of a single set of ID fans instead of ID and booster fans. For a description of the rest of the Unit 4 draft system layout refer to the Unit 1 existing layout.

5.1.2 ID Fans

The existing Unit 4 flue gas draft fan system consists of two ID fans. The Electric Machinery electric motors for each ID fan are single-speed motors that operate nominally at 900 rpm. The nameplate horsepower rating of the ID fan motors is 9,500 horsepower with a service factor of 1.15. The motors operate at a nominal voltage of 4000 volts. Flow control for the ID fans is accomplished by the use of fluid drives (American Standard Gyrol drives size 580, class 5) in between the fans and motors. It is unknown to B&V whether or not any form of damper flow control is present. The ID fans are double inlet centrifugal fans with a maximum speed capability of approximately 860 rpm due to the fluid drives. The ID fans were recently modified from their original design with rotor replacements, motor upgrades, and fluid drive modifications around the year 2005. The original ID fans for Mill Creek Unit 4 are a Green Fan design, size 1540 Type A 6158 BD. The newer rotors are a Howden design TVAF6-C 3880.04.96 DBN6F.

5.1.3 Boiler and Draft System Characteristics

Currently, the major performance characteristics of the Unit 4 boiler and existing draft system at MCR are as follows in Tables 5-1 and 5-2.

Table 5-1
Unit 4 Boiler Characteristics at MCR

Boiler total heat input	5,122 MBtu/hr (based on net plant output of 492,000 kW and heat rate of 10,410 Btu/kWh)
Boiler excess air	20 % or 3.25% oxygen – wet basis (estimated)
Loss On Ignition (LOI)	2 % (estimated)
Ambient conditions	
Dry bulb temperature	77 ^{o}F
Relative humidity	60 %
Barometric pressure	29.49 inHg

Table 5-2 **Unit 4 Existing Draft System Characteristics at MCR**	
SCR system leakage	2 % (estimated)
Air heater leakage	10 % (estimated)
ESP leakage	5 % (estimated)
Flue gas temperatures	
Boiler outlet	640 ^{o}F
SCR outlet	640 ^{o}F
Air heater outlet	330 ^{o}F
ESP outlet	330 ^{o}F
ID fan outlet	~350 ^{o}F (calculated)
Wet scrubber outlet	~130 ^{o}F (calculated)
Furnace pressure	-0.5 inwg
Draft system differential pressures	
Boiler	4.5 inw
SCR	8.0 inw
Air heater	5.0 inw
ESP	5.0 inw
Wet scrubber	10.0 inw
Stack	1.0 inw

Based on the layout of the existing draft system in Figure 5-1 and the boiler and the draft system characteristics listed in Tables 5-1 and 5-2, the estimated performance requirements of the existing ID fans are shown as the MCR point in Figure 5-2.

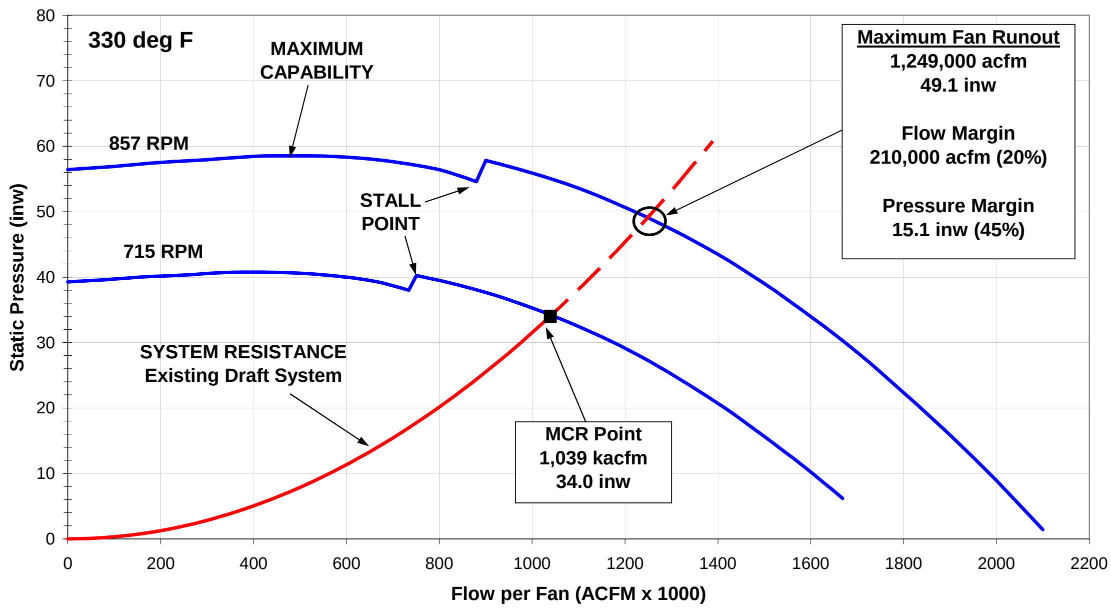

Figure 5-2
Unit 4 Existing ID Fan Performance with Existing Draft System

Based on the MCR point shown in Figure 5-2, it appears that the ID fans operate at approximately 715 rpm and have flow and pressure margins of approximately 20 and 45 percent, respectively. These margins are within the ranges of flow and pressure margins that are typically recommended by Black & Veatch.

Lastly, the existing draft system equipment and ductwork transient design pressures are listed in Table 5-3. These will be used in determining the amount of stiffening that would be required, if any, in support of the proposed AQC upgrades. These design pressures are unknown for some of the equipment and portions of ductwork of Unit 4. These may need to be determined during detailed design depending on their location in the draft system.

Table 5-3
Unit 4 Existing Flue Gas Draft System Equipment and Ductwork Transient Design Pressures

Furnace/Boiler	+5 / -7 inwg
Boiler Outlet to SCR Inlet	Unknown
SCR	Unknown
SCR Outlet to Air Heater Inlet	Unknown
Air Heater	Unknown
Air Heater Outlet to ESP Inlet	+7 / -22 inwg
ESP	+7 / -35 inwg
ESP Outlet to ID Fan Inlet	+7 / -35 inwg
ID Fan	Unknown (typically more conservative than connecting duct)
ID Fan Outlet to Wet Scrubber Inlet	Unknown **
Wet Scrubber	Unknown
Wet Scrubber Outlet to Stack Inlet	Unknown

** These pressures will need to be determined to allow the PJFF installer to apply the proper amount of stiffening to existing equipment if required.

5.2 Future Draft System

5.2.1 Layout

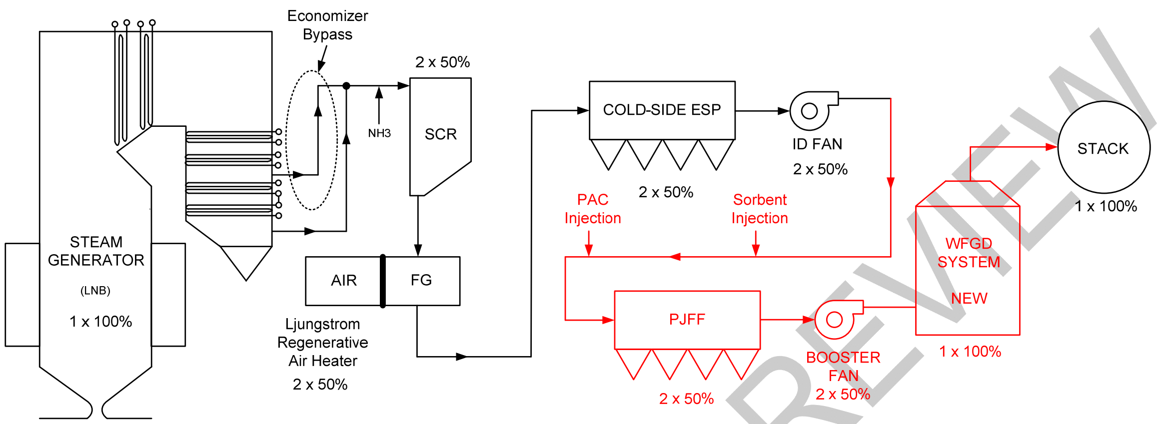

Figure 5-3
Unit 4 Future Draft System

Based on the additions to the Unit 4 draft system previously discussed, the flue gas would be redirected through the draft system as follows. At the outlet of the existing ID fans the flue gas would travel to the new PJFF system allowing for the removal of finer particulate. New booster fans would then draw the flue gas out of the PJFF system and send it to the new WFGD system. The use of new booster fans as opposed to continuing to only use the existing ID fans will be discussed later in this section. An illustration of the Unit 4 future draft system based on this description is shown in Figure 5-3.

5.2.2 Draft System Characteristics

The major performance characteristics of the Unit 4 future draft system at MCR are as follows in Table 5-4. Note that the items in bold in Table 5-4 are new.

Table 5-4 Unit 4 Future Draft System Characteristics at MCR	
SCR system leakage	2 % (estimated)
Air heater leakage	10 % (estimated)
ESP leakage	5 % (estimated)
PJFF system leakage	**3 %**
Flue gas temperatures	
Boiler outlet	640 ^{o}F
SCR outlet	640 ^{o}F
Air heater outlet	330 ^{o}F
ESP outlet	330 ^{o}F
ID fan outlet	~345 ^{o}F (calculated)
PJFF outlet	**~345 ^{o}F (calculated)**
New booster fan outlet	**~355 ^{o}F (calculated)**
WFGD outlet	**~130 ^{o}F (calculated)**
Furnace pressure	-0.5 inwg
Draft system differential pressures	
Boiler	4.5 inw
SCR	8.0 inw
Air heater	5.0 inw
ESP	5.0 inw
ID fan outlet to PJFF inlet	**2.0 inw**
PJFF	**6.0 inw**
New WFGD	**10.0 inw**
New Stack	**1.0 inw**

The two different arrangements, A and B, for the new Unit 4 AQC equipment are expected to have different overall pressure losses due to the differing lengths of ductwork. Black & Veatch has preliminarily accounted for this with the pressure drop of 2.0 inw for the ductwork between the existing Unit 4 ID fans and the new PJFF system.

5.2.3 Analysis of Existing ID Fans with Future Draft System

There is the potential that the existing ID fans could provide the only motive force to move the flue gas through the draft system. However, new ductwork would need to be arranged to locate the ID fans downstream of the PJFF system as it is highly recommended to operate a PJFF under negative draft pressure. This is expected to require an extensive amount of additional ductwork beyond what would be required with booster fans due to the location of the new PJFF system. Ductwork modifications between the outlets of the ESPs and the ID fans may be extensive as well. Another option would be to relocate the existing ID fans to the proposed location of the booster fans downstream of the PJFF avoiding the additional ductwork. However, this would involve significant time to complete, likely extending the construction outage for Unit 4 beyond that currently scheduled.

With a PJFF addition upstream, the existing ID fans in their existing configuration would have margins of approximately 9 percent on flow and 18 percent on pressure as shown in Figure 5-4 by the “Current Maximum Capability” curve and the “Maximum Fan Runout” box. These margins are below the B&V recommended ranges of flow and pressure margins, but they could be considered adequate enough to justify the reuse of the existing ID fans with the PJFF installation. However, also shown in Figure 5-4, it would be expected that the fans would be designed to operate at speeds up to 900 rpm as the electric motors are designed for this speed. The slip losses in the fluid drive do not allow the motors to operate the existing ID fans at speeds closer to 900 rpm. If a different drive system were installed to allow the existing ID fans to operate at 900 rpm, flow and pressure margins would improve. With a PJFF system installed and the capability of 900 rpm speeds, the expected ID fan flow and pressure margins in Figure 5-4 are approximately 19 and 43 percent, respectively, as shown in the “Potential Maximum Fan Runout” box. These increased margins would further warrant the reuse of the existing ID fans for Unit 4 provided the rest of the ID fan system is designed to handle the increased speeds such as the foundations, bearings, lube oil, etc.

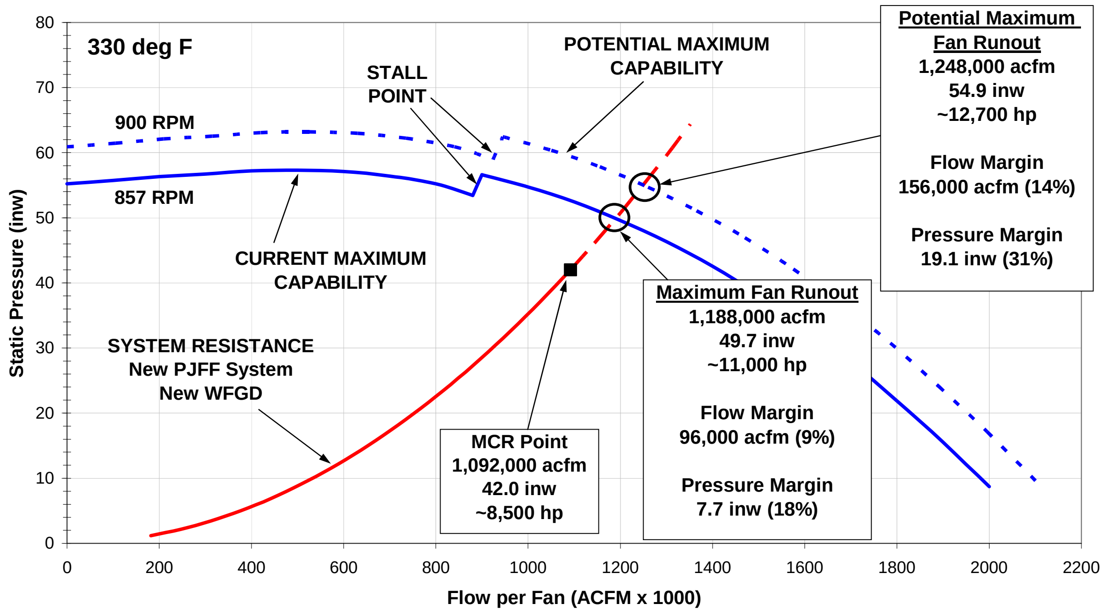

Figure 5-4
Unit 4 Existing ID Fan Performance with Future Draft System

Nevertheless, Black & Veatch recommends the use of booster fans at this time to compensate for the draft losses of the new PJFF system and the new WFGD system. The unavailability of a detailed analysis of the speed capabilities of the entire existing ID fan system, the small margins that would be available with the ID fans in their existing configuration, and the extensive amount new ductwork and ductwork modifications that would be required are the reasons for this decision. The estimated performance of the existing ID fans with booster fans downstream of a new PJFF system is shown in Figure 5-5. Note that the pressure rise required has lowered since the outlet pressure of the existing ID fans is expected to be reduced to approximately atmospheric pressure or 0.0 inwg. This will allow the PJFF system to be under negative draft pressures.

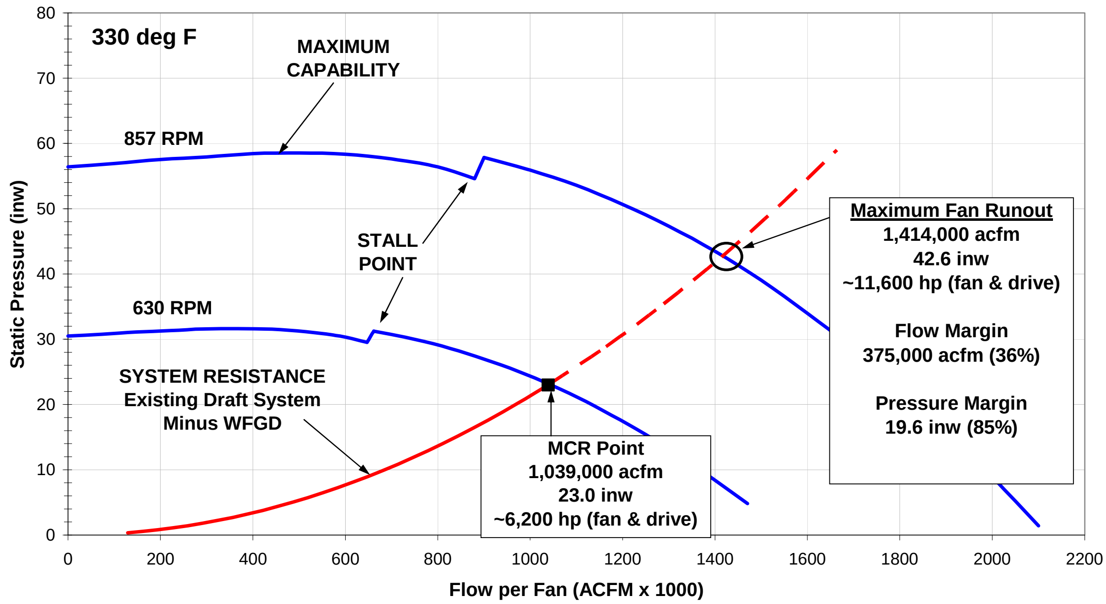

Figure 5-5
Unit 4 Existing ID Fan Performance with Future Draft System and New Booster Fans

5.2.4 Booster Fans

Based on the layout of the future draft system in Figure 5-2 and the future draft system characteristics in Table 5-4, the estimated performance requirements of the new booster fans at MCR are shown in Table 5-5. Also in Table 5-5 are the recommended Test Block conditions developed using the Black & Veatch fan sizing philosophy. Note the flow and pressure margins of 25 and 46 percent, respectively.

Table 5-5
Unit 4 New Booster Fan MCR and Recommended Test Block Conditions

	MCR	Test Block
Fan Speed (rpm), maximum	---------	900
Inlet Temperature (°F)	345	370
Inlet Density (lb/ft^3)	0.0485	0.0467
Flow per Fan (acfm) *	1,048,000	1,310,000
Inlet Pressure (inwg)	-8.0	-10.8
Outlet Pressure (inwg)	11.0	17.0
Static Pressure Rise (inw)	19.0	27.8
Shaft Power Required (HP) **	3,700	6,800
Efficiency (%) **	85	85
Number of Fans	2	2
Flow Margin (%)	---------	25
Pressure Margin (%)	---------	46

*Per fan basis with both fans in operation
**Estimated – assumes variable speed operation

5.2.5 Operating and Transient Design Pressures

With a pressure margin of 46 percent listed in Table 5-5, the new ID fans would be expected to operate the future draft system with the Test Block pressures listed in Table 5-6. The normal operating, or MCR, pressures have been shown in Table 5-6 as well for reference.

Table 5-6
Unit 4 Flue Gas Draft System Pressures at MCR and New ID Fan Test Block

	MCR Pressure (inwg)	Test Block Pressure (inwg)
Furnace/Boiler	-0.5	-0.5
Boiler/Economizer Outlet	-5.0	-6.0
SCR Outlet	-13.0	-15.8
Air Heater Outlet	-18.0	-25.1
ESP Outlet	-23.0	-31.8
ID Fan Outlet	0.0	0.0
PJFF Inlet	-2.0	-2.7
PJFF Outlet	-8.0	-10.8
Booster Fan Outlet	11.0	16.0
WFGD Outlet	1.0	1.5

With the future draft system Test Block operating pressures defined in Table 5-6, the future draft system potential minimum transient design pressure requirements can be determined and are shown in Table 5-7. The Black & Veatch philosophy for calculating the minimum required transient design pressures is the same method discussed for Unit 1.

The transient design pressures in Table 5-7 would be used in determining the amount of stiffening of existing and new equipment that would be required, if any, in support of the proposed AQC upgrades. In review, the National Fire Protection Association (NFPA) 85 requires that new flue gas ductwork and equipment between the boiler outlet and the ID fan inlet be designed for transient pressures of ± 35 inwg. Therefore, calculated transient design pressures below ± 35 inwg are disregarded and the ± 35 inwg is used as the design transient pressure for that draft system component or section of ductwork. For calculated transient design pressures over ± 35 inwg the calculated pressure is used.

Table 5-7
Unit 4 Future Flue Gas Draft System Potential Transient Design Pressure Requirements

Furnace/Boiler	± 35 inwg *
Boiler Outlet to SCR Inlet	± 35 inwg *
SCR	± 35 inwg *
SCR Outlet to Air Heater Inlet	± 35 inwg *
Air Heater	+35 * / -37 inwg
Air Heater Outlet to ESP Inlet	+35 * / -37 inwg
ESP	+35 * / -46 inwg
ESP Outlet to ID Fan Inlet	+35 * / -46 inwg
ID Fan	+35 * / -46 inwg
ID Fan Outlet to PJFF Inlet	± 35 inwg
PJFF	± 35 inwg
PJFF Outlet to Booster Fan Inlet	± 35 inwg
New Booster Fan	(Determined by Manufacturer)
Booster Fan Outlet to WFGD Inlet	+24 / -10 inwg **
WFGD	+24 / -10 inwg **
WFGD Outlet to Stack Inlet	± 10 inwg **

* Further research is needed to determine whether this would be required if lower than ± 35 inwg.

** Estimated – Ductwork and equipment downstream of the ID fans up to the stack inlet was assumed to have a minimum transient design pressure rating of +10/-10 inwg, typical of ductwork in that section of a draft system. If the actual design pressures in this section are different, stiffening would likely not be required except for the minimum positive design pressure greater than +10 inwg from the booster fan outlet through the WFGD. NFPA 85 does not specifically call out a minimum design pressure requirement for ductwork downstream of ID/Booster fans.

As mentioned earlier in the Unit 1 discussions, the AQC equipment additions and changes to all of the Mill Creek units will likely be considered major alterations or extensions to the existing facilities per the NFPA 85 code - Section 1.3 (2007 Edition). The code, in this instance, would imply that the boiler and flue gas ductwork from the boiler outlet (economizer outlet) to the ID/booster fan inlet be designed for transient pressures of ± 35 inwg at a minimum per Section 6.5. Further research is needed during detailed design to determine whether the remaining portions of the existing Unit 4 boiler and draft system meets this criteria or if they would require stiffening.

6.0 Draft Fan Variable Speed Options

The existing ID and booster fans of all Mill Creek units utilize variable speed flow control. For conceptual design B&V has kept this philosophy intact. Although the existing Mill Creek fans use fluid drives in between the fans and motors to accomplish this, B&V is basing conceptual design pricing on the installation of variable frequency drives (VFD) instead. This is due to the continued desire to utilize a 4.16 kV electrical system as opposed to a more expensive, higher voltage system. VFDs are viewed as the best option to limit in-rush current when starting fans or other rotating equipment with high inertia loading. With the draft fans of the capacities previously discussed, particularly for Units 1 and 2, it is expected that VFDs would allow the continued use of a 4.16 kV electrical system. B&V is open to further discussions on this approach in the future; however, the use of fluid drives may require the use of a higher voltage electrical system. Nevertheless, B&V has allocated sufficient physical space for the new fans to use either fluid drives between motor and fan or VFDs located in close proximity.

Additionally, B&V has provided brief descriptions of the types of variable speed technologies that were previously discussed, as well as a more efficient type of fluid drive, for use with large draft fans in the following text. The types of variable speed technologies discussed are as follows:

- Hydrokinetic (HK) fluid couplings
- Hydrokinetic fluid couplings with integral gear sets (HKG)
- Variable frequency drives (VFD)

The HK technology is similar to the current variable speed technology installed on the existing Mill Creek ID and booster fans. Within an enclosed chamber, HK technology transmits power by means of imposing kinetic energy on a working fluid which is typically oil. A pump wheel, connected to the input shaft (motor end), creates this kinetic energy which is transmitted to a turbine wheel, connected to the output shaft (fan end). The level of working fluid within the pump and turbine wheels can be varied allowing different levels of power to be transmitted to the driven equipment. These devices are placed in between the motor and fan to vary fan speeds through mechanical means.

The HKG technology contains the same type of fluid coupling as HK, but with the incorporation of a planetary gear set. The addition of a planetary gear set in conjunction with the HK technology allows the use of kinetic and mechanical energy in transmitting variable speed power to the driven equipment. With the splitting of transmitted power, most of the power is sent directly to the output, or main, shaft via the rotating planetary gear. "Only the power necessary for adjusting the speed of the driven machine is split off from the main shaft through the hydrodynamic torque converter and superimposed into the planetary gear" (Voith Vorecon – Variable Speed Planetary Gear brochure). Since most of the transmitted power is done through mechanical means, efficiency increases significantly over the HK technology as output shaft speeds decrease to the driven equipment. Similar to the HK technology, these devices are placed in between the motor and fan to vary fan speeds through mechanical means.

VFD technology accomplishes variable speed operation in a completely different manner through electronic means as opposed to mechanical means. This technology has become much more proven in recent years than in decades past. VFD operated fans consist of the motor and fan as the rotating equipment with an electrical enclosure placed relatively close to the fan. The electrical enclosure houses the solid state electronics that vary the electrical frequency as well as voltage and/or current entering the electric motors that drive the fans. Varying fan speeds in this manner is extremely efficient, as well. It is debatable whether the HKG or the VFD is more efficient during normal operation. However, an advantage of VFDs is that they allow for a true soft start capability. With both HK and HKG technologies providing for a minimum or no inertial loading during startup, uncontrolled acceleration is still present with motors. VFDs allow for controlled acceleration further reducing in-rush current from fluid drive technologies. Additionally, VFD manufacturers can also supply a "braking" feature that allows fans to coast down at a faster rate while sending electrical energy back into the aux electric system. A feature such as this could be used during upset conditions where fast acting controls are desired. However, fast acting fan inlet dampers can also allow fans to react quickly to upset conditions.

Some other items that may be contained in VFD enclosures include input and output power cabinets, coolant cabinets, transformers, fuses, and HVAC equipment. VFD electronics also require cooling and are typically supplied with a means of cooling through liquid to air heat exchangers placed outside the enclosure. Some smaller VFDs can be air cooled directly decreasing the real estate needed. Plant cooling water, typically used for the other two variable speed technologies, could also be used.

7.0 Summary

The Unit 1 major modifications and additions to the draft system being considered include a new SCR system, new PJFF system, and the refurbishment and upgrading of the existing wet scrubber system. The demolition of the Unit 1 ESP will be required to make room for the new SCR system. The Unit 1 ESP would not be replaced. Unit 2 would be similar to Unit 1. Added to Unit 3 would be a new PJFF system and new ductwork to utilize the existing Unit 4 wet scrubber system. The Unit 3 wet scrubber system would be abandoned. Unit 4 would have a new PJFF system as well and a new WFGD system. In order for the existing Mill Creek draft systems to support the installation of this additional draft system equipment to control, or enhance the control of, certain flue gas emissions, significant upgrades would be required.

To support the installation of the AQC equipment being considered, B&V has identified various improvements to the Mill Creek draft systems. Unit 1 would be equipped with a new set of ID fans to replace the existing sets of ID and booster fans. To support the operation of the SCR system at medium to low loads an economizer bypass would be included with the SCR system. Air heater modifications would also take place to support the SCR installation. Finally, the need for ductwork stiffening in some portions of the existing draft system is likely and boiler stiffening may be required as well. The improvements to the Unit 2 draft system would be similar to Unit 1. For Unit 3, B&V would incorporate the use of booster fans to compensate for the increased draft losses. However, it appears that the existing Unit 3 ID fans have adequate capacity to support the AQC upgrades as well provided that drive system upgrades and additional ductwork modifications take place. B&V has incorporated the use of booster fans to support increased draft losses for Unit 4 as well. Like Unit 3, though, the existing Unit 4 ID fans could potentially support the AQC upgrades without the assistance of booster fans. Although, with the increased distance between the existing Unit 4 ID fans and the PJFF on Unit 4 compared to Unit 3, the additional ductwork that would be required would likely be cost prohibitive. Furthermore, the real estate required for this additional ductwork may not be available. Lastly, ductwork stiffening in some portions of the existing draft system of Units 3 and 4, as well as in the boiler, may be needed.

Variable speed drive options for each new set of fans proposed for the Mill Creek units were discussed in this document as well due to the desire of the Mill Creek site to continue with variable speed operation on draft fans. The first of the three technologies brought to attention was the hydrokinetic (HK) fluid coupling. The second was the hydrokinetic fluid coupling with integral gear sets (HKG). Variable frequency drives (VFD) was the third technology. The first two accomplish variable speed operation through the manipulation of mechanical components placed in between the motor and fan shafts. The VFD technology varies speed by manipulating the electrical power sent to the fan motor. The HK technology, similar to the current variable speed equipment on all Mill Creek draft fans, has the least expensive upfront equipment costs. However, it is the least efficient of the three variable speed technologies discussed here. The HKG and VFD technologies are similar in price, for fan related equipment only, and overall efficiency over most of the speeds that will be utilized on a regular basis. However, HK and HKG technologies may require a more expensive, higher voltage electrical system due to there higher in-rush current requirements thus eliminating any potential capital cost savings. For this conceptual design phase B&V has chosen to include VFD technology. During detailed design, though, an economic analysis would be recommended to determine the most cost effective variable speed technology if LG&E/KU wishes to still consider multiple variable speed options.