SYMPOSIUM OF THE INDUSTRIAL APPLICATION OF GAS TURBINES COMMITTEE
BANFF, ALBERTA, CANADA
OCTOBER 2015

15-IAGT-104

OPTIMIZING THE BALANCE-OF-PLANT FOR A CYCLING COMBINED CYCLE OTSG FACILITY

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Keywords: *OTSG, Combined Cycle, Balance-of-Plant*

In today's Power Industry, there is a great need for flexible peaking generation to supplement load swings in the grid. Peaking operation involves frequently starting and stopping the plant, usually daily but sometimes even more frequently. From an economic standpoint, there exists a real need to be able to get the plant in and out of service as quickly as possible. Due to the complexity of the major equipment involved in Combined Cycle Power Plants (CCPPs), there are several main operating considerations that must be examined if the CCPP is intended to shut down every night in a peaking configuration. The steam cycle generally consists of a Heat Recovery Steam Generator (HRSG) or Once Through Steam Generator (OTSG), Steam Turbine, Condenser, Condenser Hotwell, Condensate Extraction Pumps, Water Polisher, and Boiler Feedwater Pumps. Knowledge regarding Steam Turbine and Condenser operation is a prerequisite to understanding the implications of running a CCPP in Peaking operation. Peaking operation and the consequences of breaking the condensate loop vacuum must be considered from mechanical, chemical, and economic viewpoints. Deaerating Condenser design considerations at part-load operation must be examined, as well as the impact on the time required to start the plant.

The optimal configuration for the closed-condensate-loop and steam balance of plant piping for peaking operation is driven by the layout and intent of the CCPP. A number of past projects executed by experienced EPCs and their typical 'best practices' in combination with IST's own 20 years of historical operating experience provide a vast amount of knowledge regarding how to optimize the Balance-of-Plant with OTSGs. The inclusions of an Auxiliary Boiler, Steam Turbine Condenser Bypass Arrangement, Atmospheric Start-Up Vents, Desuperheater(s), and/or Make-Up Water Storage Tank are all considerations that must be scrutinized. Although it is possible to make a good initial recommendation towards a 'best' configuration, often there are unavoidable site specific factors which prevent a "one size fits all" optimal plant arrangement.

The closed steam and condensate loop in a typical steam CCPP includes the following main components (shown in Figure 1 below):

- ST Condenser Hot-Well (water reservoir that is operating under vacuum).
- Condensate Extraction Pumps (sometimes called the ‘forwarding’ pumps).
- Water Polisher (for cleaning the loop water).
- Boiler Feedwater Pumps (to pressurize & deliver water to boilers).
- Boiler (High Temp/Press Steam Generator).
- Steam Turbine (turns Generator for power production).
- Steam Condenser (cools steam & returns it to hot-well as water for recirculation).

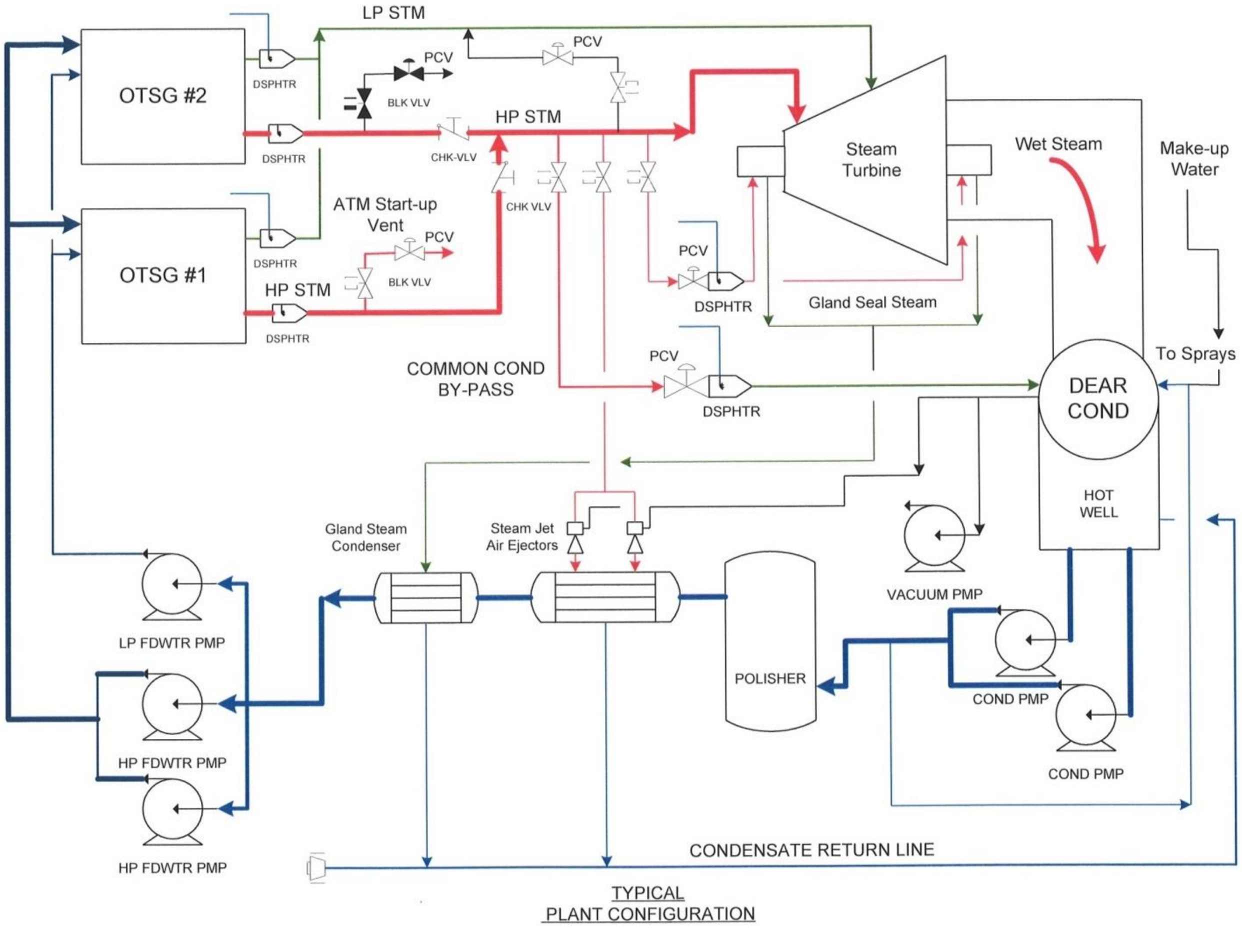

Figure 1: Typical OTSG Combined-Cycle Power Plant General Arrangement.

The steam turbine condenser hot-well serves as a water-storage reservoir for the closed condensate loop. Condensate is taken from the condenser hot-well and forwarded to a condensate polisher by the condensate extraction pumps (forwarding pumps). The polisher removes any impurities that are picked up by the steam/condensate as it circulates around the loop before allowing it to enter the OTSG. After leaving the polisher the condensate goes to the boiler feed pumps where it is pressurized for delivery into the OTSG(s). In some plants the condensate goes through a process of oxygen removal in a pressurized deaerator before entering the boilers, but the majority of CCPP’s today, particularly OTSG plants, do this inside the ST condenser as a cheaper alternative. Inside the OTSG the condensate, now called feedwater, is turned into high temperature and pressure steam which is sent to the steam turbine in order to drive the rotor that turns the electric generator to produce power for the grid. After exiting the steam turbine the steam/water-vapour passes over a condenser (typically either water or air cooled) that cools and collapses the steam back into liquid form (condensate) so that it can be re-pumped around the loop and used again. This is known as the Rankine Cycle, and it is the way that a vast majority of electric power is produced in the world today.

Additionally, almost every CCPP has a steam by-pass line around the ST to the condenser. This allows steam to be re-directed to a different part of the process in the event of a ST trip, without having to shut down the whole system.

Steam Turbine & Condenser Operation

The steam and condensate loop has to be closed for safety reasons, for the practical reason of being able to do work on the ST, and for maintaining the water chemistry so that it doesn't corrode or rust away the components of the loop. Some components (such as the condenser hot-well for example) are normally fabricated from carbon steel that would quickly rust away from contact with the high temperature water and steam if the water chemistry is not maintained within certain specifications. For a number of practical reasons the steam turbine condenser, and hence part of the condensate-loop, typically operates under vacuum, the principal reason being that more work can be produced from the steam by dropping the pressure as much as possible at the back of the rotor where steam exits the turbine and enters the condenser.

As a result of the loop being closed there are mechanical seals called gland-seals on the ST where the moving rotor shaft passes through the stationary ST casing. These gland-seals use a small amount of the steam that is produced in the plant in order to make an airtight seal at the shaft penetrations. Vacuum cannot be maintained at the condenser hot-well without the gland-seal steam, since without an effective steam-seal air will constantly be drawn into the condenser hot-well as it is pumped down to vacuum pressure.

Vacuum is normally generated either by motor driven (liquid ring) vacuum pumps, or with steam-jet air evacuators (ejectors). Frequently the vacuum pump will initially pull the vacuum down part way, and then the steam jet ejectors will take over that duty as a more cost effective means of drawing down full vacuum after the plant is up and running.

Vacuum also helps maintain water chemistry by removing corrosive oxygen & carbon dioxide that dissolves in the steam/feedwater and attack metal at high temperatures (oxygen removal per Henry's Law). This is known as deaeration of the condensate or boiler feedwater. In most CCPPs, deaeration takes place inside the ST-Condenser. This is the most economical way to deaerate while the plant is operating, since the ST-condenser operation under vacuum at saturated conditions drives oxygen levels down (typically to ~20-ppb).

There is also a Cooling Water (CW) loop on the non-steam side of the ST Condenser in which cold water is passed through the condenser tubes in order to cool and condense the steam passing over the outside of the tubes. This loop will be referred to later when examining pumping and other costs during off-peak operation.

In order to keep the condensate loop closed and circulating it is necessary to (1) have a continuous source of steam for the Steam Turbine gland seals and (2) be able to maintain vacuum on the ST-Condenser since those are the conditions under which it is designed to operate and maintain acceptable water chemistry (e.g. remove oxygen).

Peaking Operation and Breaking Condensate Loop Vacuum

From the above operating description, it follows that a CCPP performs best when operated continuously. However, “due to the addition of larger more efficient Nuclear and Fossil Power Plants to the grid, combined with reduced power consumption through conservation efforts, cogeneration, and a host of other factors, increasingly cycling or two-shift operation is being imposed on [CCPP’s]”. [1]

In a peaking CCPP when the Gas-Turbines and Heat Recovery Steam Generators shut down during periods of low electrical demand at night or over the weekend, the principal and most cost-effective means for generating steam (e.g. the HRSG/OTSG) is unavailable. If there is no auxiliary steam available (e.g. from an auxiliary-boiler or other source) for gland seals at the ST, then the plant must break condenser vacuum during off-peak shutdown periods.

Air ingress as a result of breaking vacuum causes dissolved oxygen (DO) levels in the condensate to rise and go out of specification, and remain that way for some time during re-start. This generates a significant oxygen-corrosion risk to system components in a daily cycling plant.

The following quotes from qualified industry experts emphasize the importance of controlling dissolved oxygen levels in Power Plants:

- “One of the most frequently encountered corrosion problems (in boilers) results from exposure of metals to dissolved oxygen.” [2]
- “DO is dominant in the vast majority of corrosion problems. Many are completely solved simply by its removal.” [3]
- “It is generally accepted that feedwater impurities, especially oxygen (& acid chloride) are the most serious contributors to the corrosion process in systems in contact with feedwater, condensate, and steam.” [4]

The Electronics Power Research Institute (EPRI) and other sources recommend DO levels be kept below 10 ppb for systems containing mixed metallurgy. The Heat Exchanger Institute (HEI) uses 7 ppb as the design standard for Steam Surface Condensers. This implies that the dissolved oxygen levels in the condensate residing in the condenser & in the feedwater entering the boiler must be maintained at 7 ppb or less at all times, particularly for systems containing ferrous metallurgy. Failure to do so will result in premature corrosion-assisted-fatigue cracking of boiler tubes and excessive corrosion, pitting, and failure of other components such as the condenser hotwell or other pressure vessels in the loop (refer to Figures 2 & 3 below).

Ref # G706723 Part 1 Issue 1
Date: July 31, 2007

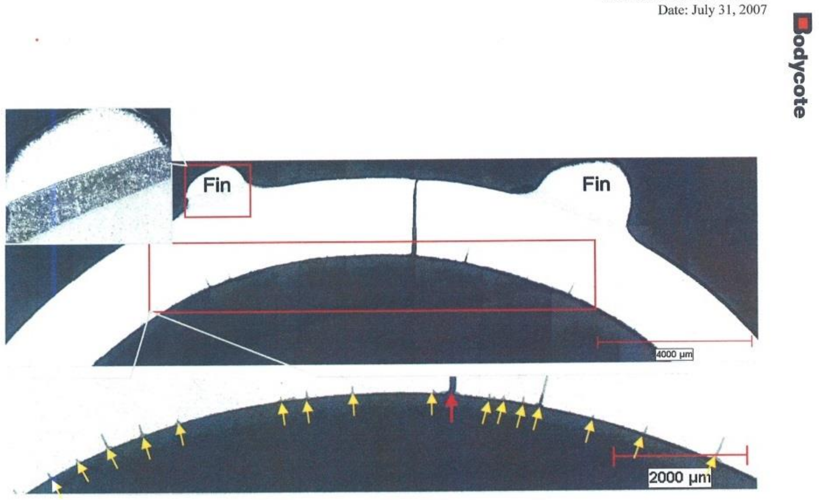

Figure 8: Micrographs takrn from the prepared section marked "B-B" in Figure 1 before etching, illustrating cross-sectional view of the main crack (red arrow) and numerous smaller cracks (yellow arrows) observed along the inner surface (Not etched). The inset illustrates the brazing weld and the fins (etched).

Figure 2: OTSG Boiler Tube with Oxygen Induced Corrosion Assisted Fatigue Micro-Cracks.

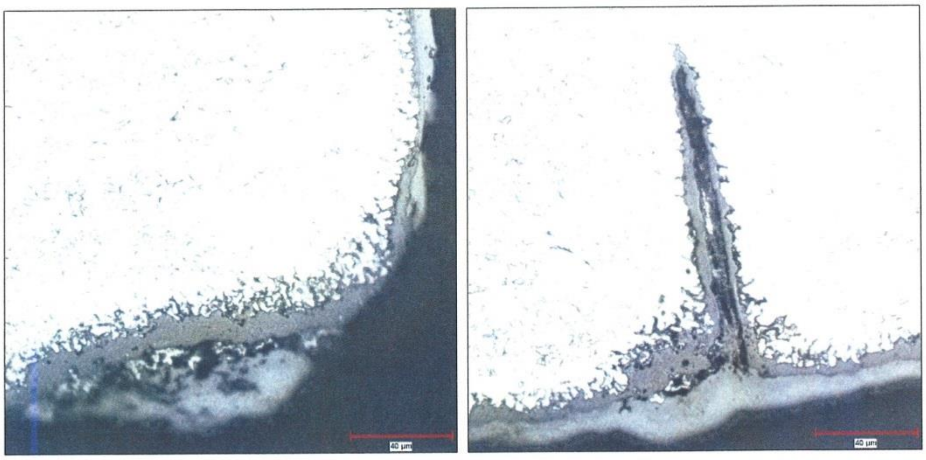

Figure 11: Locally enlarged micrographs taken from the main crack and one of the smaller cracks shown in Figure 8 after etching, illustrating bright grains adjacent to the oxide layers along the cracks. (Original magnification: 500x. Etched with 10% ammonium persulfate electrolytic etchant)

Figure 3: Close-up of Oxygen Induced Corrosion Assisted Fatigue Micro Cracks.

Air ingress also causes flash rusting or "hematite blooming" on all exposed carbon steel surfaces in the condenser hotwell, deaerators, and flash tanks, resulting in high iron transport (e.g. high Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)) throughout the system. Polisher loading as well as the cost of polisher operation will be higher due to high TDS and TSS from iron transport. Higher make-up water costs will accrue from venting during start-up and dumping of bad water. The photos in Figure 4 below show the effect of flash-rusting and high iron transport throughout the steam/feedwater system.

Figure 4: Flash Rusting (Hematite Blooming) Inside Condenser Hotwell (Top Left), Fouled Polisher Element due to Iron Transport from Flash Rusting (Top Right), OTSG Boiler Tubes Coated with Transported Iron Oxide (Bottom Left), OTSG Boiler Tube Showing Iron-Oxide Deposits due to High TDS

In order to maintain acceptable water (condensate) chemistry the plant must continuously control:

- Dissolved oxygen levels (DO)
- Total Dissolved Solids (TDS or ‘Hardness’)
- pH (or acidity of the water)

At least two of the three will go out of specification on an interim basis when vacuum is broken. Therefore a key operating consideration in a Peaking CCPP is whether or not to shut down the closed-condensate loop and break vacuum at night. After breaking vacuum the closed-condensate-loop must be brought back into service each day. Establishing water quality and then subsequently starting the ST will add considerably to the time required for the total plant to reach peak load upon subsequent dispatch.

Cost Considerations for Breaking/Not-Breaking Condensate Loop Vacuum

There is an energy cost penalty associated with running the plant internals at night while off the grid. To operate, for example, an auxiliary boiler overnight and provide steam to the ST gland-seals and the condenser steam-jet air evacuators, there is a heat energy cost for the NG fuel. There are overnight pumping costs for operating the drive motors on the condensate extraction pumps, LP feedwater pump for the auxiliary boiler, and the condenser CW pump as a minimum. The largest pumping cost is typically for circulating the condenser CW through the cooling-tower side of the loop (typically 400-500 hp motors are required in a 125MW facility). If it is an air-cooled condenser, then the fans have to be powered. These electrical loads necessary to the operation of any power plant are referred to as parasitic loads.

Using Ontario Electricity prices ($0.07/kW-hr off-peak and $0.12/kW-hr peak), the following is a rough estimate of the potential annual off-peak operating cost in a typical CCPP that is estimated to be off-line for 8-hours per day:

$$
\begin{aligned}
NG\ Fuel\ Price &= \frac{\$0.00733}{ft^3} \\
Auxiliary\ Boiler\ Daily\ NG\ Fuel\ Cost &= \frac{\frac{25MMBTU}{hr} * \frac{\$0.00733}{ft^3} * 8\frac{hr}{day}}{1020\frac{BTU}{ft^3}} = \frac{\$1473}{day} \\
Auxiliary\ Boiler\ Annual\ NG\ Fuel\ Cost &= \frac{\$1437}{day} * 365\frac{day}{yr} = \mathbf{\$524,505} \\
Pump\ Power\ Consumption &= (400+60+100)hp * 1.341\frac{kW}{hp} = 751\ kW \\
Annual\ Pump\ Power\ Cost &= 751\ kW * 8\ hr * \frac{\$0.07}{kW-hr} * 365\frac{day}{yr} = \mathbf{\$153,504} \\
Annual\ Operator\ Cost &= \frac{\$100}{hr} * 8\frac{hr}{day} * 365\frac{day}{yr} = \mathbf{\$292,000} \\
Estimated\ Annual\ Cost\ to\ Close\ Condensate\ Loop &= \mathbf{\$970,009}
\end{aligned}
$$

In respect to up-front capital costs it is cheaper to build a CCPP without an installed auxiliary steam source. A small package boiler capable of producing 20,000 lb/hr of steam at 225 psig & 420°F and purchased in Canada would add approximately $200K to the plant capital cost, uninstalled.

There are several methods to reduce the operating cost penalty that is incurred by having to run equipment when the plant is not sending electricity to the grid and generating revenue. One option is to use a lower horsepower CW by-pass pump (e.g. 40 hp vs 500 hp pump operation at night) to maintain night-time circulation and CW loop chemistry where applicable. The GTAA Power Plant won a best practices award for doing precisely this. Another option is to include a VFD on the CW pump (or other) motor. At Encana's Cavalier Power Plant, they operate two 400 hp CW pumps at peak load (with one installed standby pump). One of the three pumps has a VFD installed on the motor (~$130K capital cost) to allow it to shutdown at night, soft start and stop, and also save considerable money during wintertime operation when it runs at part load. Some CCPP's are a part of larger process plants such as a fossil power plant whereby auxiliary steam sources are readily available and can be cheaply brought into the power plant on low cost 2-3" diameter carbon steel steam lines.

In a plant with an auxiliary steam source, the opposite of the previous operating concerns is true. The plant will have the fastest possible start each morning in the rush to get on the grid and deliver power at peak prices (total CCPP plant to 100% load in 1 hour or less is achievable if the ST is slow-rolled using auxiliary steam). Decreased equipment maintenance costs are a benefit over the plant life-cycle (e.g. less corrosion, cyclic-fatigue cracks, press-part replacements, plant downtime, etc). There will be reduced day-to-day polisher operating costs (reduced ion transport & longer polisher-train run times) and lower make-up water costs (e.g. no venting or blow-down losses). If a typical two-on-one CCPP (e.g. 125MW) could achieve one additional hour per day of peak power production through a fast start, it has the potential to offset the calculated overnight operating cost as follows:

$$Annual\ Revenue\ from\ Extra\ Hour\ of\ Production = 30000\ kW - hr * \frac{\$0.12}{kW - hr} * 365\frac{day}{yr} = \mathbf{\$1,314,00}$$
$$Annual\ Additional\ Plant - Wide\ Savings = \mathbf{\$100,000}$$
$$Estimated\ Annual\ Savings\ to\ Close\ Condensate\ Loop = \mathbf{\$1,414,000}$$

This more than offsets the operating cost penalty of $0.97M/yr. The customer may simply choose to pay the high cost of maintenance provided that they make enough money on power-production. However, it would at least make sense for any given customer to consider how to configure their plant with an awareness of the benefits and consequences available through Balance-of-Plant optimization.

Deaerating Condenser Design Considerations for Part-Load Operation

The technical considerations for designing a ST deaerating condenser that is expected to operate in a turndown mode (or even off) due to cyclic and/or off-peak operation must be considered in the design. Daily cycling in a Peaking CCPP will force the condenser to operate at part-load. This usually results in operation with increased backpressure in the condenser and increased condensate sub-cooling, and therefore increased oxygen absorption in the condensate (Henry's Law).

Two main reasons DO cycles-up at low loads are (1) the air removal system standard designs do not deaerate condensate satisfactorily at low loads, and (2) air in-leakage is greatest at low loads, when a larger portion of the turbine housing and condenser auxiliary systems operate under vacuum. In order to maintain acceptable DO levels during condenser part-load operation, the design of the condenser itself must account for part-load operation.

Closed Condensate Loop Conclusions

In order to keep the condensate loop closed and circulating it is necessary to (1) have a continuous source of steam for the gland seals and (2) be able to maintain vacuum on the ST-Condenser for all conditions under which it is designed to operate and maintain acceptable water chemistry (e.g. remove oxygen). Simply stated, this translates into whether or not an Auxiliary Boiler should be included in the Balance-of-Plant (BoP) configuration.

Other plant components to consider along with an Auxiliary Boiler are:

- Auxiliary Boiler with HP-to-LP Steam Letdown Station
- ST-Condenser By-Pass Arrangement
- Atmospheric Start-Up Vents

- Desuperheaters
- Make-Up Water Storage Tank

Table 1 below shows a summary of 17 previous OTSG Project CCPP BoP configurations that were executed by a range of EPC's.

Plant	Auxiliary Boiler	HP ST/Condenser By-Pass	LP ST/Condenser By-Pass	HP Start-Up Vent	LP Start-Up Vent	HP Desuper heater	LP Desuper heater	Plant Type
Plant 1	Y	Y, Common	Y, Common	Y	N	Y	N	Peaking
Plant 2	N	Y, Common	Y, Common	Y	Y	Y	Y	Peaking
Plant 3	Y	N	N	Y	Y	Y	N	Peaking
Plant 4	N	Y, Dedicated	Y, Dedicated	N	N	N	N	Peaking
Plant 5	Y	Y, Dedicated	Y, Common	Y	N	Y	N	Peaking
Plant 6	Y	Y, Dedicated	Y, Dedicated	N	N	N	N	Peaking
Plant 7	Y	Y, Dedicated	Y, Dedicated	N	N	N	N	Base/ Peaking
Plant 8	N	Y, Dedicated	Y, Dedicated	N	N	N	N	Base
Plant 9	Y	Y, Dedicated	N/A	N	N/A	Y	N/A	Peaking
Plant 10	N	Y, Dedicated	N	Y	N	Y	N	Peaking
Plant 11	Y	N	N	Y	N	Y	N	Base/ Peaking
Plant 12	N	Y, Common	N/A	Y	N/A	Y	N/A	Base
Plant 13	N	Y, Common	Y, Common	Y	Y	Y	N	Base
Plant 14	N	Y, Common	Y, Common	Y	N	Y	N	Peaking
Plant 15	N	Y, Dedicated	Y, Dedicated	N	N	Y	Y	Peaking
Plant 16	N	Y, Common	Y, Common	Y	Y	Y	Y	Base/Peaking
Plant 17	N	Y, Dedicated	Y, Dedicated	Y	N	Y	Y	Peaking

Table 1: Steam BoP Piping Configurations on Past OTSG Projects.

There appears to be no consistency in the CCPP configuration, with every plant being a little different; there is certainly no "typical" configuration.

Auxiliary Boiler with HP-to-LP Steam Letdown

With no auxiliary steam source, when the gas-turbines shut down at night there will be no way to make steam in the CCPP. The plant therefore must break vacuum and live with the problems that go along with oxygen ingress, hematite-blooming, and transient operation with the water quality outside of the specification (e.g. eventual boiler tube failures). Without an auxiliary steam source, the piping must be warmed and pressurized after boiler start, gland-seals must be established, vacuum must be pulled on the condenser, and water quality must be brought back into specification – all of which takes time. Water cannot be continuously circulated through the polisher and back to the condenser for TDS control, and acceptably low oxygen levels cannot be maintained. All these factors act to lengthen the daily start-up time required to get a Peaking CCPP up to full power.

If an Auxiliary Boiler is included in combination with an HP-to-LP Steam Letdown station, then the entire ST rotor can be kept hot and spinning during overnight shutdown using the auxiliary steam. Encana Corporation does this at the Cavalier power plant in Strathmore, Alberta, and can reach peak power on the entire CCPP in less than 60 minutes.

In a fast starting plant HP steam is brought into service well before LP. It can therefore be advantageous to have an HP/LP Letdown Station for introducing HP steam into the LP distribution system, with or without auxiliary steam available. Whether the LP users are fed from the LP system or individual HP letdowns depends on the expected LP normal operating pressure. Gland seal steam supply for example is typically operated at 250-300 psig, which may not fit with an LP coil supplying a normal ST rotor at an operating pressure of 75-125 psig. In either case, a properly sized HP/LP Letdown Station to initially pressurize the LP system can help quicken the start-up of that system, and the overall plant as a result.

Figure-5 below shows a BoP arrangement that allows the fastest possible start.

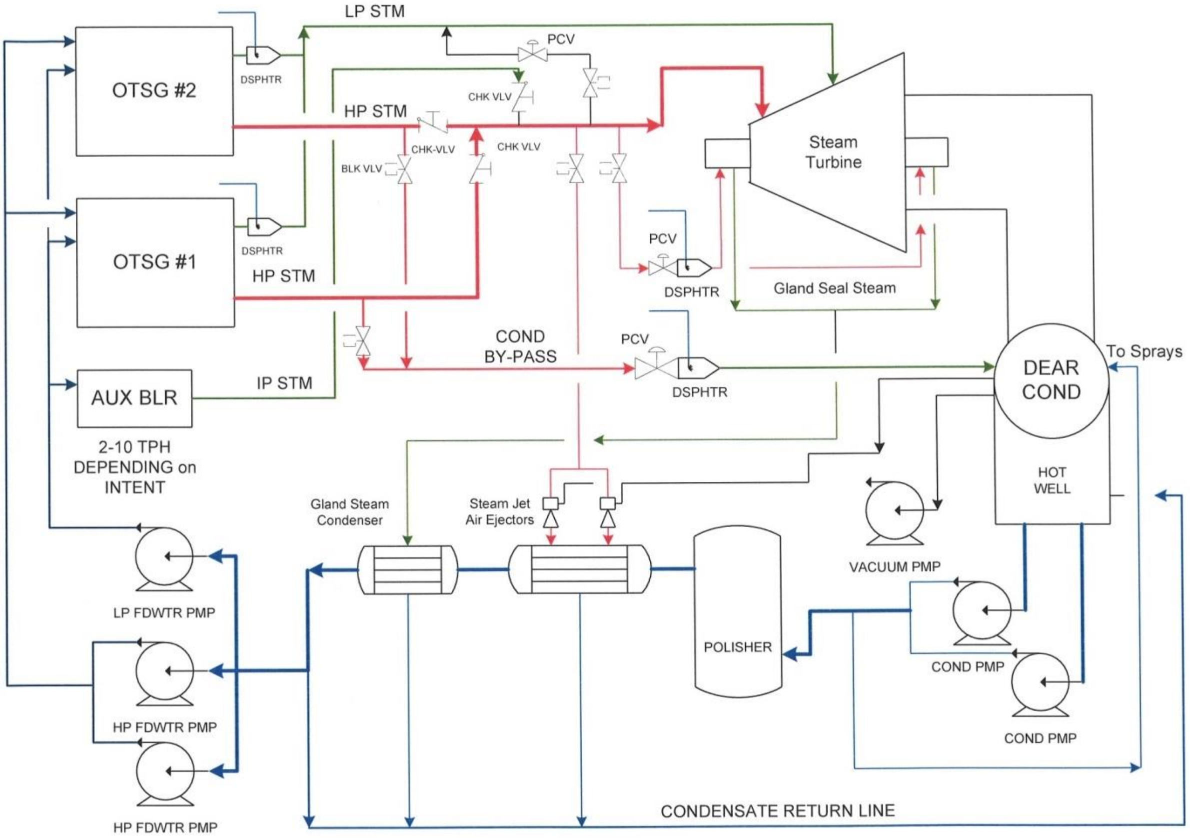

Figure 5: Fast-Start Plant Configuration with Auxiliary Boiler.

Using the auxiliary steam, any one or more of the following plant components can be kept hot and operational (listed in order of precedence): gland-seals, deaerating condenser, closed condensate loop, steam-jet air ejectors, HP distribution piping, HP ST rotor, LP distribution piping, and LP ST rotor. Hence, the Auxiliary Boiler capacity can be sized knowing the intended operating condition of the plant during off-peak operation.

Figure 5 shows an Auxiliary Boiler capacity ranging for 2-10 tons-per-hour (TPH). Figures 6a & 6b explain the range by showing the minimum and maximum turndown conditions that are possible during off-peak operation. In the minimum turndown (i.e. lowest steam capacity) case (Figure 6a), the Auxiliary Boiler is sized to simply provide the minimum steam required for the ST gland seals, and an electric vacuum pump is operated on a deaerating condenser designed for part-load/no-load operation. In the maximum turndown (i.e. highest steam capacity) case (Figure 6b), the Auxiliary Boiler is sized with enough capacity to provide steam to the gland-seals, operate the steam jet air ejectors, and slow roll the ST.

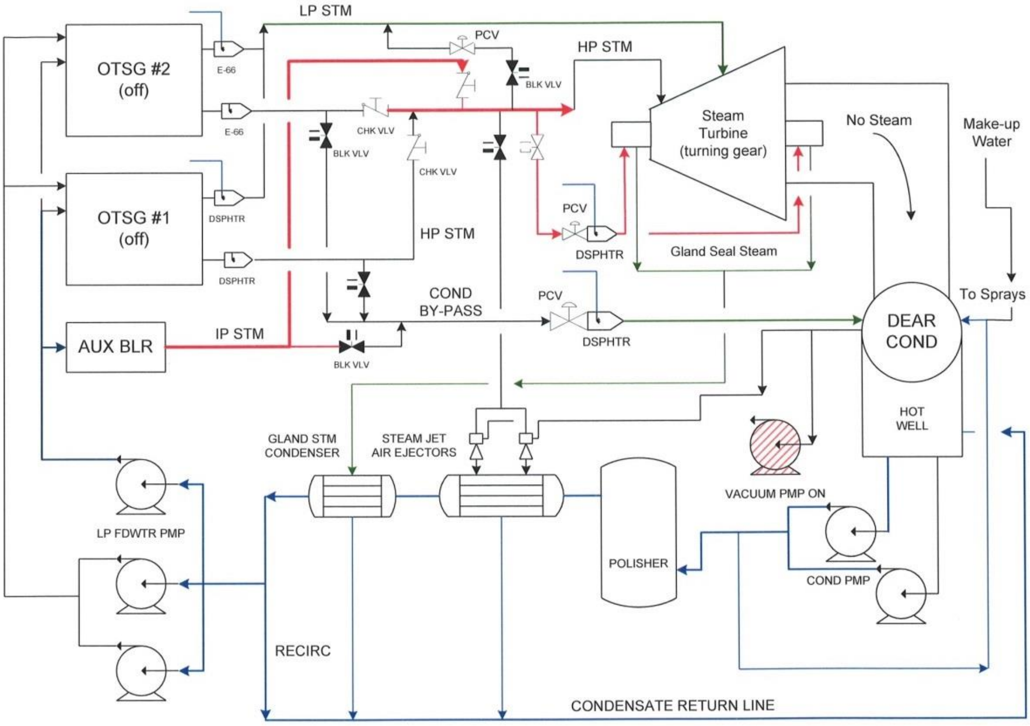

Figure 6a: Minimum Turndown Off-Peak Plant Operation. Auxiliary Boiler provides steam only to the ST gland seals.

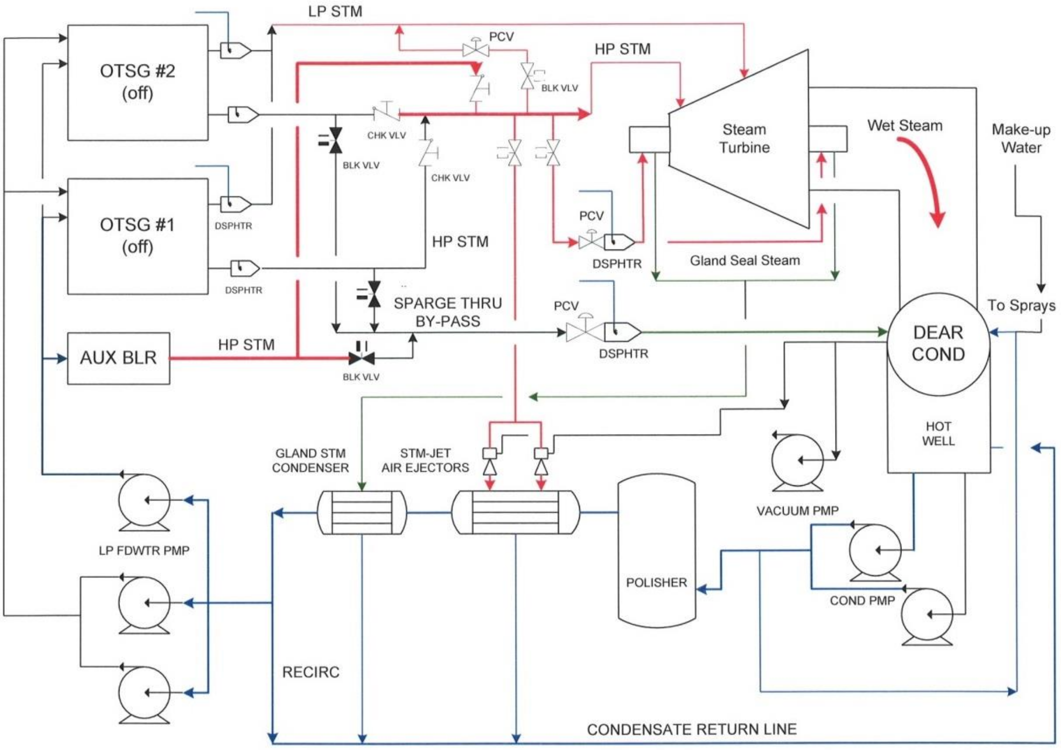

Figure 6b: Maximum Turndown Off-Peak Plant Operation. Auxiliary Boiler provides steam to the ST gland seals, steam jet air ejectors, and to slow-roll the ST.

Steam Turbine Condenser By-pass

Most CCPP’s have a ST By-Pass to the condenser such that if the ST trips the steam/condensate loop can remain operational, with the aim of quickly recovering the lost power generation. The BoP can be configured to have (1) a dedicated by-pass on each boiler, or (2) a common by-pass off of the main (or common) steam line that directly feeds the ST.

With a boiler-dedicated condenser bypass configuration the OTSG’s can start directly into the steam distribution system (e.g. into the condenser by-pass, ST, or both), reducing noise, saving water, and reducing start-up time. Note that noise reduction can be important in an urban setting, particularly if the plant stops/starts daily.

The alternative to the boiler-dedicated by-pass arrangement is to have a common ST by-pass to the condenser. With a common condenser by-pass it is necessary to have a dedicated atmospheric start-up vent on each boiler in order to allow subsequent boiler starts into an operating & pressurized distribution system.

Atmospheric Start-up Vent

The OTSG must have a dedicated Atmospheric Start-Up Vent if any one of the following three conditions applies to a project:

1. There is no auxiliary steam source for gland-seals and pulling vacuum on the ST condenser.
2. The ST Condenser By-Pass is routed off of the common steam distribution piping.
3. The Distribution Piping Design Temperature Limit is lower than the GT exhaust gas temperatures, in which case the steam has to be temporarily routed out of the system until it can be attemperated and cooled down.

Though many plants shut down and break vacuum, frequently no provision is made for circulating the condensate loop through the polisher. Typically this is because without an auxiliary steam source for the gland seals, vacuum cannot be reached on the condenser and the condensate loop cannot be operated. Hence there is no way to bring TDS (conductivity) or DO into spec prior to introducing water into the boiler. There is also no means to circulate the water and no time to get it within specification quickly enough in a fast-start peaking plant.

HP Desuperheaters

A unique feature of the OTSG which must be considered is that during initial start-up, the exiting steam temperature is essentially equal to GT exhaust temperature. This condition can persist for a considerable period of time. It is often necessary to incorporate a desuperheater into the outlet piping of the OTSG in order to attemperate the steam temperatures down to an acceptable level before allowing the steam to be routed into the distribution piping. This is done by using a Desuperheater spray nozzle to inject boiler feedwater into the steam process stream, in order to cool it down.

In order to facilitate proper mixing/blending and prevent standing water being introduced to the steam line, there needs to be a certain minimum steam flow across the desuperheater spray nozzle in order to enable the desuperheater control loop and allow injecting of the cooling water into the steam line. Entrained water droplets will damage the ST rotor. This creates a concern about where to direct the initial minimal steam flow prior to having the ability to cool it down using the desuperheater control loop.

This can be addressed by designing a short length of plant piping up to and including the steam Atmospheric Start-Up Vent near to the OTSG using more expensive high-temperature materials. Installing a desuperheater spray nozzle sized for good turndown, and briefly limiting the steam mass flow on start-up until the desuperheater loop is enabled will get the steam attemperated down to an acceptable temperature level without carrying a lot of heat and mass into the main sections of the distribution piping. In that way, only a limited amount of steam piping has to be constructed using higher cost materials.

LP Desuperheaters

With the trend towards faster starting, it may be desirable to get the LP circuit into operation well before the HP coil reaches temperature control, which normally takes 45- 50 minutes as a minimum. If a fast LP start is desired, then LP desuperheaters are essential because LP steam temperature can initially be well above the LP steam distribution piping design temperatures and in fact even approach GT exhaust gas temperature when starting in advance of letting the HP-coil reach steam temperature control. If the temperature cannot be controlled sufficiently using the desuperheater in combination with a limited segment of high temperature piping, it may be necessary to use an LP Atmospheric Start-Up Vent in combination with the LP Desuperheater, similar to the HP arrangement previously discussed.

Make-Up Water Storage Tank

There are always some losses in the closed-condensate loop, particularly if you start up through Atmospheric Start-Up Vents and drains as discussing previously. Even a closed and continuously operating loop can have up to 1% losses through traps, leaks, and drains. Therefore there is always a make-up stream of demineralized water into the closed-condensate-loop that is most commonly introduced into the ST-Condenser or hot-well.

From a capacity perspective, the equipment in this de-mineralized make-up water stream can be sized to produce 3-5% of what is circulating. However, there should be a free standing tank to allow some capacitance on the make-up line in order to accommodate steam blows during commissioning, polisher train regeneration and backwashing, and other unforeseen operating considerations. Figure 7 below shows the condensate-loop with a typical make-up water line arrangement including a storage tank for capacitance.

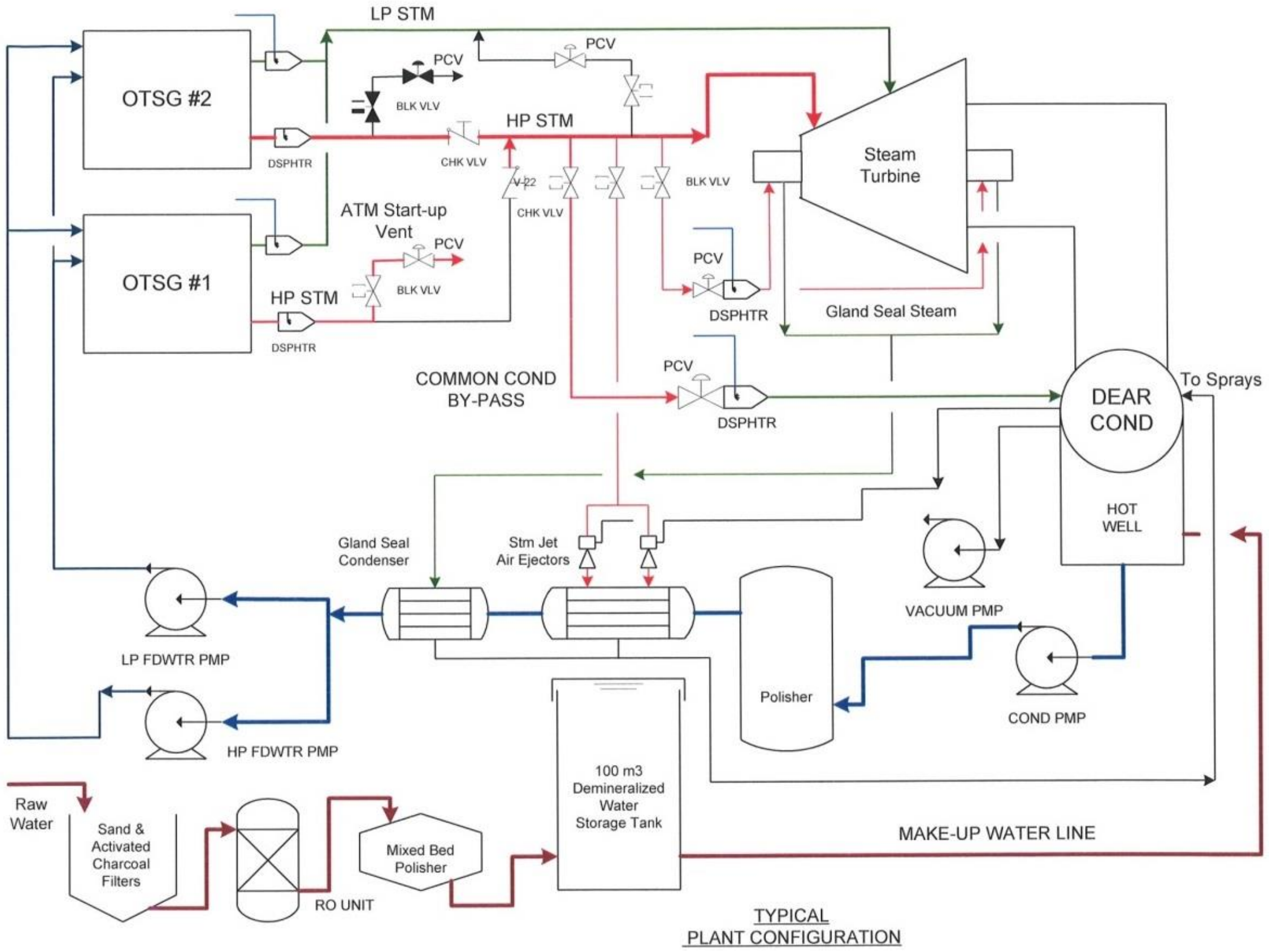

Figure 7: Closed Condensate Loop showing Make-Up Line with Storage Tank.

Conclusion

Figure 8 below shows an optimal steam BoP configuration including an Auxiliary Boiler and Atmospheric Start-Up Vents for accommodating high GT exhaust gas temperatures and the associated high initial boiler exit steam temperatures.

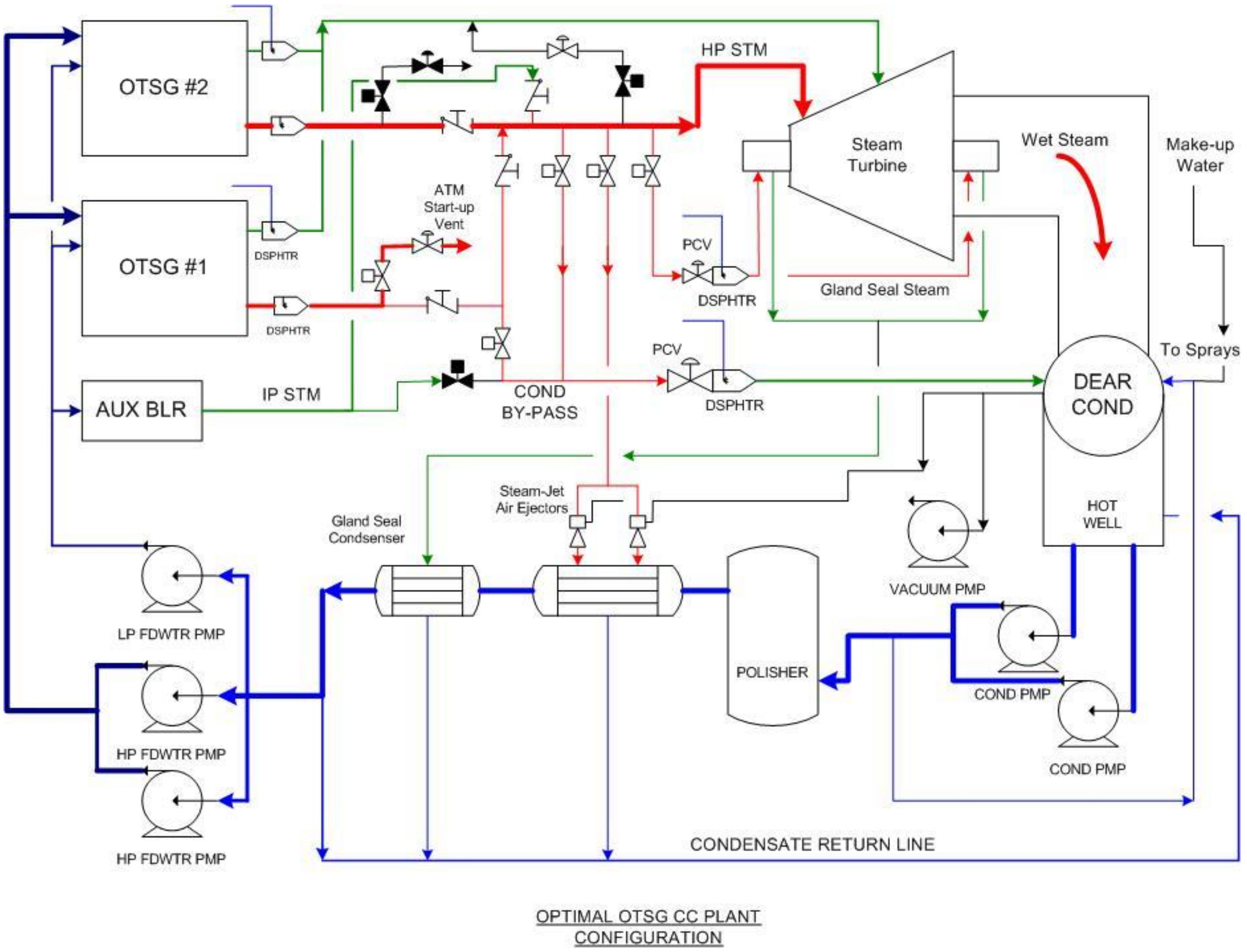

Figure 8: Fast Start Arrangement with Auxiliary Boiler & Atmospheric Start-Up Vents for High Temperature Steam.

The following recommendations should be followed when considering alternatives for optimizing the steam-side BoP in a Peaking CCPP with OTSGs:

1. Install an Auxiliary Boiler such that Condensate Loop Vacuum can be maintained.
2. The ST-Condenser should be designed for part-load operation.
3. If the GT exhaust-gas temperature allows, Dedicated ST Condenser By-passes should be used as they result in less water consumption & lower noise emissions.
4. The inclusion of HP Desuperheaters is GT exhaust-gas temperature dependent.
5. LP Desuperheaters should be used to facilitate daily fast start. They allow the LP steam coil to be started well before the HP steam coil reaches modulating temperature control.
6. Atmospheric Start-Up Vents are required if breaking vacuum and there is no auxiliary steam source. If Atmospheric Start-Up Vents are required, then there is no advantage to having boiler-dedicated by-passes - use a common by-pass instead as a lower capital cost alternative.
7. Atmospheric Start-Up Vents are required for high applications where the GT exhaust temperature is greater than the steam temperature setpoint.
8. HP-to-LP Letdown Stations are recommended for maximum operating flexibility, especially for fast starts.
9. Include a stainless-steel or polymer-resin Make-Up Water Storage tank if planned for and installed during the plant build.

References

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