

## AN INTEGRAL APPROACH TO DESIGNING OF AN OPTIMIZED AND RELIABLE ANTI-ICING SYSTEM UNDER OFF-DESIGN OPERATING REGIMES IN A GAS TURBINE

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### ABSTRACT

*Anti-icing systems (AIS) are used in aviation and in ground gas turbines operating in humid climates where relative humidity is above 80% with mist and the temperature of the intake air drops to 5°C and below. Ice formation can disrupt the compressor work by causing vibrations, inlet flow blockage or even a surge in some cases. An anti-icing system is activated in such cases to heat the inlet air before it reaches the compressor. The objective of this work is to design and study an anti-icing system (AIS) for different ambient air parameters and different gas turbine modes of operation. A particular climatic situation (Saint-Petersburg, Russia) is considered as the basis for assessing the suitability of different anti-icing systems and to choose the best configuration out of different possible arrangements. The present work is divided in three major tasks. The first task involves the choice of the anti-icing system arrangement. The second task is to design the heating air supply system by determining the geometric sizes of bypass pipeline with fully open damper to ensure conduction of required air flow at the anti-icing system design condition. In the final task, the entire process is integrated and automated to calculate multiple iterations for different gas turbine operating regimes to assess the reliability of the designed anti-icing system at all operating conditions of the gas turbine. Such assessment is critical as it helps to identify the operating conditions at which the designed anti-icing system would not be able to heat the intake air to a certain temperature above the dew point temperature.*

Keywords: Anti-icing, Secondary flow system, Gas Turbine operating regimes

### NOMENCLATURE

$dp$	Design point
$C_d$	Discharge coefficient
$\zeta$	Resistance coefficient
$a_i$	Polynomial coefficients
$\varepsilon$	Pressure ratio
$G$	Mass flow rate

$h$	Enthalpy
$P$	Power
$p$	Total pressure
$T$	Total temperature

### 1. INTRODUCTION

Open cycle gas turbines take the air from ambient, compress it in a compressor and pass it through a combustor to produce hot combustion products. It is evident, thus, that the ambient conditions deeply impact the performance of Gas turbines. Due to this reason, most gas turbines incorporate some form of inlet air treatment such as filtering, inlet air heating etc. [1] Inlet air filters form an essential part in the inlet air treatment system. When used in the form of pulse jet filters, they double their purpose by not only removing the contaminants in inlet air but also by serving as an efficient mechanism for anti-icing. Pulse filter can remove hoarfrost in much the same way that they clean themselves of dust. Pulse filters have high efficiency with coarse dense materials as heavy particles are easy to shake loose from filter media. Such heavy particles, owing to their high inertia, can move against the incoming air and are not drawn back onto the filter. The pulse filters have lower efficiency against small particles. The pulse filters are difficult to clean where the inlet air contains high percentage of sticky and goeey unburned hydrocarbons and under environment with high moisture content in the air. In climatic conditions which are too cold and humid, the ice formation in the intake is a critical phenomenon restricting the reliable operation of the gas turbine. [2, 3] On one hand there are anti-icing systems which completely prevent the formation of ice by manipulating the inlet air condition as required, there is another category of deicing systems that get activated only to prevent the ice formation from reaching a hazardous level. [4] Precipitate icing occurs if water is ingested as liquid or solid at temperatures too close or below the freezing point temperature. Precipitation remaining suspended in the air-stream causes no special problems. However, ice has a great tendency to adhere strongly to most surfaces. Ice buildup can be a critical problem

when the temperature is near freezing. When a body of air cools at a relatively constant moisture content, a point is reached at which the vapor condenses and forms water droplets. This point is called the dew point and the associated temperature is known as the dew point temperature which plays a very significant role in ice formation. If the temperature is reduced further than the dew point temperature, it results in super-cooling of the droplets. This condition is unstable and results in a rapid buildup of frost on contact with any solid surface. [2] There is a significant risk of ice buildup in the gas turbine intake if the following two conditions are achieved in terms of ambient properties. [1]

1. The surface temperature in the intake system is lower than the dew point temperature of the air ( $T_{\text{surface}} < T_{\text{dp}}$ ). This results in the condensation of water vapor from air to the surface.

2. The surface temperature in the intake system is below freezing point temperature ( $T_{\text{surface}} \leq 0 \text{ }^\circ\text{C}$ ). This leads to the formation of ice from the water which has condensed on the surface.

The above mentioned criteria are general, whereas, different OEM's employ anti-icing systems during operation based on their own specific criteria. For example, General electric recommends to activate the anti-icing system when the temperature falls below 40 F (4.4°C) in combination with relative humidity greater than 70 %. [1] As long as the surface temperature is above the dew point temperature, condensation will not occur and ice will not form even if the surface temperature is below freezing point temperature. Hence, the dew point temperature is a good measure to assess the possibility of ice formation and to judge the reliability of anti-icing system. In this paper the reliability of anti-icing system is decided based on whether the inlet air temperature could be raised by a certain value (6°C) above the dew point temperature by the use of anti-icing system.

## 2. OUTLINE OF APPROACH

A base gas turbine cycle at a certain design operating condition is taken as the first step for this study (Figure 1).

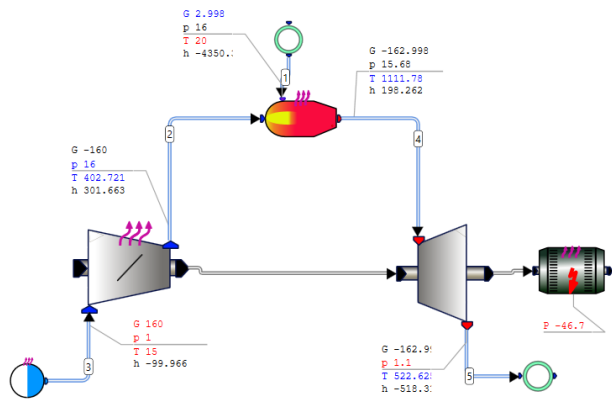


Figure 1: THE BASE GAS TURBINE CYCLE

Cycle parameters from this base cycle are used to design different cycle components such as the compressor, Turbine etc. Once these components are designed, we can take in to account their off-design operating characteristics while calculating the cycle performance under different operating regimes. This gives more realistic cycle calculation taking in to account actual component performance under different scenarios. The next step is to evaluate and compare different anti-icing arrangements under a predefined ambient condition which requires implementation of such systems. The inlet heating system that we are focusing on in this study can derive the hot air/gases either from the compressor in form of bleed air, or from the turbine exhaust or in some cases the source of heat can also be external from the base gas turbine. Weighted assessment of pros and cons of different arrangements along with a fairly accurate estimate of the maximum operating duration for which such systems are supposed to be active can help identify the optimum scheme for the current gas turbine and geographic conditions. This paper discusses three different schemes under a specific operating condition and compares their impact on the performance. The complete secondary flow loop for the anti-icing system was designed in the next step. Finally, the cycle calculation and the calculation of secondary flow were integrated to perform a combined off design study. This step is important as the change in cycle parameters affects the secondary flow characteristics in the anti-icing loop and an integrated and iterative study is must to obtain the complete performance of the Gas turbine when an anti-icing system is operational.

### 2.1 Base Gas Turbine

The base gas turbine cycle in this study is a fairly simple one. (Figure 1) It is a ground-based gas turbine operating at the inlet condition of 15°C temperature and 1 bar with rated mass flow rate of 160 kg/s. The design pressure ratio for the compressor is 16 and the rated electrical power output from the cycle is 46.7 MW. Natural gas is used as the fuel in the burner. Table 1 shows the specifications of the base gas turbine.

Table 1: SPECIFICATIONS OF THE BASE GAS TURBINE

Component	Property	Value
Compressor	Inlet Temperature	15 °C
	Mass flow rate	160 kg/s
	Inlet Pressure	1 bar
	Pressure Ratio	16
Burner	Fuel	Natural Gas
	Combustion Efficiency	98%
	Pressure Recovery Coefficient	0.98
Turbine	Inlet Temperature	1111.78 °C
	Outlet Pressure	1.1 bar
Generator	Electric output	46.7 MW

Design specifications obtained from this base cycle are then used to design the compressor in a commercial

turbomachinery design software AxSTREAM® and to obtain its off-design performance map which has been used throughout the off-design calculations that follow. This is done because the change in compressor performance greatly impacts the overall cycle performance under different than design operating condition. While it is important to use the turbomachinery that provides the best performance under the design conditions, at which the cycle is operating for most of its lifetime, it is equally true that the same conditions cannot be maintained even vaguely for all times. Specially, our focus in this study is to assess different operating conditions and hence it is must to take in to account the off-design operation of components. However, the change in turbine performance is less critical than that for the compressor hence this study focuses on the later and the turbine performance is calculated independently during each cycle calculation. Figure 2 shows the off-design performance maps for the compressor which are used in this study.



**Figure 2:** OFF-DESIGN COMPRESSOR MAPS USED IN CYCLE CALCULATIONS

## 2.2 Comparison and selection of Anti-icing schema

The monthly average climatic conditions of Saint-Petersburg, Russia are considered as the reference for this study. Saint-Petersburg is chosen not only because it is close to the arctic circle which makes it suitable for assessing conditions that have potential of inlet icing in gas turbines but also because it is the northern most of the larger cities with a large population of around five million which makes it even more important for the gas turbines to operate reliably all the time.

[10] Table 2 shows the data of average temperature and relative humidity over the year at Saint-Petersburg. [11]

**Table 2:** MONTHLY AVERAGE CLIMATE DATA FOR SAINT-PETERSBURG (SOURCE: [www.timeanddate.com/weather](http://www.timeanddate.com/weather))

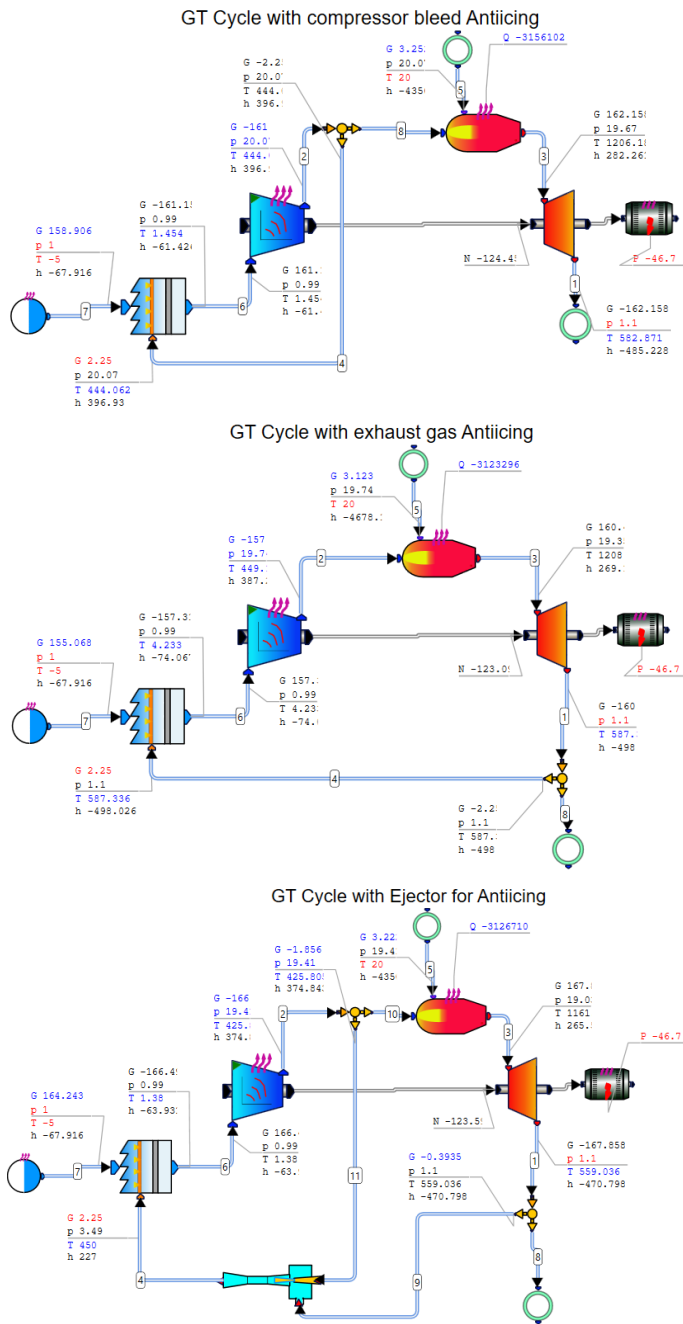
Month	Relative humidity (%)	Average Temperature (°C)
January	86	-5
February	84	-5
March	78	-1
April	69	5
May	65	11
June	70	16
July	72	19
August	76	17
September	81	12
October	84	6
November	87	0
December	87	-3

There are many different arrangements possible for an anti-icing system induction in the gas turbine cycle. In this study, chemical and mechanical methods of anti-icing are not discussed. The emphasis, here, is on different possibilities in inlet heating based anti-icing systems. It is also considered that the system has to be self-reliant and associated with the inherent operation of the gas turbine and does not require any external source of heating. After keeping all these factors in to consideration, three different anti-icing arrangements were studied at a specific ambient operating condition. In the first system, hot air is extracted from the outlet of the compressor and fed to the inlet of the gas turbine for heating of the intake air.

The second system used some of the exhaust gases leaving the turbine to heat the intake air by mixing with it. The third system is based on an ejector which combines the compressor bleed air and the turbine exhaust gases to provide the hot flow for inlet air heating. The schematic diagrams for the three systems considered in this study are shown in Figure 3. We have considered the ambient temperature of  $-5\text{ }^{\circ}\text{C}$  and ambient pressure of 1 bar with inlet relative humidity of 100% and no presence of liquid water content for the comparison of these systems. The electrical power output is kept unchanged from its design value of 46.7 MW. The same mass flow of hot air/gases is used for comparison of effectiveness of every system.

Table 3 shows different parameters of the gas turbine cycle for the comparison of these systems. The table shows that the temperatures at critical locations in the gas turbine cycle for all the three arrangements are closely matching (around  $\pm 5\%$  variation). All the three arrangements also capably heat the inlet air to the required temperature above the dew point hence the systems under comparison are all suitable and reliable for the given design condition as per our set criteria. The difference however lies in the variation of efficiency compared to the base cycle. While the compressor bleed anti-icing system reduces

the efficiency by about 2.5%, the reduction is the lowest in the exhaust gas anti-icing at about 2.2%. That is about a 0.3% difference in efficiency for the highest and lowest efficiency schemes in the comparison.



**Figure 3:**DIFFERENT ANTIICING ARRANGEMENTS FOR THE GAS TURBINE

On the other hand, both the exhaust gas anti-icing and ejector anti-icing systems use the exhaust gases for heating the incoming air which has its own disadvantages. Firstly, the

exhaust gases are rich in moisture content which can create problems in the gas turbine. Impurities in the exhaust gases can also cause fouling in the compressor. In such cases, the filters are usually heavily loaded and require more frequent maintenance. The SO<sub>x</sub> and NO<sub>x</sub>, if present in the exhaust gases, may also lead to corrosion problems in the gas turbine inlet and compressor. Moreover, the exhaust system is a low pressure system which may also create difficulties in directing the exhaust gas flow to the inlet system. This is taken care of in the ejector anti-icing system by incorporating an ejector which uses high pressure air from the compressor to drive the exhaust gases effectively. However, this is achieved in the ejector system with some compromise in cycle efficiency and with an additional component in the scheme. Use of the exhaust gases is still not completely eliminated in this system too. If the gas turbine exhaust is used in a bottoming cycle, any loss in the exhaust energy is equivalent to losing the efficiency of the combined cycle and such a loss would more or less take away all the benefits of such systems compared to the compressor bleed anti-icing systems. The compressor bleed system, even though with some performance reduction, offers a simple approach to provide efficient anti-icing with the least complexity and without any additional equipment. Hence this study finds the compressor bleed anti-icing the most suitable and studies it further at off-design operating regimes of the gas turbine.

**Table 3:** COMPARISON OF PARAMETERS FOR GAS TURBINES WITH DIFFERENT ANTIICING ARRANGEMENTS

Parameter	Scheme	Compressor bleed Anti-icing	Exhaust gas Anti-icing	Ejector Anti-icing
Heating air/gas mass flow (kg/s)		2.25	2.25	2.25
Heated Air temperature (°C)		1.454	4.233	1.38
Dew Point temperature at inlet (°C)		-5.24	-2.59	-4.81
dT		6.694	6.823	6.19
Compressor Outlet temperature (°C)		444.06	449.12	425.81
Turbine inlet temperature (°C)		1206.08	1208.83	1161.33
Turbine outlet temperature (°C)		582.87	587.34	559.04
Reduction in Cycle Thermal Efficiency (%)		2.5115	2.2003	2.2333

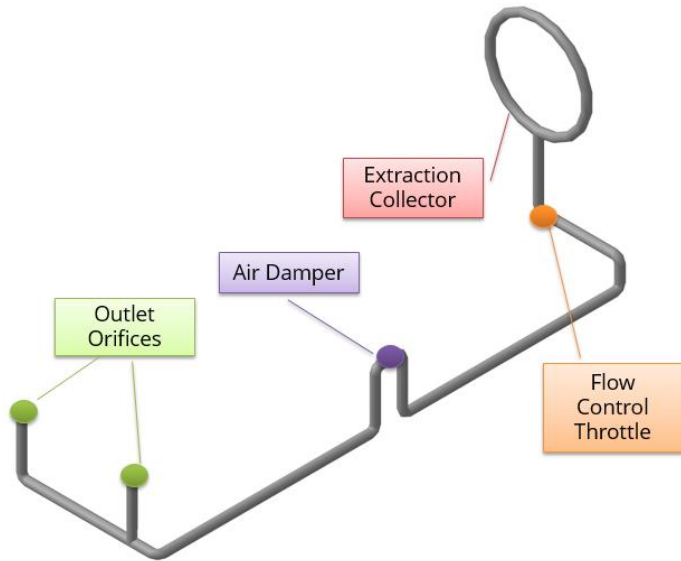
### 2.3 Design of secondary flow loop for the antiicing system

After finalizing the anti-icing scheme for the study, the next step involves the design and calculation of the secondary flow loop for this system. Figure 4 shows a representative schematic of such a bleed air supply system for inlet cooling. It represents the pipeline section from the air inlet behind the compressor to the supply point to the air intake device. A

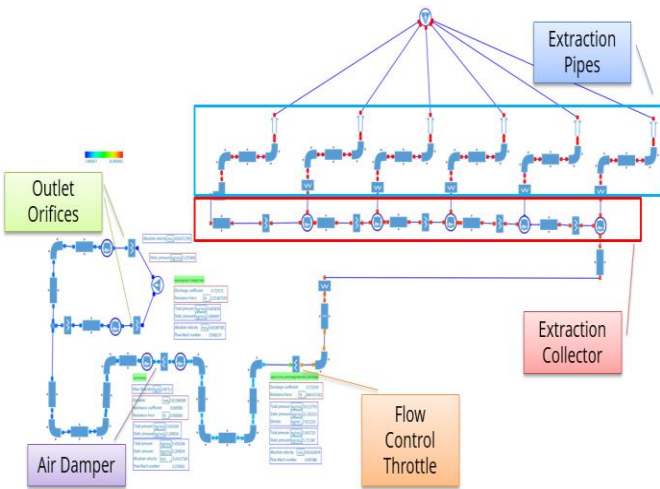
similar scheme was simulated in a commercial package AxSTREAM® NET as shown in Figure 5.

$$d_2 = d_1 \sqrt{\frac{V_2}{V_1}} \quad (1)$$

Where  $V = G * \vartheta$ , “G” represents the mass flow rate and “ $\vartheta$ ” is the specific volume for any component. Subscript 1 is used for the original scheme, whereas, subscript 2 represents the parameters of adjusted scheme for the current parameters.

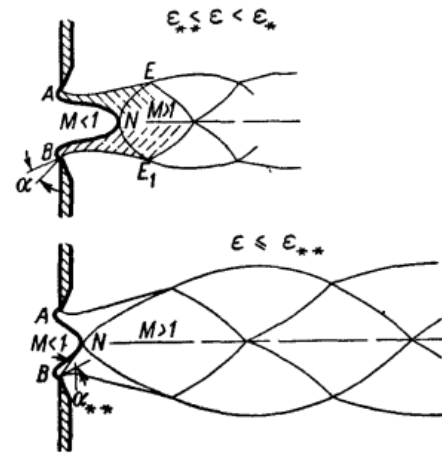


**Figure 4:** BYPASS PIPELINE CONFIGURATION FOR COMPRESSOR BLEED ANTIICING SYSTEM

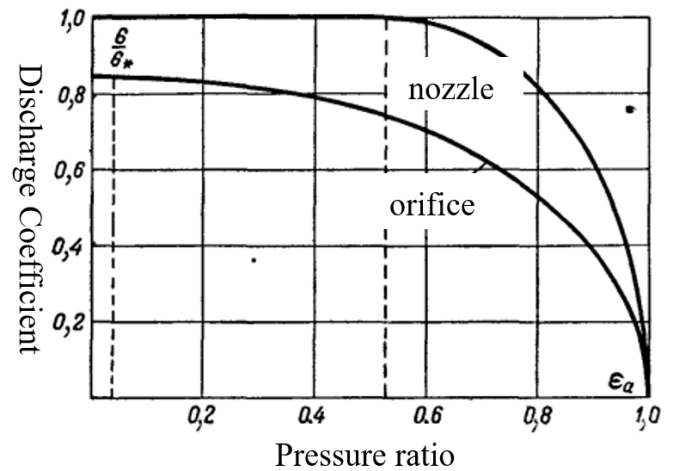


**Figure 5:** SIMULATION OF THE BYPASS PIPELINE

The calculation of such a scheme requires determination of geometric parameters of all sections such as tract diameters, lengths, damper parameters, throttle parameters, etc. Thermodynamic parameters at inlet and outlet are also required for the calculation of flow through this system. These parameters are derived from the cycle calculation. The geometric parameters were derived after scaling of an existing similar Anti-icing system for the required volumetric flow rates in the present case. Equation 1 showcases how the diameters were adjusted from the existing system to the new system for this study.



**Figure 6:** THE VELOCITY PROFILES WHEN FLOWING OUT OF THE ORIFICE WITH SHARP EDGES



**Figure7:** DEPENDENCY OF DISCHARGE COEFFICIENT ON PRESSURE RATIO ACROSS ORIFICES AND NOZZLES

The air damper and the flow control throttles were simulated as local fluid flow resistances where the resistance coefficients were calculated using scripts. Choking on the throttle, damper and outlet orifices was analyzed taking into account the second critical pressure ratio. It is believed that locking in an orifice with sharp edges does not occur in the flat outlet section, as for an ideal nozzle, and the velocity profile has a curved shape as shown in Figure 6. The chart in Figure7

shows how the discharge coefficient varies with pressure ratio across an orifice. [6] Using the curve fitting, the distribution can be described as a polynomial given in Equation 2 with the corresponding polynomial coefficients  $a_0$  to  $a_3$  as given.

$$C_d = \sum_{i=0}^3 a_i \varepsilon_a^i \quad (2)$$

$a_3 = -3.43644385$   
 $a_2 = -4.000697958$   
 $a_1 = -1.462909483$   
 $a_0 = 0.898887149$   
 for  $\varepsilon_a < 0.037$ , then  $C_d = 0.85$

Discharge coefficient ( $c_d$ ) was converted to resistance coefficient ( $\zeta$ ) using the Equation 3.

$$C_d = \frac{1}{\sqrt{\zeta + 1}} \quad (3)$$

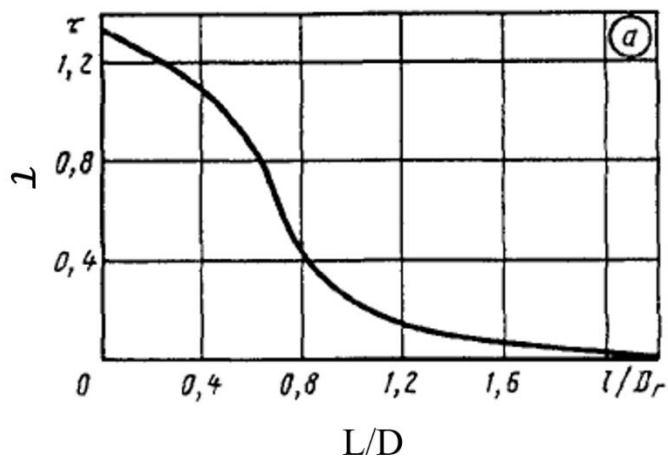
The outflow from the orifices into an unlimited volume, as in the case of outlet orifices, is described well by Equation 2. It also accurately describes the flow through a throttle (orifice with sharp edge) with regard to the second critical pressure ratio at speeds close to the speed of sound. However, at low speeds, it gives a significant error, so in such cases, Equation 4 is used for the calculation of resistance coefficient. [7]

$$\zeta = [0.707 \left(1 - \frac{F_0}{F_1}\right)^{0.375} + \left(1 - \frac{F_0}{F_2}\right)] \quad (4)$$

Control Valve is calculated without taking into account second critical pressure ratio and by using Equation 5. [7]

$$\zeta = \left[ 0.5 \left(1 - \frac{F_0}{F_1}\right)^{0.75} + \tau \left(1 - \frac{F_0}{F_1}\right)^{1.375} + \left(1 - \frac{F_0}{F_1}\right)^2 \right]^2 \quad (5)$$

Here,  $\tau$  is taken from the curve fitting polynomial given in Equation 6 for the chart shown in Figure 8.



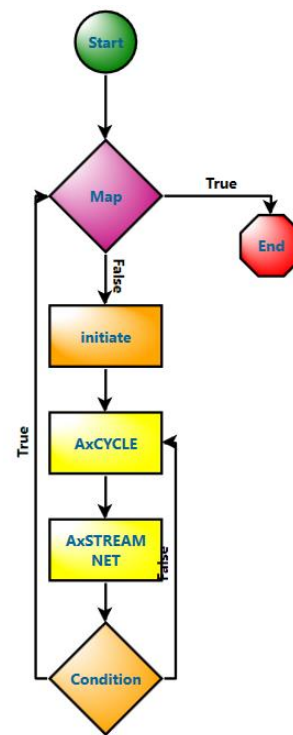
**Figure 8:** DISCHARGE CHARACTERISTICS FOR A CONTROL VALVE

$$\tau = \sum_{i=0}^4 a_i \frac{1}{D^i} \quad (6)$$

$a_4 = -0.788144346$   
 $a_3 = 3.390958664$   
 $a_2 = -4.235960137$   
 $a_1 = 0.5619168$   
 $a_0 = 1.324446984$

Once the scheme is simulated and calculated successfully, it can be integrated along with the cycle calculation in a single calculation loop for the off-design performance study of the entire system.

### 2.3 Integrated off design calculation of gas Turbine with Anti-icing system



**Figure 9:** INTEGRATED PROCESS LOOP FOR THE OFF-DESIGN CALCULATION OF GAS TURBINE WITH ANTI-ICING SYSTEM

Assessment of the reliability of any anti-icing system in a gas turbine is an iterative task that involves the determination of cycle performance taking in to account the off design operation of its different components, transfer of thermodynamic parameters for the secondary flow calculation in the Anti-icing scheme, and iterative matching of the required heating flow rates from the cycle calculation and from the calculation of the secondary flow scheme. Once this is done for one condition, the same has to be repeated for the entire off-design range that one has to study.

Figure 9 shows an integrated process loop for the off design study of the gas turbine performance along with the anti-icing

system. The loop combines the cycle calculation, calculation of anti-icing system loop, matching of the bleed air mass flow rates, and variation of ambient parameters and power outputs for the off design simulation. Table 4 below shows the parameters considered for off-design calculation along with their respective ranges.

**Table 4: VARIABLES AND THEIR RANGES FOR OFF-DESIGN STUDY OF THE GAS TURBINE**

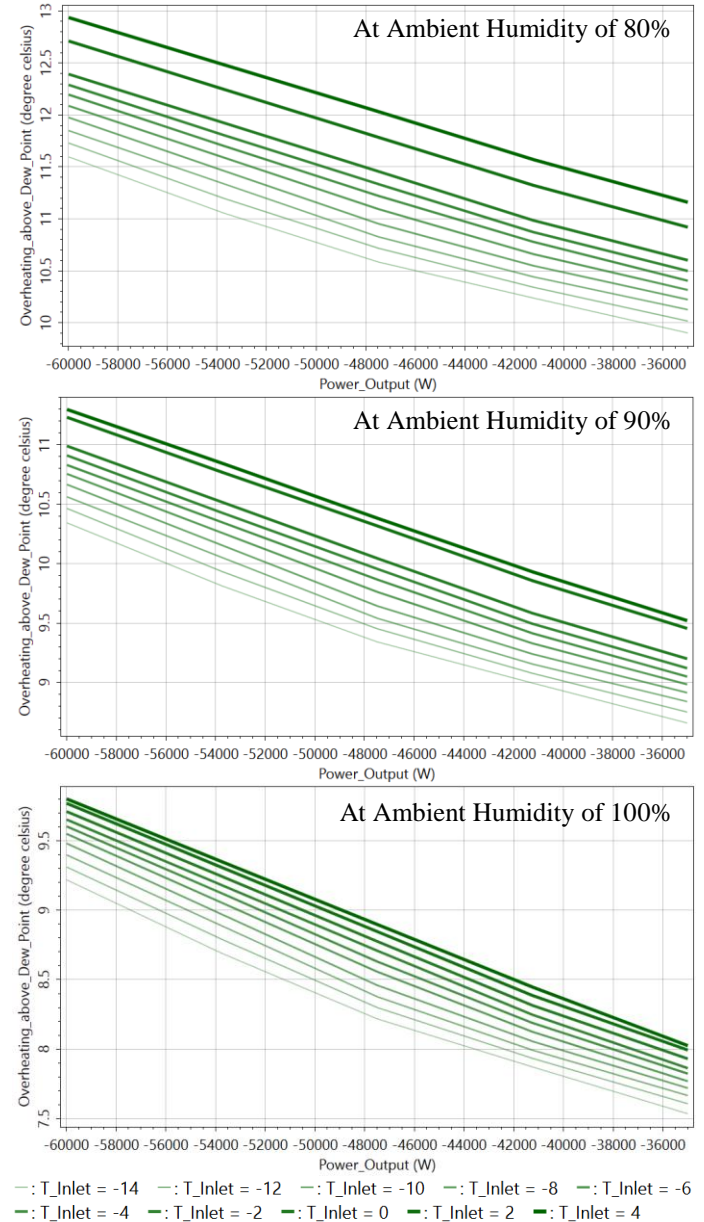
Variable parameter	Power output	Air Inlet Temperature	Relative humidity of inlet air	Liquid moisture content in inlet air
Range	35 - 60 MW	-14 - 4 °C	80 - 100 %	0 - 0.5 gm/m <sup>3</sup>

The “Map” block in the process is to carry out different iterations of generator electric power and inlet air temperature for off design calculation. The humidity and water content in the ambient air are assigned in the cycle scheme directly. Calculation in “AxCYCLE” block is performed to solve the cycle scheme and to determine the parameters at all points of the gas turbine scheme, as well as to find out the dew point temperature of inlet air and the temperature of air after application of anti-icing with a given flow rate of heating air. The initial assumption of heating air flow rate is obtained from the “Initiate” block for the first iteration and from the “AxSTREAM NET” block for every consecutive iteration till the flow matching is achieved between the cycle calculation results and the results of the secondary flow calculation. Calculation in “AxSTREAM NET” block is carried out to simulate the full hydraulic characteristics of the bypass pipeline with the initial data obtained from the “AxCYCLE” block. As a result of this calculation, the air mass flow rate, which passes through the system at the given thermodynamic boundary conditions and at the designed bypass geometry with fully open damper, is determined. The “Condition” block uses a script to compare the heating mass flow rates from the cycle calculation and from the secondary flow network calculation in order to assure flow matching between the two before switching to the next off-design calculation. The script also calculates the overheating of the air at the outlet of the anti-icing system above the dew point temperature. Finally, all the parameters of interest are transferred back to the “Map” block from the corresponding blocks to plot the results of off-design calculation in graphical form. This process continues in a loop until all the off-design operating regimes are calculated.

### 3. RESULTS AND DISCUSSION

The aim of this study is to obtain the possible overheating of the inlet air above the dew point temperature at fully open damper when the ambient conditions and the power output of the gas turbine change. As discussed earlier, if the air temperature can be maintained above the dew point

temperature at all times, the possibility of ice formation can be avoided. However, a margin of overheating above the dew point is considered in order to assure the reliability at all conditions. It is considered that the anti-icing system has to increase the temperature of the inlet air by more than 6 °C above the dew point at any given condition in order for it to be considered fully reliable. Such a safety margin helps avoiding any unforeseen anomaly in the system and any local acceleration that may reduce the flow temperature unpredictably may also be taken care of.



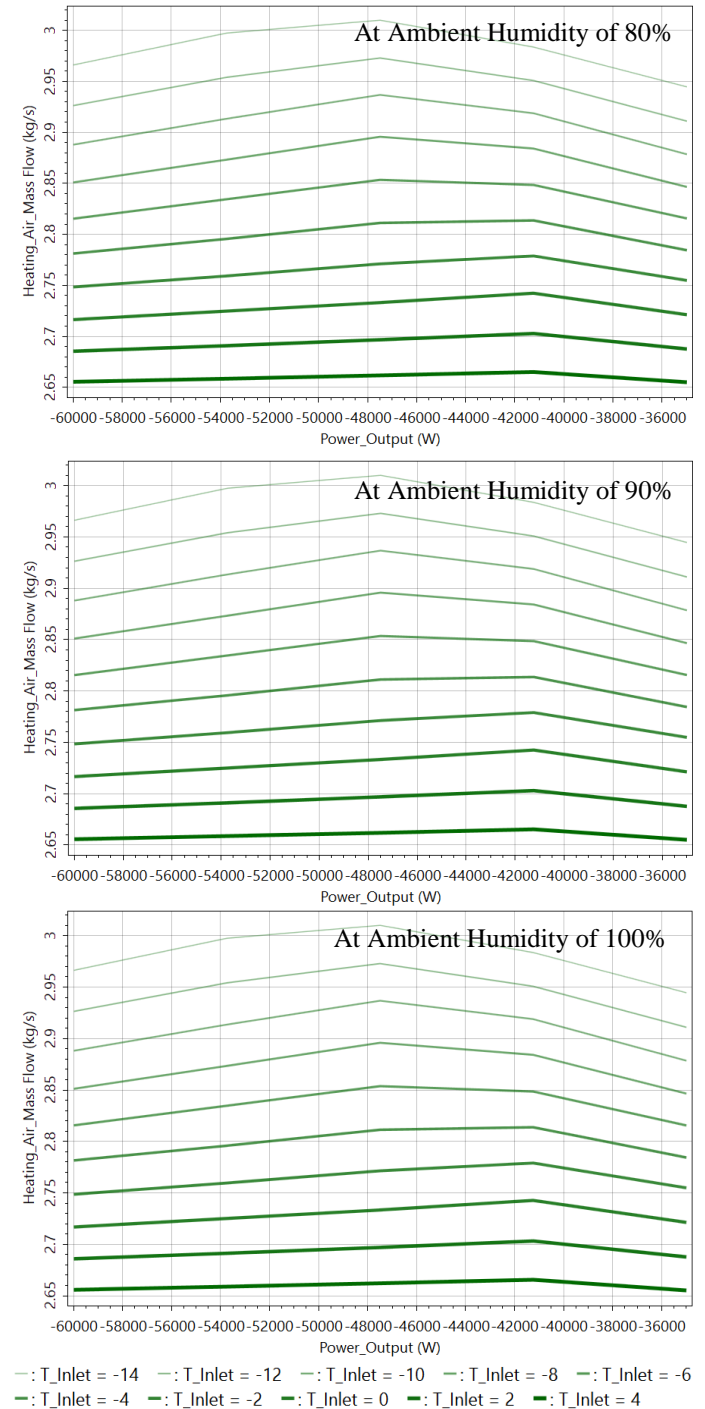
**Figure 10: AIR OVERHEATING ABOVE DEW POINT TEMPERATURE WITH FULLY OPEN DAMPER WHEN CONDITIONS CHANGE**

Figure 10 shows the inlet air overheating above its dew point at different power outputs of the gas turbine and at different relative humidity. The inlet air in these cases is considered free from any liquid water content. It can be seen that the air is sufficiently overheated for every considered combination in these figures. It means that the anti-icing system performs reliably, with fully open damper, at all the considered off-design regimes when the inlet air is free from any liquid water content. This is expected as the base condition we considered for the anti-icing system design ( $-5^{\circ}\text{C}$  inlet temperature, 100% inlet relative humidity, and  $0\text{ gm/m}^3$  inlet water content) is itself overcompensating all these off-design scenarios at the rated power condition. The off-design pressure ratios for the compressor (varying between 18.5 to 21 for the given operating conditions and design characteristics) assures required heating mass flow for anti-icing at other power outputs as well. Figure 11 shows the heating air mass flow rates for the same off design scenarios considered in Figure 10. The temperatures of heating air extracted from the compressor discharge is found to vary between  $415^{\circ}\text{C}$  to  $485^{\circ}\text{C}$  during the off-design assessment.

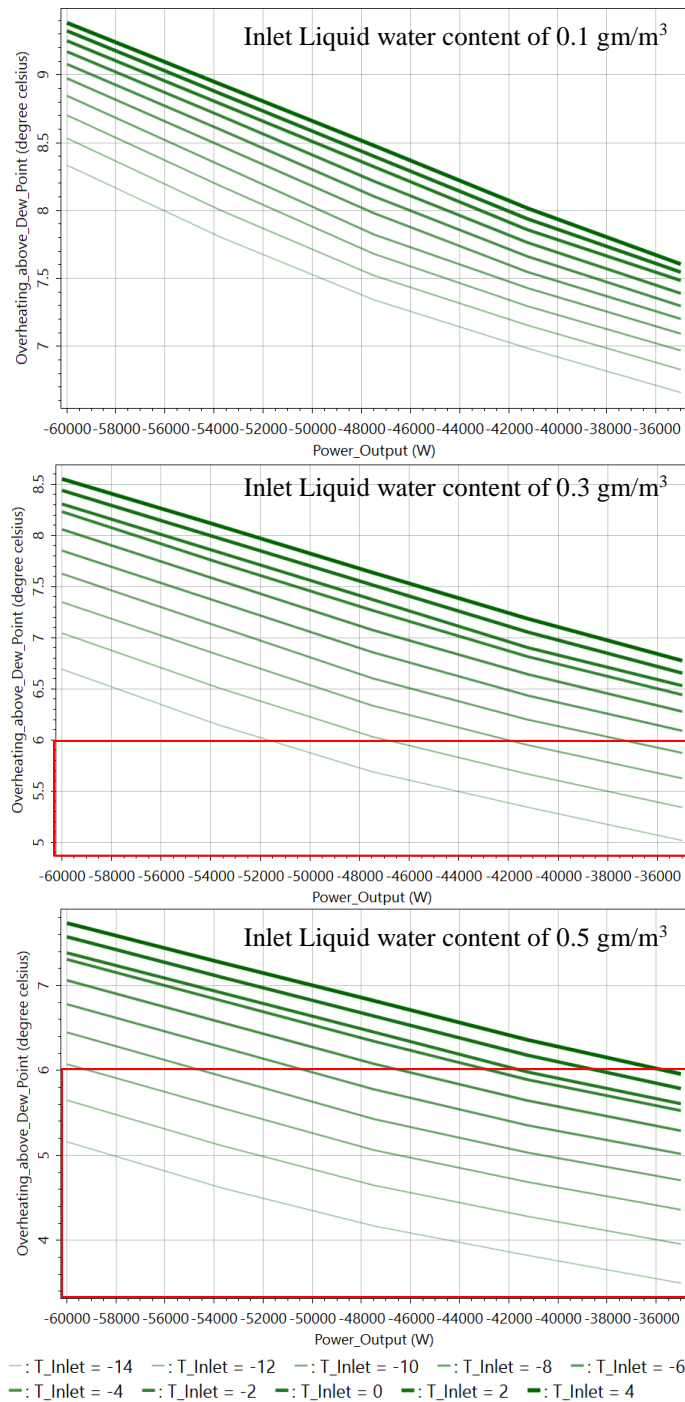
It can be clearly seen from the figure that the heating air mass flow hardly changes when the inlet relative humidity changes and it is more or less a function of gas turbine power output, and inlet air temperature only. It can also be seen that the heating air mass flow that passes through the anti-icing system at fully open damper increases first, as the gas turbine power output increases. After a certain power output, the mass flow starts to reduce for all the inlet air temperatures. This effect is more pronounced when the inlet air temperature is low. with increasing load, the increase in pressure difference in the compressor contributes to an increase in flow through the anti-icing pipeline. At the same time, as the pressure difference rises, the temperature at the outlet of the compressor rises and the air becomes less dense which increases its volume and speed in the pipeline.

This results in increased hydraulic losses, thereby, reducing the flow through the network. Up to a certain power output, the increase in flow rate due to the increase in pressure outweighs the second factor. The pressure increase gradually slows down and the temperature increase is quite stable. Therefore, after a certain power output, the second factor begins to prevail and massflow through the anti-icing system gradually decreases. This reasoning is well justified by the observations on compressor outlet pressure and temperature. Figure 12 shows the overheating for the inlet air above its dew point when the inlet moisture content is not zero. It can be seen that the anti-icing system performs reliably for all combination with inlet liquid water content of  $0.1\text{ gm/m}^3$ . However, as the content of liquid water in the inlet air rises, the designed anti-icing system ceases to provide the required overheating for some combinations of inlet relative humidity and power output. This is also natural as there is already some amount of liquid water present in the inlet air which can get converted to ice. When the liquid water content in the inlet air is high, the anti-icing system cannot increase enough the heat of the mixed air at the inlet to

evaporate all the drip moisture contained in the air. The reliability of anti-icing then depends solely on how capably the system can avoid the temperature from falling below the freezing point. This also proves the importance of moisture removal in the gas turbine inlet even with the anti-icing system fully operational.



**Figure 11:** HEATING AIR MASS FLOW RATE WITH FULLY OPEN DAMPER WHEN CONDITIONS CHANGE



**Figure 12:** AIROVERHEATING ABOVE DEW POINT TEMPERATURE WITH FULLY OPEN DAMPER AND 100% RELATIVE HUMIDITY

#### 4. CONCLUSION

- This study provides an integral approach to design an anti-icing system for a gas turbine keeping in consideration the complete cycle performance along with the off-design characteristics of its components.

- This approach not only helps designing an anti-icing system for the specified operating climates but also capably identifies the possible failure scenarios for the anti-icing operation and thus helps to avoid those scenarios.
- Even though this study focuses on the anti-icing system operation with fully open damper with the overheating above the dew point obtained as the output parameter, the flexibility of the approach is such that it allows for the determination of valve regulation when the goal is to achieve a certain overheating above the dew point at all operating conditions.
- The approach also allows to incorporate the turbomachinery design in to the loop in case the performance maps for those are not already available.

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