

# Evaluation of Gas Turbine Startup and Shutdown Emissions for New Source Permitting

Paper # 546 Session No. EI-2a

Joseph J. Macak III

Mostardi Platt Environmental, 1520 Kensington Road, Suite 204, Oak Brook, IL 60523-2139

## ABSTRACT

Utility deregulation and the increase in electrical demand have led to a surge in new gas turbine-based power projects. The number of applications has enabled the regulators and public to become more educated about simple-cycle and combined-cycle gas turbine operations, duct-firing, emissions controls, and emission rates as a function of temperature and load condition.

Many of the simple-cycle gas turbine projects are being permitted as non-Prevention of Significant Deterioration (PSD) projects by limiting operating hours, or fuel consumption, to ensure that annual emissions do not exceed PSD trigger levels. The calculation of annual emissions based on normal operating loads, without taking into consideration the increased NO<sub>x</sub>/CO/VOC emission levels during startups/shutdowns, is technically wrong and will be challenged by regulators.

Combined-cycle projects, especially those with post-combustion NO<sub>x</sub> control such as Selective Catalytic Reduction (SCR), have elevated startup/shutdown emissions as well. For example, intermediate load combined-cycle plants may operate 16 hours per day, five days per week, 52 weeks per year, resulting in 260 startups/shutdowns per unit annually. During startups, the SCR system cannot be turned on until the temperature inside the Heat Recovery Steam Generator (HRSG) at the SCR grid reaches a temperature of approximately 575 deg F. With combined-cycle units often taking as long as 180 minutes to reach this temperature, the increase in emissions may require further evaluation.

In addition to emission increases, lower plume buoyancy (due to lower air flow and stack exit temperature) during the startup sequence must be considered in the air dispersion modeling study to ensure that exceedances of the National Ambient Air Quality Standards (NAAQS), or PSD significance levels, do not occur.

This paper examines the regulatory issues relating to startup/shutdown emissions, emissions profiles during gas turbine startups/shutdowns, annual emissions calculations, a methodology for evaluating the air quality impacts of startup emissions, and compliance with emission limitations.

## BACKGROUND

Utility deregulation and increase in electrical demand has led to a surge in new gas turbine-based power projects. The number of applications has enabled the regulators and public to become more educated about simple-cycle and combined-cycle gas turbine operations, duct-firing, emissions controls, and emission rates as a function of temperature and load condition.<sup>1</sup>

## Simple-Cycle Gas Turbines (Peaking Applications)

Industrial and aero-derivative gas turbines may range in size from less than one megawatt to over 200 MW per gas turbine. In most cases, the primary fuel is natural gas with low-sulfur distillate oil as a back-up fuel. Given that gas turbines combust low sulfur and low ash fuels, the major air pollutants emitted from gas turbines are nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), and volatile organic compounds (VOC). In most peaker applications, NO<sub>x</sub> emission controls will consist of water injection into the combustors, or DLN (dry, low NO<sub>x</sub>) combustors.<sup>2</sup>

Simple cycle gas turbines are ideal for peak load generation because of their ability to start up quickly, producing electrical power in 10 to 30 minutes. As shown in Table 1, gas turbine heat rate and emissions performance improves as load increases.

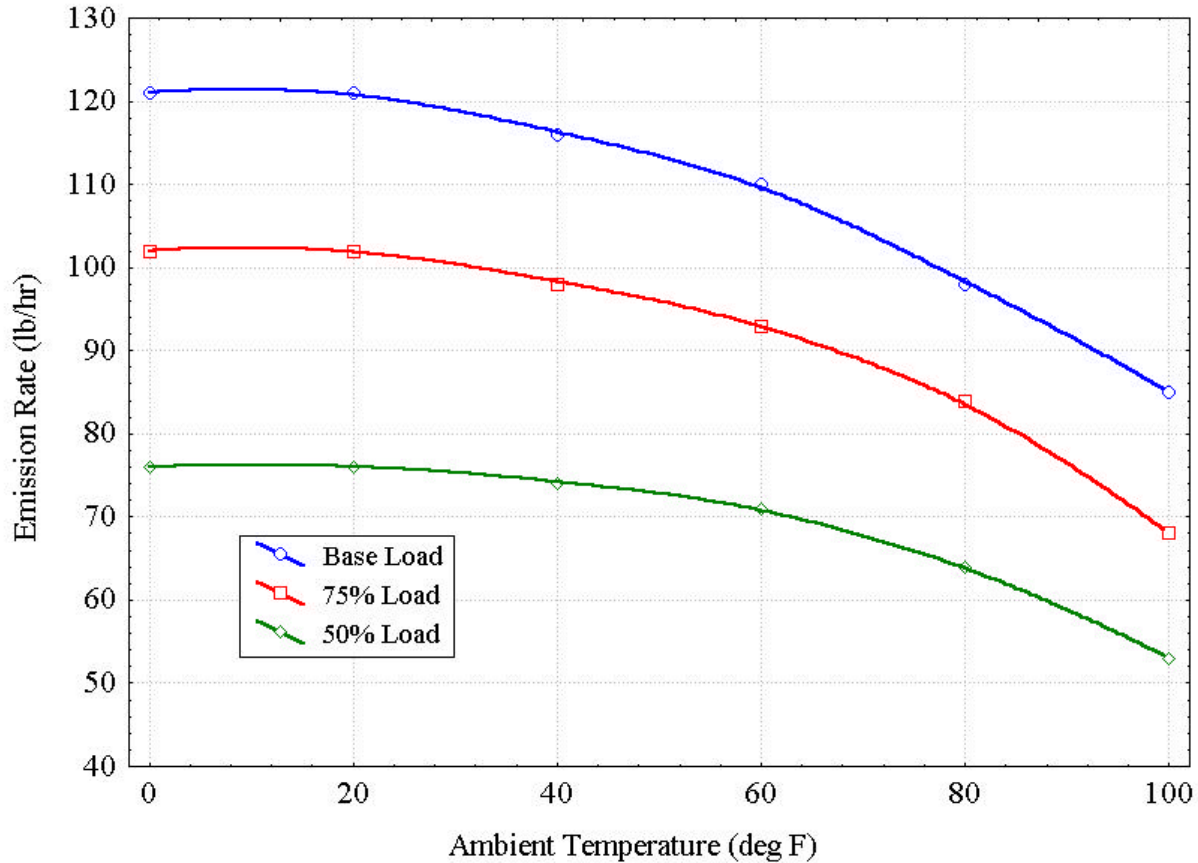
**Table 1.** Example Startup Profile for a Nominal 80 MW Simple Cycle Gas Turbine with Dry, Low NO<sub>x</sub> Combustors.

Load Condition (% CT Load)	BASE	80%	60%	40%	20%	Idle	Purge	Time Weighted Startup Average
Duration (Minutes)	32.0	5.0	5.0	5.0	5.0	5.0	3.0	
Ambient Temperature (deg F)	60	60	60	60	60	60	60	
Relative Humidity (%)	60	60	60	60	60	60	60	
Barometric Pressure (PSIA)	14.43	14.43	14.43	14.43	14.43	14.43	14.43	
GT Net Power Output (KW)	81610.0	65290.0	48970.0	32650.0	16320.0	NA	NA	
GT Fuel Flow (lb/hr)	42,232	35,701	30,701	25,224	18,789	11,728	0	
GT Heat Input (million Btu/hr, HHV)	958	810	696	572	426	266	0	
GT Heat Input (million Btu/hr, LHV)	864	731	628	516	384	240	0	
Heat Rate (Btu/KWH, LHV)	10,590	11,190	12,830	15,810	23,560	NA	NA	
GT Heat Input (GJ/hr, LHV)	11,352.5	11,995.7	13,753.8	16,948.3	25,256.3	NA	NA	
Y-Factor (40 CFR 60 Sub GG)	11.2	11.8	13.5	16.7	24.9	NA	NA	
Allowable NO <sub>x</sub> (ppmvd at 15% O <sub>2</sub> )	96.7	91.5	79.8	75.0	75.0	75.0	75.0	
Total Exhaust Flow (lb/hr)	2,324,000	1,913,000	1,627,000	1,405,000	1,368,000	1,100,000	650,000	1,889,717
GT Exhaust Temperature (deg F)	1003.0	1040.0	1092.0	1100.0	900.0	350.0	60.0	911
Stack Exhaust Flow (ACFM)	1,481,666	1,250,813	1,100,753	954,638	807,721	387,143	144,752	1,172,549
Stack Exit Velocity (ft/sec)	130.9	110.5	97.2	84.3	71.3	34.2	12.8	104
NO <sub>x</sub> (ppmvd at 15% O <sub>2</sub> )	15.0	15.0	15.0	120.0	100.0	45.0	0.0	33
NO <sub>x</sub> (lb/hour)	52.7	44.2	37.7	245.8	151.2	38.6	0.0	71
CO (ppmvd at 15% O <sub>2</sub> )	15.0	15.0	25.0	75.0	200.0	1000.0	0.0	118
CO (lb/hour)	32.1	26.9	38.3	93.5	184.1	522.7	0.0	89
VOC's (ppmv, wet basis)	1.9	1.9	1.9	1.9	9.4	28.5	0.0	4.6
VOC's (lb/hour)	2.4	2.0	1.7	1.5	7.2	17.6	0.0	3.8
PM-10 (lb/hour)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

Emissions from gas turbines vary significantly as a function of ambient temperature, load, and pollutant concentration. To illustrate this point, Figure 1 shows typical NO<sub>x</sub> emission rates (lb/hr) from a gas turbine as a function of temperature and load. Figure 1 reflects a constant NO<sub>x</sub>

concentration (ppmvd at 15% O<sub>2</sub>). The gas turbine generator limit is reached at approximately 20 deg F, below which NO<sub>x</sub> emissions tend to remain constant.

**Figure 1.** Combustion turbine NO<sub>x</sub> emissions as a function of load and ambient temperature for a typical gas turbine operating at a constant NO<sub>x</sub> concentration (ppmvd at 15% O<sub>2</sub>) in the exhaust.



Below 50% load, emission concentrations may increase, especially for gas turbines with DLN combustors. This is especially true for carbon monoxide (CO) and volatile organic compounds (VOC) since it is common for CO and VOC emissions to increase during part load operation. Should the emission concentrations increase during part load operation, the profile would be very different and the part load curve may be the "worst case" for permitting. The use of full load emissions data for these pollutants during permitting would lead to potential noncompliance situations after operation. If part load operation is only a transient condition and not a normal operating load, then an exemption from the air permit limit would be necessary for the transition from start-up through minimum operating load, and from minimum load through shutdown of the unit. However, if the combustion turbine will operate at the lower load condition, the higher carbon monoxide and hydrocarbon levels should be applied for in the permit application.<sup>2</sup>

In order to account for engine-to-engine variations in performance, fuel composition, uncertainty in measurements during stack testing (and continuous monitoring), and future upgrades (e.g.,

increase power output at a later date), another useful strategy is to provide a safety margin to all emission rates in the initial permit application. Typical margins applied to combustion turbine mass emission rates range from two to four percent.

Many of the simple-cycle gas turbine projects are undergoing permitting as non-Prevention of Significant Deterioration (PSD)<sup>3</sup> projects by limiting operating hours, or fuel consumption, to ensure that annual emissions do not exceed PSD trigger levels. The calculation of annual emissions based on normal operating loads, without taking into consideration the increased NO<sub>x</sub>/CO/VOC emission levels during startups/shutdowns, is technically wrong and will be challenged by regulators.

### ***Calculation of Annual Emissions***

In order to account for the variation in gas turbine emissions for peaking units, a good approximation is to utilize emissions data representative of the annual average temperature for the plant site. For example, if the annual average temperature is 60 deg F but the gas turbines generally run during the summer months (temperatures above 80 deg F), the use of 60 deg F emissions and performance data would be conservative for permitting purposes. Assuming the data in Table 1 is representative for a site with four gas turbines that run an average of fourteen hours per day for 160 days per year, the calculation of annual emissions can be found in Table 2 assuming one hour for the startup hour and the remainder of the day at base load. Shutdown emissions were excluded because the unit can shutdown much quicker than it can start up).

**Table 2.** Annual emissions approximation for a four unit peaking facility when start-up emissions are included.

Number of Gas Turbines:		4		
Average Operating Hours per Operating Day:		14		
Average Operating Hours per Year:		2240		
Number of Days per Year:		160		
Emissions at Annual Average Temperature				
Pollutant	Base Load Emissions (lb/hr)	Average During a Startup Hour (lb/hr)	Daily Emissions (lbs)	Annual Emissions (TPY)
NO <sub>x</sub>	52.7	71.2	756.4	242.1
CO	32.1	89.2	506.3	162.0
VOC	2.4	3.8	35.3	11.3
SO <sub>2</sub>	2.1	1.7	29.4	9.4
PM10	5.0	5.0	70.0	22.4

If start-up emissions were ignored, then the annual emissions would be 236.1 tons of NO<sub>x</sub>, 143.7 tons of CO, 10.9 tons of VOC, and 9.6 tons of SO<sub>2</sub> (PM10 would remain the same). Since gas turbine engine and emissions performance varies with fuel type, ambient conditions, and type of gas turbine selected for the project, site specific engine and emissions performance data must be

evaluated for any given permit application. If the low load emissions data is not warranted by the manufacturer, it may be necessary to add additional margin to the emission rates to account for uncertainty.

## Combined-Cycle Gas Turbines

Combined-cycle gas turbine projects utilize heat recovery steam generators (HRSG's) to generate steam to power a steam turbine-generator. The higher thermal efficiency makes combined-cycle plants ideal for intermediate load applications. In many cases, supplemental duct firing in the HRSG provides additional heat that can be recovered, thereby allowing more power to be produced in the steam cycle. The construction of HRSG's allows for the installation of post-combustion NO<sub>x</sub> control such as Selective Catalytic Reduction (SCR).

Combined-cycle gas turbines have elevated startup/shutdown emissions, just as in the case of simple-cycle gas turbines. For example, intermediate load combined-cycle plants may operate 16 hours per day, five days per week, 52 weeks per year, resulting in 260 startups/shutdowns per unit annually. During startups, the SCR system cannot be turned on until the temperature inside the Heat Recovery Steam Generator (HRSG) at the SCR grid reaches a temperature of approximately 575 deg F. With combined-cycle units often taking as long as 120 to 180 minutes to reach this temperature (cold start), the increase in emissions may require further evaluation.

The typical emission limitations for combined-cycle gas turbines are based on hourly limitations and annual tons per year (TPY). However, in some instances, state agencies have imposed 24-hour block or rolling average emission limitations. These conditions, if not properly accounting for start-up and shutdown emissions, can make it impossible to achieve compliance. Consider the example in Table 3 for a hypothetical combined cycle plant equipped with SCR for NO<sub>x</sub> control and no oxidation catalyst. The intermediate load unit runs for 16 hours per day, and has a daily (block) 24-hour NO<sub>x</sub> limit of 3.5 ppmvd @ 15% O<sub>2</sub>, and a CO limit of 30 ppmvd @ 15% O<sub>2</sub>. The unit is capable of achieving NO<sub>x</sub> less than 3.5 ppmvd @ 15% O<sub>2</sub> for all loads above 50%, and concurrently achieves CO emissions less than 25 ppmvd @ 15% O<sub>2</sub> (with minor excursions).

Depending upon the manner in which offline emissions (i.e. 0.0 ppm and 0.0 lb/hr), and start-up/shutdown emissions are to be counted, the unit may or may not be in compliance with the 24-hour limits. If the facility is allowed to average all 24 hours, including off line hours, then the NO<sub>x</sub> and CO averages are 7.0 and 29.6 ppmvd @ 15% O<sub>2</sub>, respectively. NO<sub>x</sub> fails to achieve the 3.5 ppmvd limit, while CO meets the 30 ppmvd limit. If the facility is allowed to exclude startup and shutdown emissions, the NO<sub>x</sub> and CO averages are 3.3 and 16.4 ppmvd @ 15% O<sub>2</sub>, complying with the 24-hour limits. However, if all operating data must be averaged, including startup and shutdown periods, the NO<sub>x</sub> and CO averages are 10.5 and 44.6 ppmvd @ 15% O<sub>2</sub>, and both exceed the 24-hour limits.

**Table 3.** Hypothetical example of an intermediate load combined cycle plant with 24-hour average NO<sub>x</sub>/CO limitations.

---

Hour	Status	NO <sub>x</sub> (ppmvd @ 15% O <sub>2</sub> )	CO (ppmvd @ 15% O <sub>2</sub> )
1	Unit Off	0	0
2	Unit Off	0	0
3	Unit Off	0	0
4	Unit Off	0	0
5	Unit Off	0	0
6	Startup	55	250
7	Startup	45	125
8	>50% Load	3.2	15
9	>50% Load	3.5	20
10	>50% Load	3.2	15
11	>50% Load	3.4	22
12	>50% Load	3.3	15
13	>50% Load	3.3	10
14	>50% Load	3.1	9
15	>50% Load	2.9	8
16	>50% Load	3.2	11
17	>50% Load	3.4	18
18	>50% Load	2.7	22
19	>50% Load	3.5	33
20	>50% Load	3.8	15
21	Shutdown	25	125
22	Unit Off	0	0
23	Unit Off	0	0
24	Unit Off	0	0
Daily 24-hr Average (Including Unit Off)		<b>7.0</b>	29.7
Daily 24-hr Average of Operating Time Only, Including Startup/Shutdown		<b>10.5</b>	<b>44.6</b>
Daily 24-hr Average of Operating Time, Excluding Startup/Shutdown		3.3	16.4

## **NEW SOURCE PERFORMANCE STANDARDS (NSPS)**

In the New Source Performance Standards, 40 CFR 60.8(c)<sup>4</sup>, it states “Operations during periods of startup, shutdown, and malfunction shall not constitute representative conditions for the purpose of a performance test, nor shall emissions in excess of the level of the applicable emission limit during periods of startup, shutdown, and malfunction be considered a violation of the applicable emission limit unless otherwise specified in the applicable standard.”

During a startup and shutdown, intermediate load combined-cycle facilities with duct firing will not be operating duct burners (which are regulated under 40 CFR 60, Subpart Da)<sup>5</sup> and therefore, should only be considered 40 CFR 60, Subpart GG<sup>6</sup> units (i.e., Stationary Gas Turbines) during startup/shutdown periods. Since gas turbines have no applicable federal standard that applies during startups and shutdowns, one should attempt to have startup and shutdown emissions excluded from compliance averaging. However, the mass emissions from these units must still be counted for comparison to periodic (e.g, annual) mass emission limitations.

Regardless of the NSPS language, EPA guidance is that emissions should be reduced as much as possible during periods of startup and shutdown.<sup>7</sup>

## **FEDERAL POLICY ON STARTUP EMISSIONS FOR SIPS**

States differ on the use of exemptions during periods of startup and shutdowns. Some states provide outright exemptions from emission limitations during startups and shutdowns, but others set numeric limits for startups and shutdowns on a case-by-case basis.

On September 29, 1999, the EPA reiterated their policy for State Implementation Plans (SIPs) regarding excess emissions during malfunctions, startup, shutdown, and maintenance, originally contained in memoranda from Kathleen Bennett, formerly Assistant Administrator for Air, Noise and Radiation dated September 28, 1982 and February 15, 1983.

As EPA stated in its 1982 memorandum, because excess emissions might aggravate air quality so as to prevent attainment or interfere with maintenance of the ambient air quality standards, EPA views all excess emissions as violations of the applicable emission limitation. Nevertheless, EPA recognizes that imposition of a penalty for sudden and unavoidable malfunctions caused by circumstances entirely beyond the control of the owner or operator may not be appropriate. Accordingly, a State or EPA can exercise its “enforcement discretion” to refrain from taking an enforcement action in these circumstances.

The main question of interpretation that has arisen regarding the old policy is whether a State may go beyond this “enforcement discretion” approach and include in its SIP a provision that would, in the context of an enforcement action for excess emissions, excuse a source from penalties if the source can demonstrate that it meets certain objective criteria (an “affirmative defense”). This policy clarifies that States have the discretion to provide such a defense to actions for penalties brought for excess emissions that arise during certain malfunction, startup, and shutdown episodes.

EPA did not approve an affirmative defense provision that would undermine the fundamental requirement of attainment and maintenance of the NAAQS, or any other requirement of the Clean Air Act. Pursuant to Section 110(1)<sup>8</sup>, EPA may not approve a SIP revision if “the revision would interfere with any applicable requirement concerning attainment and reasonable further progress.”

EPA also clarified how excess emissions that occur during periods of startup and shutdown should be addressed. In general, because excess emissions that occur during these periods are reasonably foreseeable, they cannot be automatically excused. However, EPA recognizes that, for some source categories, even the best available emissions control systems might not be consistently effective during startup or shutdown periods. In areas where the respective contributions of individual sources to pollutant concentrations in ambient air are such that no single source or small group of sources has the potential to cause an exceedance of the NAAQS or PSD increments, these technological limitations may be addressed in the underlying standards themselves through narrowly-tailored SIP revisions that take into account the potential impacts on ambient air quality caused by the inclusion of these allowances. In these instances, as part of its justification of the SIP revision, the State has been instructed to analyze the impact of the potential worst-case emissions that could occur during startup and shutdown.

For some source categories, given the types of control technologies available, there may exist short periods of emissions during startup and shutdown when, despite best efforts regarding planning, design, and operating procedures, the otherwise applicable emission limitation cannot be met. Accordingly, except in the case where a single source or small group of sources has the potential to cause an exceedance of the NAAQS or PSD increments, it may be appropriate, in consultation with EPA, to create narrowly-tailored SIP revisions that taken these technological limitations into account and state that the otherwise applicable emissions limitations do not apply during narrowly defined startup and shutdown periods. To be approved, these revisions should meet the following requirements:

1. The revision must be limited to specific, narrowly-defined source categories using specific control strategies (e.g., combined-cycle facilities burning natural gas and using selective catalytic reduction);
2. Use of the control strategy for this source category must be technically infeasible during startup or shutdown periods;
3. The frequency and duration of operation in startup or shutdown mode must be minimized to the maximum extent practicable;
4. As part of its justification of the SIP revision, the state should analyze the potential worst-case emissions that could occur during startup and shutdown;
5. All possible steps must be taken to minimize the impact of emissions during startup and shutdown on ambient air quality;
6. At all times, the facility must be operated in a manner consistent with good practice for minimizing emissions, and the source must have used best efforts regarding planning,

design, and operating procedures to meet the otherwise applicable emission limitation; and

7. The owner or operator's actions during startup and shutdown periods must be documented by properly signed, contemporaneous operating logs, or other relevant evidence.

Gas turbine projects are commonly accepted as one of these source categories that fit this description and meet the seven requirements. What this all means to the owner or operator of a gas turbine facility is that state regulators may require a thorough examination of the air quality impacts of startup and shutdown emissions during the permitting process. Modeling approaches for simple cycle and combined cycle gas turbine projects are discussed below. To obtain the most flexibility, the owner/operator of the gas turbine facility will want to obtain either a startup/shutdown exemption from emission limitations, or an elevated level applicable for operation below minimum load.

## **AIR QUALITY IMPACT ANALYSES**

Dispersion modeling techniques are used to quantify the air quality impacts from emission sources on the ambient environment. A few years ago, this type of analysis was only required for major new sources (e.g., PSD projects), but it has now expanded to non-PSD gas turbine projects in many states. Computer programs such as SCREEN3, ISCST3, and ISC-PRIME are commonly accepted EPA models. In addition to emission increases during gas turbine startups and shutdowns, lower plume buoyancy (due to lower air flow and stack exit temperature) during the startup sequence must be considered in the air dispersion modeling study to ensure that exceedances of the National Ambient Air Quality Standards, or PSD significance levels, do not occur.

### **Simple Cycle Gas Turbine Peaking Facilities**

Since the gas turbine startup sequence is significantly longer than the shutdown sequence (10-30 minutes versus <10 minutes), evaluation of only the startup sequence emissions should be sufficient for the air quality impact demonstration. For this evaluation, a six unit arrangement was modeled using the ISCST3 model with the emission rates and stack exit parameters from Table 1 (stack height of 80 feet, stack diameter of 15.5 feet). To enhance the conservatism, it was assumed that all six units would start up at the same time, and that the startup emissions profile could continue for up to three hours. The goal of the study was to demonstrate that the higher CO emissions and lower plume buoyancy during a facility startup would not jeopardize the short term (1-hour) ambient air quality standard for CO, nor the short term (3-hour) ambient air quality standard for SO<sub>2</sub>. The results of the modeling study can be found in Table 4. Even though PSD increments and Significant Impact Levels (SIL) do not apply for non-PSD projects, a useful evaluation is to compare predicted impacts to the SIL.

**Table 4.** Results of Dispersion Modeling Study To Evaluate Short-Term Air Quality Impacts for Six Simple Cycle Gas Turbines Starting Up At The Same Time.

	<b>Maximum 1-Hour CO Impact (ug/m<sup>3</sup>)</b>	<b>Maximum 3-Hour SO<sub>2</sub> Impact (ug/m<sup>3</sup>)</b>
Base Load	21.0	1.12
80% Load	68.0	1.52
60% Load	102.0	1.50
Startup Period	236.8	1.51
NAAQS	40,000	1300
Sig. Impact Level	2,000	25

Several things are quite obvious. First, even though the CO emissions (lb/hr) for the startup period are 2.8 times higher than full load (see Table 1), the ground level impacts due to reduced plume buoyancy are 11.3 times higher. Yet, even in this case, the maximum predicted CO concentration of 236.8 ug/m<sup>3</sup> is significantly less than the NAAQS and SIL. Even with all six units starting up at the same time for this example, the ground level CO impacts are very minimal. However, results will vary on a case by case basis as a function of number and type of gas turbines, fuel selection, startup duration, startup emission profiles, stack height, stack diameter, building heights (downwash issues), distance to plant fencelines, terrain, meteorology, etc.

For natural gas fuel in gas turbines, SO<sub>2</sub> emissions are almost negligible and the evaluation of SO<sub>2</sub> ambient impacts might be considered a waste of time. But if the gas turbines could fire distillate oil as a backup fuel, this analysis must be expanded to oil-fired emissions.

### **Combined-Cycle Intermediate Load Facilities**

The air quality impact analysis for combined cycle facilities is more rigorous, given that most larger combined-cycle facilities would trigger PSD review. For this example, it was assumed that there were four 180 MW gas turbines operating in combined cycle with duct firing, with NO<sub>x</sub> emissions controlled to 4.5 ppmvd @ 15% O<sub>2</sub> with SCR. The operating range for the units is 50% load or greater. Further, it was assumed that the facility could operate up to 8760 hours per year as a base load facility, or up to 16 hours per day, 7 days a week, 52 weeks per year as an intermediate load facility. The complete air quality impact analysis would require evaluation of the facility NO<sub>x</sub>, SO<sub>2</sub>, CO, and PM10 emissions at maximum operation, 75% load, and 50% load for the entire year to complete the typical PSD modeling comparisons to SIL, pre-construction monitoring significance levels, and the NAAQS. The startup emissions profile could also be modeled similar to the simple cycle example presented above.

The most interesting evaluation for this plant, however, is to determine how the intermediate load operation of this facility might affect the annual NO<sub>x</sub> SIL as compared to operation for the entire year at full load. In order to accomplish the evaluation, the daily NO<sub>x</sub> emissions profile was programmed into the ISCST3 model using hourly scaling factors as shown in Table 5. A scaling factor of 16.667 was applied to the first two hours of the startup to raise the NO<sub>x</sub> emission rate up to mass emission rate associated with 75 ppmvd @ 15% O<sub>2</sub> (i.e., SCR not in operation), and 8.335 for the third operating hour (assumes SCR turned on after 30 minutes into the third hour,

for an overall startup period from first firing to SCR in operation of 150 minutes). The next eleven hours were modeled at full load, followed by the final hour without SCR (16.667 scaling factor). Note that the scaling factors used for this analysis are hypothetical and the actual values should be utilized for an actual modeling study.

**Table 5.** Emission Parameters for Sample Combined Cycle Plant Operating As An Intermediate Load Facility.

Parameter	Full Load	Start-up	Comments
Stack Height (m)	45.72	45.72	
Temperature (deg K)	351.21	351.21	Temperatures do not vary as significantly in combined cycle plants due to the presence of the HRSG.
Exit Velocity (m/sec)	19.3243	12.954	
Stack Diameter (m)	5.4864	5.4864	
NO <sub>x</sub> (g/sec)	4.536	4.536 (*)	NO <sub>x</sub> emission rate scaled in ISCST3 on an hourly basis as shown below.
		(*) Hourly Scaling Factor	
Hours 1-5	NA	0	Off line
Hours 6-7	NA	16.667	Start-up (No SCR)
Hour 8	NA	8.3335	Start-up (SCR partial hour)
Hours 9-20	NA	1	SCR in operation
Hour 21	NA	16.667	Shutdown (No SCR)
Hours 22-24	NA	0	Off line

The modeling results demonstrate that for 8760 hours per year, the maximum annual NO<sub>x</sub> impact was only 0.28 ug/m<sup>3</sup>, which is less than the 1.0 ug/m<sup>3</sup> SIL. However, the maximum annual NO<sub>x</sub> impact for intermediate load operation was 1.33 ug/m<sup>3</sup>, which is above the SIL. In this example, the owner/operator of the source would most likely attempt to optimize the startup sequence and emissions in order to avoid triggering the PSD SIL, that could result in additional modeling of other sources and "increment" consumption.

## PERMIT RESTRICTIONS

Most gas turbine projects undergo initial source testing with EPA Reference Test Methods<sup>9</sup> to demonstrate compliance with applicable emission limitations. However, these test programs are

typically performed for stable load conditions and not transient conditions. The use of continuous emissions monitoring systems (CEMS) provides a reliable measurement of NO<sub>x</sub> and CO emissions, including during the transient startup and shutdown conditions. In Illinois, recent permits issued have conditions such that require the development of site specific startup emission factors. An example condition reads "Unless continuous emissions monitoring is conducted for the particular pollutant, measurement shall also be performed for emissions of NO<sub>x</sub>, CO, and VOC (also called volatile organic materials, VOM) during startup of the turbine, in accordance with a plan approved by the agency. For purposes of these measurements, the permittee may adapt EPA reference methods<sup>9</sup> as necessary to address the short duration and transient conditions of startups."

Permit conditions similar to the above startup testing condition are becoming more common in order to address the EPA SIP guidance concerning excess emissions during startups and shutdowns.

## **CONCLUSION**

The increase in the number of gas turbine projects over the past few years has led to a closer scrutiny of the air emissions and associated air quality impacts. The calculations presented in this paper, as well as the modeling scenarios evaluated, are intended to serve as a starting point for the development of strategies and procedures to evaluate gas turbine startup emissions.

Each gas turbine project must be evaluated on its own merit, since there are an infinite number of combinations of gas turbines, site arrangements, stack parameters, fuels, operating scenarios, terrain effects, and emission profiles. What proves to be insignificant air quality impacts for one gas turbine project may indeed be significant for a similar size project at another location.

In the event that startup emissions result in unacceptable impacts, the owner/operator may consider modifications to the plant design (e.g., taller stacks) to reduce the impacts to acceptable levels. Operational adjustments, such as avoiding simultaneous multiple unit startups, may also help mitigate air quality impacts.

## **REFERENCES**

1. Macak, J. J. and Greidanus, B.E. 2000. "Strategies for Successful Gas Turbine Siting, Permitting, and Operational Flexibility," Proceedings of the Air & Waste Management Association Annual Conference and Exhibition, Salt Lake City, UT, June.
2. Macak, J. J. and Schott, G. A. 1993. "Environmental Permitting Strategies and Considerations for Combustion Turbine Projects," Proceedings of POWER-GEN '93 AMERICAS, 6th International Conference and Exhibition for the Power Generation Industries, November 17-19, 1993, Dallas, TX, Book III, Volume VII, Non-Utility Power Generation.
3. 40 CFR 52, Subpart A –Approval and Promulgation of Implementation Plans, Section 52.21, "Prevention of Significant Deterioration of Air Quality."
4. 40 CFR 60, New Source Performance Standards.

5. 40 CFR 60, Subpart Da, New Source Performance Standards for Steam Electric Generation Units.
6. 40 CFR 60, Subpart GG, New Sources Performance Standards for Stationary Gas Turbines.
7. Personal E-Mail correspondence with Mr. Sims Roy, USEPA, RTP, September 5, 2000.
8. Clean Air Act Amendments of 1990. P.L. 84-189, approved July 14, 1955; as last Amended by P.L. 101-549, approved November 15, 1990; 42 U.S.C. §~ 7401 *et seq.*
9. 40 CFR 60, Appendix A, Reference Test Methods.

## **KEYWORDS**

- Air Permitting
- Air Quality Modeling
- Combined Cycle Gas Turbines
- Combustion Turbines
- Dispersion Modeling
- Duct Burner Emissions
- Emission Limit Exemptions
- Environmental Permitting
- Gas Turbines
- Independent Power Generation
- Operational Flexibility
- Peaking Units
- Power Generation
- Prevention of Significant Deterioration
- Shutdown Emissions
- Simple Cycle Gas Turbines
- Startup Emissions