PEPSE® Analysis of Advanced Combustion Turbine Cycles

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Introduction

Rochester Gas and Electric Corporation serves the upstate New York area, with corporate headquarters in Rochester, New York. Electric generation consists of a 500 MW nuclear plant, five (5) coal fired units with a total output of 350 MW, hydro-electric stations on the Genesee River with a total output of 50 MW, and two (2) 18 MW combustion turbines. RG&E is also a partner with neighboring utilities for 200MW of oil fired generation and 150 MW of nuclear. RG&E has 2100 employees and serves approximately 300,000 customers. The RG&E system peak electric demand was 1374 MW in July of 1994.

Background

Combustion turbines utilized for electric power generation are classified as either "frame" or "aeroderivative" machines. The frame machines are heavy duty, single shaft turbines direct connected to a generator. Turbine speed is 3000 or 3600 RPM for either 50 or 60 cycle electric power. The rugged turbine casing is designed for high reliability and long life. The aeroderivative machines are turbines originally designed for aircraft engines. They are high performance, light weight and dependable, though are designed to require routine inspection and maintenance. The aero machines have been converted from high thrust jet engines to shaft drive machines by adding an additional power turbine at the back end of the engine. This additional turbine converts the high energy exhaust stream into mechanical energy on the output shaft.

The aeroderivative combustion turbines are multiple shaft machines. The low pressure compressor is driven by the low pressure turbine, at a rotational speed that is optimized for the pressure ratios and flows. The high pressure compressor is separately driven by the high pressure turbine. In some machines, the additional power turbine is on a third shaft, independent from the compressor sections. The General Electric aeroderivative combustion turbines are offered in sizes of 14MW (LM1600), 23MW (LM2500), 35MW (LM5000) and 42MW (LM6000).

Advanced Combustion Turbine Cycles

Intercooled Cycle

The first advanced cycle modeled is the intercooled cycle. The compressed air is cooled partway through the compression process, to reduce the work required to complete compression. The GE LM6000 was chosen for this study, as the two section compressor can be more easily adapted to intercooling than on a frame machine. The LP section has 5 stages and the HP section has 14 stages. The total compression ratio is 29:1, and this is proportioned between the two sections. In the standard machine, without intercooling, the compressor discharge temperature is calculated to be 1055F. The intercooler between the two sections reduces the final air temperature to 650F, which reduces the compressor power consumption by 14 MW.

High Performance Combustion Turbine

The performance of this turbine can be improved by increasing the firing temperature. The first rows of blades in the turbine section are subjected to the highest temperatures, and the metallurgical properties of those blades determines the maximum allowable firing temperature. In high performance machines, these blades are cooled with air from the compressor discharge that bypasses the combustor. The blades have internal passages for this cooling air, and the blade is maintained at a temperature below the firing temperature. With an intercooled compressor, the high pressure compressor discharge temperature is reduced, and therefore the cooling is more effective. This allows the firing temperature to be increased without sacrificing blade life.

PEPSE Modeling

The standard combustion turbine is modeled with a type 44 compressor, driven by the turbine, and a type 9 turbine. Normally one component of each type is included to model the combustion turbine unit. For the intercooled case, two type 44 compressors are included in series, one representing the LP section and one the HP section. A type 20 heat exchanger in between is used to model the intercooler. The efficiencies of the individual compressor sections must be modified to match the overall compressor efficiency. There is a control on the fuel flow to maintain the desired turbine inlet temperature. For the high performance turbine, the cooler air allows a greater mass flow through the machine. There is a control on the inlet air mass flow to match the volume flow of the base case. The firing temperature is increased to 2500F, which takes advantage of the cooler air exiting the high pressure compressor and is the expected maximum allowable based upon current blade cooling technology.

The PEPSE output from this modeling is as follows:

	GE LM6000	Intercooled	High Perf Intercooled
Gross Turbine Power, MW	116	118	186
LP Compressor Power, MW	19	19	24
HP Compressor Power, MW	54	40	50
Net Shaft Output, MW	43	59	112
Net Heat Rate, BTU/KWH	8170	7750	6410
LP Comp Inlet Temp, F	59	59	59
LP Comp Exit Temp, F	325	325	325
HP Comp Inlet Temp, F	325	100	100
HP Comp Exit Temp, F	1055	650	650
Firing Temp, F	2220	2220	2500
Air Flow, KLb/Hr	978	978	1250
Exhaust Flow, KLb/Hr	994	1000	1280
Fuel Input, MBTU/Hr (LHV)	350	465	715

Humidification Cycle

Another method for improving the cycle is to add water vapor to the compressed air prior to introduction to the combustor. This increases the mass flow through the turbine without increasing the work of the compressor. The humidified air is expanded through the turbine and the water can be recovered from the exhaust. This is added to the intercooled combustion turbine to further enhance the performance. The electric generation is increased, though the heat rate degrades somewhat.

PEPSE Modeling

A type 50 mixer is added between the HP compressor and the combustor. Water is added to make air with 100% relative humidity at the outlet. The actual device used to add water to the airstream is called a saturator, and it is more sophisticated than simply spraying water into the air. The type 50 mixer over simplifies the processes occurring within the saturator, but for an initial analysis the results are sufficiently accurate.

The PEPSE output from this modeling is as follows:

	GE LM6000	Intercooled	Humidified Intercooled
Gross Turbine Power, MW	116	118	126
LP Compressor Power, MW	19	19	19
HP Compressor Power, MW	54	40	40
Net Shaft Output, MW	43	59	67
Net Heat Rate, BTU/KWH	8170	7750	7920
LP Comp Inlet Temp, F	59	59	59
LP Comp Exit Temp, F	325	325	325
HP Comp Inlet Temp, F	325	100	100
HP Comp Exit Temp, F	1055	650	650
Firing Temp, F	2220	2220	2220
Air Flow, KLb/Hr	978	978	978
Exhaust Flow, KLb/Hr	994	1000	1033
Fuel Input, MBTU/Hr (LHV)	350	465	535

Westinghouse Combustion Turbines

Westinghouse has a line of frame combustion turbines which have increased in performance as the technology was developed. The trend continues to higher compression ratios and higher combustion temperatures. The performance of the 501 series is as follows:

Turbine Model	501D	501F	501G
Operational Date	1976	1992	1997
Power, MW	95	162	230
Firing Temp, F	2005	2350	2575
Air Flow, MLb/Hr	2.81	3.46	4.32
Exhaust Temp, F	956	1075	1100
Pressure Ratio	12.6	15.0	19.2
Heat Rate, BTU/KWH (LHV)			
Simple Cycle	10,925	9550	8860
Combined Cycle	7280	6250	5875

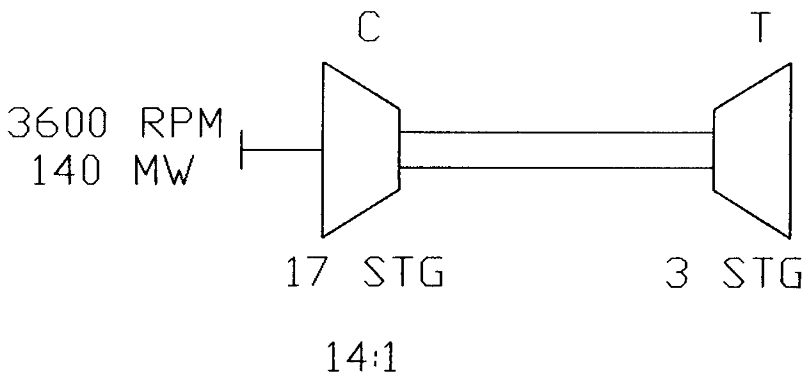
Westinghouse offers two modified frame machines with improved cycle performance. The first is a steam injected cycle, with high pressure steam generated in a Heat Recovery Steam Generator. The steam is expanded through a back pressure turbine and then is injected into the combustion turbine for power augmentation. This cycle provides high power levels and a heat rate better than a combined cycle without the need for a condenser. The second is a cascaded cycle, with intercooling and humidification, which utilizes standard turbo machinery components to provide high system performance.

Conclusion

PEPSE can be utilized to analyze these advanced combustion turbine cycles, and is especially useful in predicting performance when there is limited definitive information available.

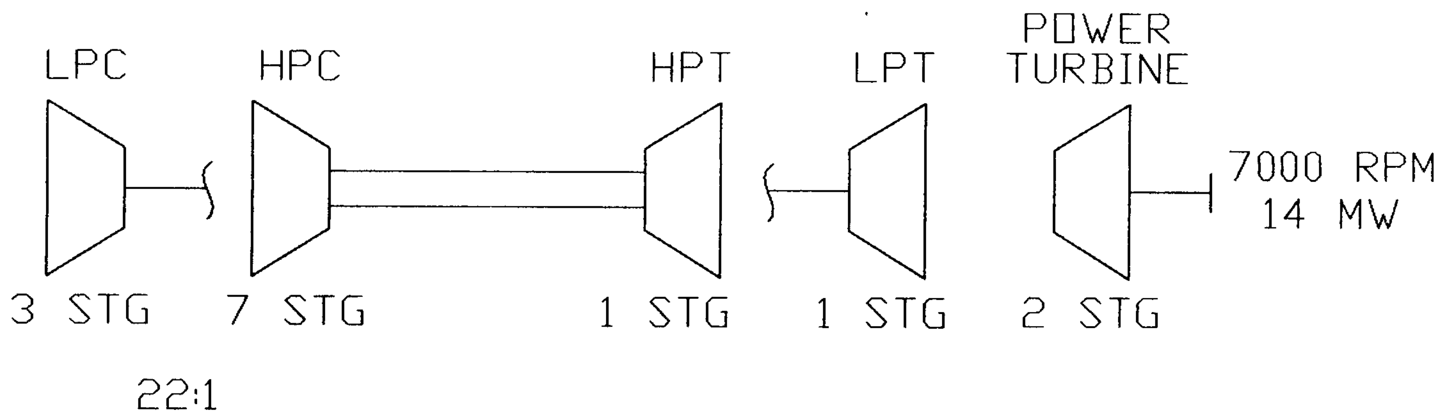
COMBUSTION TURBINE SHAFT CONFIGURATION

GE MS 7001F



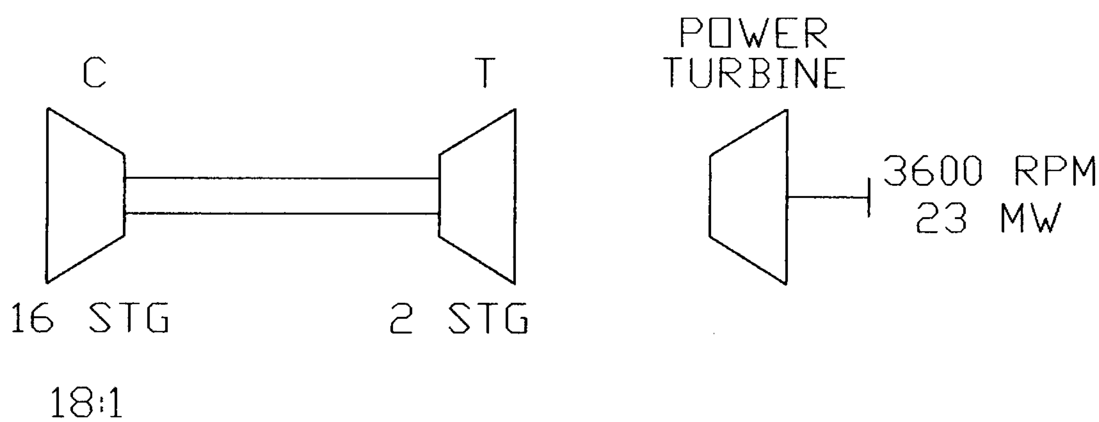
COMBUSTION TURBINE SHAFT CONFIGURATION

GE LM 1600



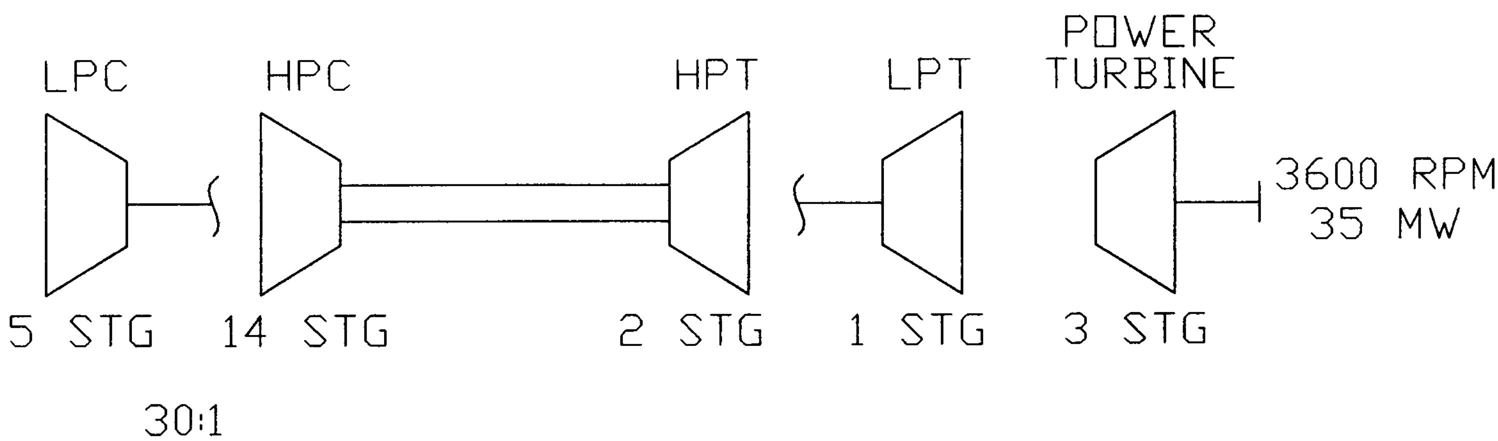
COMBUSTION TURBINE SHAFT CONFIGURATION

GE LM 2500



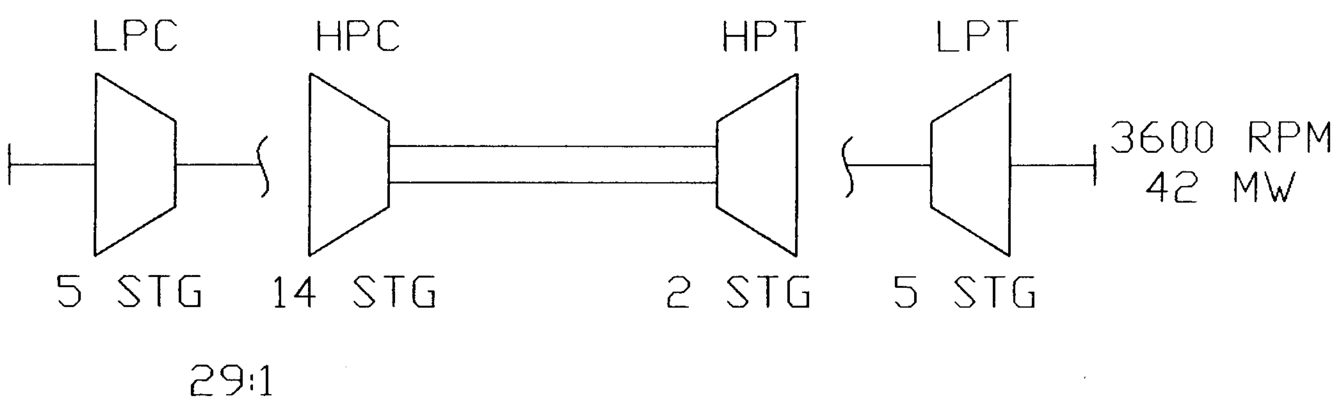
COMBUSTION TURBINE SHAFT CONFIGURATION

GE LM 5000

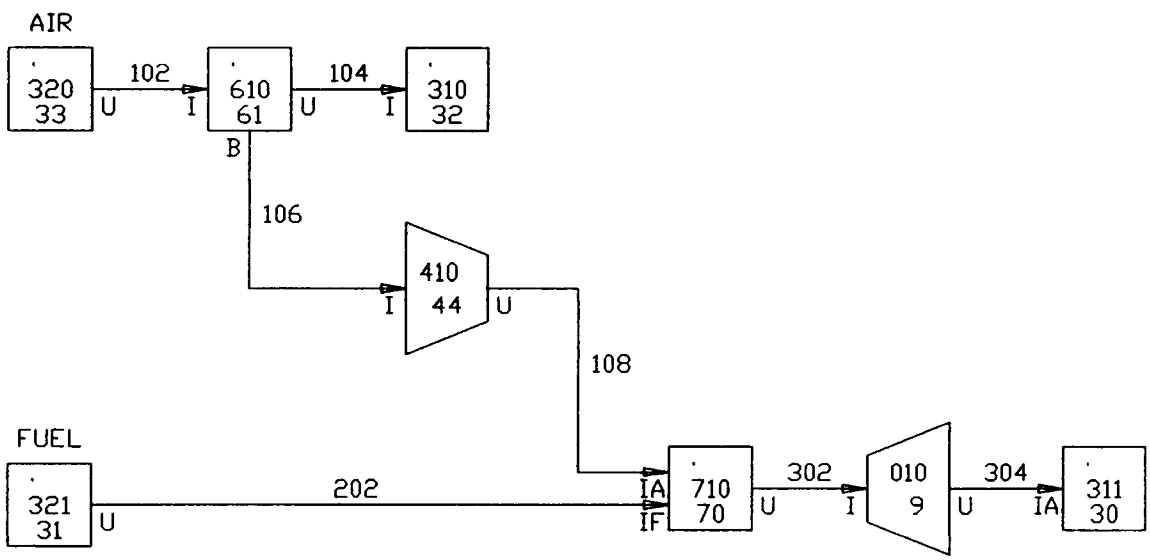


COMBUSTION TURBINE SHAFT CONFIGURATION

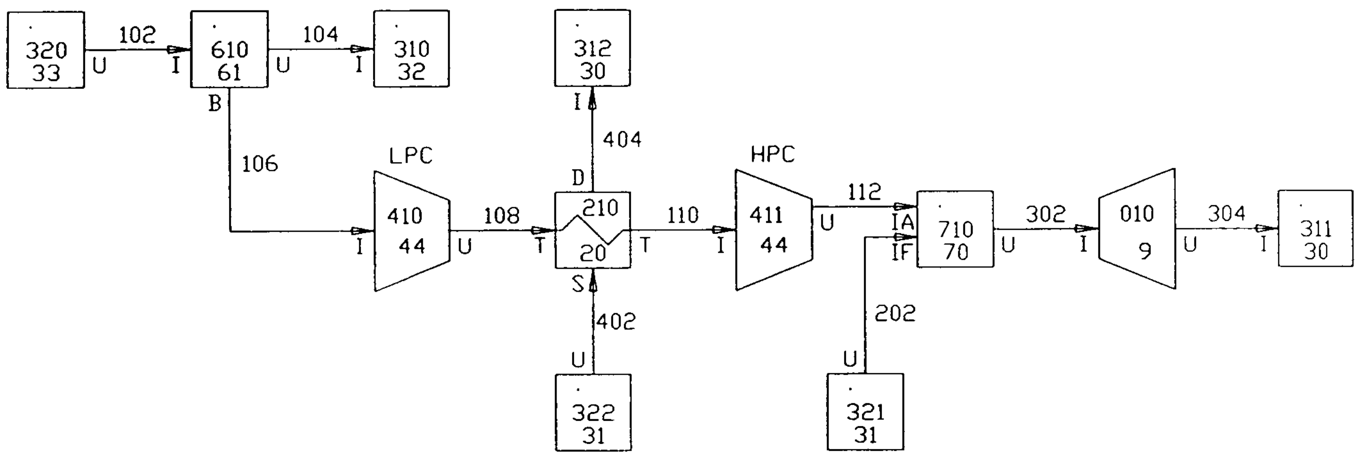
GE LM 6000



STANDARD COMBUSTION TURBINE PEPSE SCHEMATIC



INTERCOOLED COMPRESSOR PEPSE SCHEMATIC



HUMIDIFIED AIR CYCLE
PEPSE SCHEMATIC