Small Scale Combined Heat and Power

by

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Introduction

Combined heat and power or CHP is a well-accepted technology. Also known as cogeneration, many thousands of examples are installed and operating throughout the world. One of the most common versions uses a gas turbine to drive a generator to produce electricity. At the same time, the gas turbine's exhaust heat is used to produce thermal energy in the form of steam, hot water or hot air. The thermal energy can be used for comfort heating and domestic water heating as well as for air conditioning using an absorption chiller. It can also be used for heating, baking or drying products as well as for other applications.

The two major challenges in the successful development of CHP are the cost of the hardware and the ability to operate efficiently at part thermal load. Both of these challenges become more severe as the CHP system becomes smaller. The components in this proposal are inexpensive compared with those in conventional CHP. The system only operates with full thermal and full electric load.

The cost of a conventional gas turbine-driven CHP system is generally too high to be considered for small residential or commercial loads. Although the rotor groups could be derived from turbochargers, which have annual production rates in the millions and are therefore inexpensive, the need for precision controls, starting mechanisms, recuperators, fuel gas compressors and heat recovery units with bypasses drive up the cost.

If the generator set <u>is not</u> paralleled with the utility, precision controls will be needed to maintain voltage and frequency. If the set <u>is</u> paralleled with the utility, precision controls will be needed to bring the electric output to the correct voltage, frequency and phase before paralleling. These sophisticated controls also monitor the loads and match the generator set output to the load. A critical need is to control fuel flow during startup so that the generator set will accelerate to its operational speed without overheating. An additional function is to control the bypass on the exhaust heat recovery unit so that the thermal output matches the thermal load.

The starting mechanism generally consists of a starter motor, the appropriate electrical and mechanical devices to engage and disengage the motor and the source of starting energy that is generally batteries. These batteries usually have an associated charger.

Recuperators tend to be the most expensive single component in gas turbines and microturbines that are so equipped. They transfer heat from the exhaust into the air entering the combustor to reduce fuel consumption and improve efficiency. However, they also reduce the thermal output.

The exhaust heat recovery units need bypasses so that the output can be reduced. CHP systems that are not paralleled with the grid operate at electrical power outputs that match the electric load. This also determines the thermal output. When the thermal loads are less than the thermal output, the bypass reduces the output to match the load, thus wasting energy and reducing system efficiency. A typical example of reduced thermal load would be when the thermal output is used for heating or air conditioning and the weather is mild.

The combustors on conventional gas turbines operate at several atmospheres of pressure. If the fuel is natural gas, it must be compressed to a pressure higher than that of the combustor or it will not flow into the combustor. These gas compressors are expensive and tend to be inefficient thus imposing a significant parasitic load on the CHP system and reducing the efficiency.

Maximum efficiency in a CHP system occurs when all of the thermal energy is used beneficially. Thus it is very hard to achieve efficient operation, and therefore economic operation, when the loads change rapidly and substantially. Thermal loads change precipitously as comfort heating, process heating and water heating units cycle on and off. Compounding the problem, the thermal output from the CHP system changes as the gas turbine attempts to load follow electrically as appliances and other loads cycle on and off.

Proposed Concept

The proposed concept is for a combined heat and power system that does not use the above components and does not modulate to match either thermal or electric loads. It is driven by a subatmospheric gas turbine. It operates with the combustor at or slightly below atmospheric pressure so that it does not require a fuel gas compressor.

The major components are derived from parts that are currently in high production to reduce cost. There are no precision controls, starter motor, starting batteries, battery charger, recuperator, heat recovery bypass or fuel gas compressor. It is very efficient as it only operates with full electrical and thermal output. It is suitable for residential, commercial and other applications. In general, it uses either readily available, inexpensive components or components that are derived from ones that are currently in mass production.

The thermodynamic cycle used by the gas turbine is a subatmospheric Brayton cycle that was reduced to practice by The Garrett Corporation in the 1970's. It is also the basis of U.S. Patent 4,280,327 entitled “Solar Powered Turbine System” issued 28 July 1981 to Robin Mackay, and Patent 4,347,711 entitled “Heat Actuated Space Conditioning Unit with Bottoming Cycle” issued to James C. Noe and David W. Friedman on 7 September 1982. The cycle is described as an “inverted Brayton cycle” on page 135 of David Gordon Wilson’s book “The Design of High-efficiency Turbomachinery and Gas Turbines” published by the MIT Press in 1984.

The objective of this proposal is to replace a heating system that operates in cyclical fashion such as a water heater or a furnace. These units do not modulate. They operate at rated output until the desired temperature is reached and then shut down until heat is needed again. Thus when the heating system is required and turned on, the system starts and provides the heat using the rejected heat from the gas turbine. Simultaneously, the system produces electricity in parallel with the facility’s electric system and reduces the amount of electricity purchased from the electric utility. If the power produced is more than the facility is consuming, the additional power can be delivered to the utility for sale or for credit against future or past purchases of electricity.

Figure 1 describes the hardware. The rotating group consists of an induction motor/generator driving a centrifugal compressor wheel and a radial inflow turbine wheel through a step-up gearbox and shafts. The motor/generator is electrically tied to the facility’s grid through a breaker. The thermostat reads the temperature of the fluid to be heated – typically air in a furnace or water in a water heater.

When the thermostat calls for heat, it sends a signal to the fuel valve enabling it but not opening it. Simultaneously, it sends a signal to the breaker, closing it and allowing electricity to flow into the induction motor/generator. The motor/ generator then accelerates towards its synchronous speed less its negative slip angle. Thus, as an example, with 60-Hertz electricity, a two-pole motor generator and a five percent slip angle, the motor/generator would start to accelerate towards 3600 rpm less five percent or 3420 rpm.

As the compressor and turbine are connected to the motor/generator through the step-up gearbox and shafts, they too will rotate. As an example, if the step-up gearbox had a ratio of 20:1, they would accelerate towards 68,400 rpm.

The compressor will pull a partial vacuum in the heat recovery unit and the pressure sensor even though some air will be flowing through the preheater, combustor and turbine into the partial vacuum. When the pressure sensor senses that the pressure is appropriate, it sends signals to the igniter energizing it and to the fuel valve that was already enabled by the thermostat. The fuel valve either opens immediately or, if the igniter needs time to warm up, after a short delay. Combustion is started.

Ambient air entering the system is preheated in the preheater by the warm air being discharged from the compressor. It is further heated in the combustor to turbine inlet temperature. It then expands through the turbine. The turbine now produces power that is more than sufficient to drive the compressor. The excess power accelerates the rotating components through and beyond the synchronous speed of the motor/generator that now delivers power to the electric load. With the fuel flow fixed, the induction/generator will stabilize at a positive slip angle and provide a fixed amount of electricity and a fixed amount of thermal energy.

The air leaving the turbine goes into the heat recovery unit where it heats the desired fluid. It then passes through the pressure sensor and is compressed to about atmospheric pressure. It then preheats the incoming ambient air that is going to the combustor. When the thermostat senses that the temperature in the fluid being heated is hot enough, it sends signals to open the breaker and to close the fuel valve. The system shuts down.

The breaker, induction motor/generator, thermostat and pressure sensor should be readily available through catalogs. The compressor and turbine should be available as a turbocharger, recognizing that a lubrication system will be needed. The fuel valve, igniter, combustor and any required safety devices should be available as a package at low cost as they would be essentially identical to those used in dryers or furnaces. They do not modulate and operate only at essentially atmospheric pressure. The preheater is air-to-air with low temperatures and could be the heat exchanger in a residential hot air furnace. The heat recovery unit could be the heat exchanger in a hot air furnace or a hot water heater depending on what is to be heated. In the case of the water heater, the hot water may well be stored within the heat recovery unit. The gearbox would be custom made but using conventional technology.

In production, there would undoubtedly be consolidation of the rotating components. Figure 2 shows the gearbox with a compressor hung off one side of the high-speed shaft of the gearbox and a turbine hung off the other side. At the same time, the motor/generator is hung off the low speed side.

The system only operates when there is a full thermal load and when all of the heat available from the system can be used. Correspondingly, it assumes that the electricity produced will be used to reduce the amount of power purchased from the electric utility or will be sold to the utility for credit against past or future purchases. Thus it only operates at very high efficiencies.

The proposed concept is suitable for use anywhere that there are water heaters used for processes, dishwashing, swimming pools, comfort heating or domestic hot water. It is also suitable for producing hot air for heating, baking and drying. There is a wide range of potential customers including residences, schools, bakeries, hospitals and any facility that has cyclical heating loads.

23 October 2003
Patent applied for

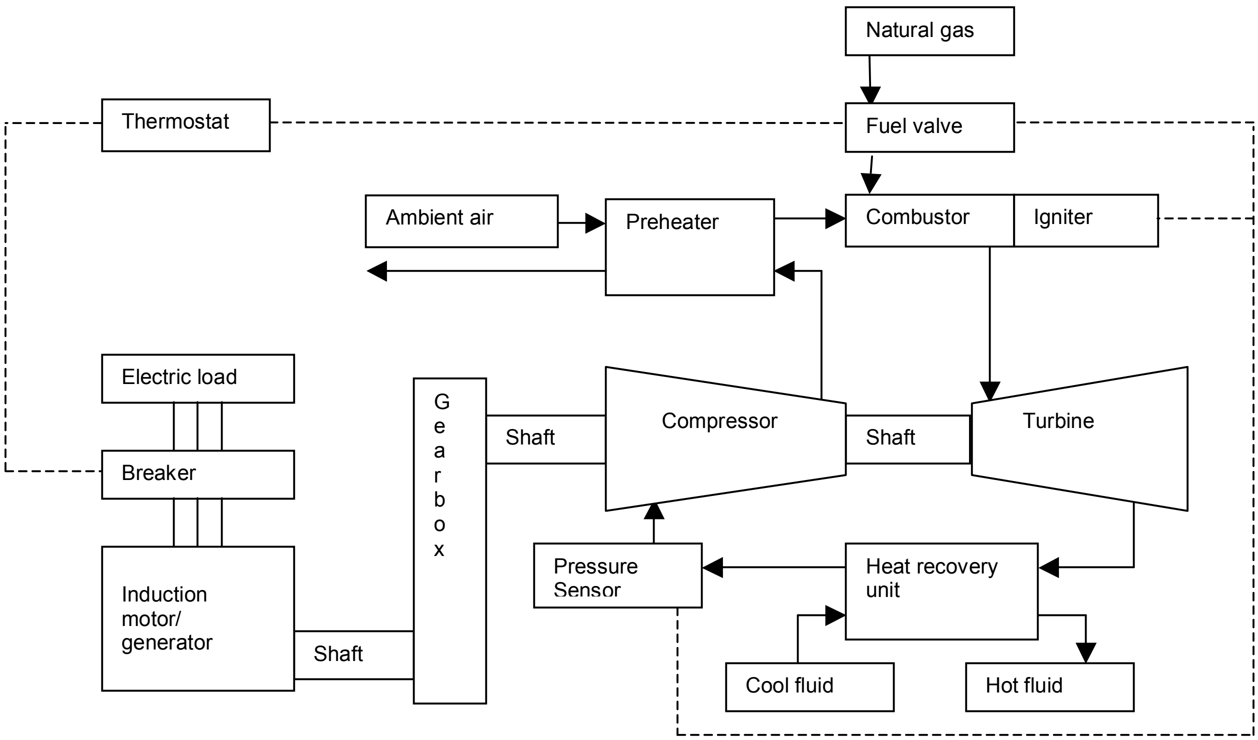

Figure 1

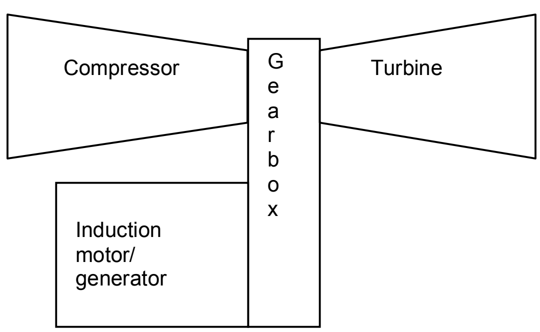

Figure 2