International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:268
Vol.2, No.5, May 2013 DOI:10.15693/ijaist/2013.v2i5.77-81

Potential of Micro Turbines for Small Scale Power Generation

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***Abstract*- This paper reviews the current and future state of art micro turbine technology in the developed countries. It investigates the environmental, energetic and economic benefits of this technology such as low emissions, high grade energy heat, low operation and maintenance costs while at the same time weighing the limitations of the technology, most prominently the expensive installation cost and lower efficiency for similar power output I.C. engines. The focus of the paper is to study its feasibility and potential use in developing countries such as India for small scale power generation.**

Index terms -Gas Micro Turbines, Distributed Generation (DG), emissions, Combined Heat and Power (CHP)

I. Introduction:

Micro turbines are a relatively new distributed generation technology being used for stationary energy generation applications. They are finding use as a replacement for small scale power generation. Microturbines offer many advantages as compared to other available technologies, such as I.C. Engines, for small-scale power generation, including: a small number of moving parts, compact size, lightweight, greater efficiency, lower emissions, lower electricity costs, and opportunities to utilize waste fuels. Waste heat recovery can also be used with these systems to achieve efficiencies greater than 80%. Due to their small size, relatively low capital costs, expected low operations and maintenance costs microturbines are expected to play a major role in the DG Sector.

Micro turbine technology today is the result of development work in small stationary and automotive gas turbines, auxiliary power equipment, and turbochargers, much of which was pursued by the automotive industry beginning in the 1950s. The size range for micro turbines available and in development is from 30 to 250 kilowatts (kW), while conventional gas turbine sizes range from 500 kW to 250 megawatts (MW). Micro turbines run at high speeds and, like larger gas turbines, can be used in power-only generation or in combined heat and power (CHP) systems. They are able to operate on a variety of fuels, including natural gas, sour gases (high sulfur, low Btu content), and liquid fuels such as gasoline, kerosene, and diesel fuel/distillate heating oil. In resource recovery applications, they burn waste gases that would otherwise be flared or released directly into the atmosphere. Micro turbines entered field testing around 1997 and began initial commercial service in 2000.

Microturbines are classified by the physical arrangement of the component parts: single shaft or two-shaft, simple cycle, or recuperated, inter-cooled, and reheat. The machines generally rotate over 40,000 revolutions per minute. The bearing selection—oil or air—is dependent on usage. A single shaft microturbine with high rotating speeds of 90,000 to 120,000 revolutions per minute is the more common design, as it is simpler and less expensive to build. Conversely, the split shaft is necessary for machine drive applications, which does not require an inverter to change the frequency of the AC power.

Microturbine generators can also be divided into two general classes:

- Unrecuperated (or simple cycle) microturbines—In an unrecuperated turbine, compressed air is mixed with fuel and burned under constant pressure conditions. The resulting hot gas is allowed to expand through a turbine to perform work. Simple cycle microturbines have lower efficiencies at around 15%, but also lower capital costs, higher reliability, and more heat available for cogeneration applications than recuperated units.
- Recuperated microturbines—Recuperated units use a sheet-metal heat exchanger that recovers some of the heat from an exhaust stream and transfers it to the incoming air stream, boosting the temperature of the air stream supplied to the combustor. Further exhaust heat recovery can be used in a

cogeneration configuration. The figures below illustrate a recuperated microturbine system. The fuel-energy-to-electrical-conversion efficiencies are in the range of 20 to 30%. In addition, recuperated units can produce 30 to 40% fuel savings from preheating.

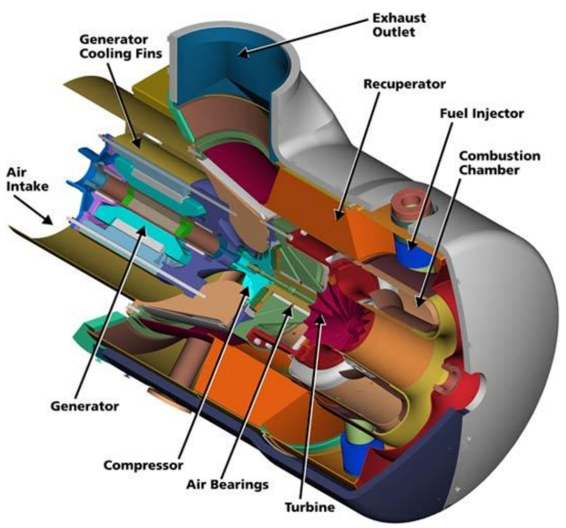

Figure 1 Recuperated MT

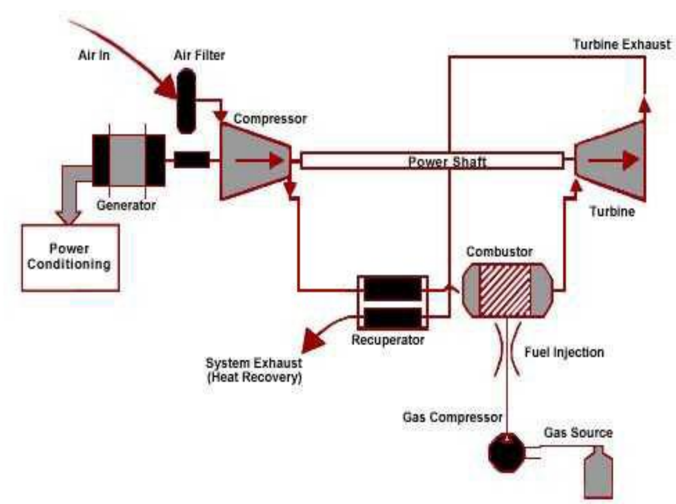

Figure 2 Unrecuperated MT

II. Benefits and Limitations of the Microturbine Technology

Micro-turbines offer a number of potential advantages compared to other technologies for small-scale power generation. They enjoy the following benefits:

- Compact size
- High power to weight ratio leading to reduced fabrication costs
- Small number of moving parts
- Lower noise
- Multi-fuel capabilities
- Lower emission (NOx < 9 ppm)

In addition, gas turbines enjoy certain merits relative to internal combustion engines in the context of micro-power generation such as:

- High-grade waste heat
- Low maintenance cost
- Low vibration level
- Short delivery time.
- The balancing problems are few due to absence of reciprocating and friction components
- The use of lubricating oil is very low. In fact the latest and most efficient microturbines use air bearing which eliminates the possibility of maintenance and lubrication completely.

The technology is however ridden with a few drawbacks as well. Main technical barriers to the implementation of micro-turbine technology are:

- At present, the gas turbine has a lower efficiency in its basic configuration than an equal power output reciprocating engine.
- The efficiency of the gas turbine decreases at partial load and burning of lower heating value fuels may not be feasible, depending on the type of the turbine.
- Electricity distribution systems are generally unsuitable for the installation of a large number of small plants and they require modification, the costs of which have to be taken into account.
- Micro-turbine plant, require power conditioning to produce electricity at grid frequency and this brings further additional costs to an installation.

The technology also faces a few non-technical barriers:

- Maintenance requires more skilled personnel than does the reciprocating engine
- Small gas turbines are expensive compared to reciprocating engines.
- Grid connection standards.

III. Comparison of DG Sets with Micro Turbines

	Conventional DG Set	**Capstone Micro Turbine**
Life Resource	10,000- 15,000 hrs	40,000 hrs

Oil Change	Yes	No
Water cooling	Yes	No
Ultra Low emissions	No	Yes
Heat Recovery Capability	Limited	Yes
Maintenance frequency	Monthly	Annually
Grid Quality Power	No	Yes
Noise Level	Loud	As low as 55 dBA
Vibration	Present	None
Capital Cost	US $ 500/kW	US $ 1000/kW
Technology	Well Established	Under Demonstration

IV. Current Trends:

A. Calabasas Landfill Microturbine Power Generation Project

The Los Angeles County had installed a micro turbine at its landfill site where landfill gas is used as the fuel. The plant became operational in October 2002 and a review of the plant's progress was done which illustrated the use of the technology. The power plant ran on low BTU gas which many critics visioned as a drawback. But utilizing a selective approach to landfill gas collection and handling, a successful project was developed that generates enough electricity to run the onsite gas blowers.

The District had purchased ten 30 kW microturbines from the company Capstone, to provide backup during the peak periods for the smooth functioning of the plant.

The pretreatment system is quite advanced to handle the landfill gas by removal of siloxanes and other volatile matter and thus obtain rich content of methane.

After eight months of operation, the District evaluated the total power production including capital recovery and operations and management cost at 5.6 cents/kWh assuming a 10 year lifespan at 4% interest. The average cost of power at the site was 14 cents/kWh which directly means a saving of 8.4 cents/kWh.

As far as the emissions were concerned, the South Coast Air Quality Management District (SCAQMD), the local air quality agency, lists the emissions limits at:

- NOX, as NO2 (9 ppm @ 15% O2)
- CO (50 ppm @ 15% O2)
- PM (0.1 gr/dscf @ 12% O2)
- NMHC, as hexane (10 ppm @ 3 % O2)

The Capstone 30 model with the desired modifications was in fact producing the following emissions:

- NOX, as NO2 (1.3 ppm @ 15% O2)
- CO (36 ppm @ 15% O2)
- NMHC, as hexane (2.3 ppm @ 3 % O2)

Thus it could be concluded that the micro turbine project at the landfill site for power generation provided benefits well below the stipulated emission limits.

Jonah Field : Case Study

The Jonah Field of Wyoming is owned by BP, America. The Field is the largest on-shore natural gas region and has 297 billion cubic meters of natural gas. Initially, BP had to waste environmentally unfriendly fuel to pump out the gas using pneumatic pumps. In August 2007, the company agrees to install a C30 Capstone MT. The MT uses a small amount of clean natural gas (referred to as dry) to generate 20 kW of power.

The Company then had the idea of running the MT on wet flash gas, which was usually wasted by burning in the combustor. The MT successfully used the Flash gas as fuel causing further savings. The results that were obtained are:

- The initial MT had run for 18 months without any operational problems.
- The MT generated 20 kW of electricity that runs the pumps for pumping out the gas from the Earth.
- The Company had decided to replace the earlier used Solar Panels for electricity generation since the MT could produce electricity every day, irrespective of the weather.
- The company recorded a significant reduction in green house gases.
- Savings of nearly 12 million standard cubic feet of natural gas that once was used to power the fuel pumps.

The results of this study were so favorable that BP America decided later to install MTs at five more Jonah Field sites. They also plan to use the electricity produced by the MT for powering automation, chemical injection and cathodic protection as well as the Vapour Recovery Unit to recover flash gas on site.

C. Benefits of a Combined Microturbine-Organic Rankine Cycle for power generation

This case study investigates the potential benefits that can be obtained from the implementation of a combined micro-turbine organic Rankine cycle (MT-ORC) versus a simple micro-turbine or a topping-cycle CHP system. The analysis was performed for sixteen different geographic locations using micro-turbines of sizes 30, 65, and 200 kW.

- It is found that for some cities where the use of a micro-turbine is not cost effective, the combination of MT-ORC is a viable alternative to grid power.
- For the micro-turbines considered, in terms of the total electric power, the ones with smaller power levels benefit the most (percentagewise) when combining them with an ORC.
- A minimum bound for the power-to-heat ratio of a building that results in MT-ORC operation being superior to that of CHP operation, is obtained.
- The total power generated by the combined MT-ORC system increased by 30%, 26%, and 20% the 30 kW, 65 kW, and 200 kW micro-turbines, respectively.
- This power depends on the conditions of the exhaust gases available from the micro-turbine as well as on the operating conditions and the composition of the organic working fluid in the ORC.
- Typically, dry or isentropic organic fluids are chosen because they do not need to be superheated to achieve acceptable waste heat recovery efficiencies.

In general, it was found that the MT-ORC is more beneficial than a Simple MT when the thermal requirements are low and thus is a good alternative for power generation.

V. The Future of Micro turbines

Existing micro-turbine systems range in size from 25 to 80 kW. The future products may be up to 500 kW or even 1000 kW. Research is also being carried out in the range <25 kW (e.g. 1 kW, 10 kW). Turbec, a multinational in Sweden is developing a product with an output from 100 kWe. Turbec was formed in 1998 and is joint venture between ABB and Volvo. The company's base product is the T100, a 100 kWe cogeneration unit using a Volvo engine and Bowman alternator and electronics.

Micro-turbo, a multinational in France, is working on a project to study, define and test the most critical and innovative components to be further integrated in a high efficiency, low cost and low emission, and small gas turbine CHP system. The most critical components of the high-efficiency gas turbine system, in the power range from 200 up to 350 kW are: the high-efficiency aerodynamic components of the advanced, inter-cooled, recuperated gas turbine; the heat exchanger recuperator; the catalytic combustor; and the integrated, into the turbo-machinery shaft High-Speed Alternator (HAS) for cost reduction. The development of the major critical components of an efficient, innovative, small gas turbine CHP system will create an improved combined heating and power system. The more efficient thermodynamic gas turbine cycle, which will increase the efficiency of the small gas turbine from between 20% and 25% to more than 35%, will produce a reduction of more than 10% in CO2 emissions. The innovative catalytic combustor, which is one of the main developments, is an effective way to reduce the emission of pollutants (NOx and CO) to a level which will be required in the near future (one digit emission level). It will also enable low heating value fuels issued from biomass (biogas) to be effectively burnt.

In the US, three manufacturers made commitments to enter the micro-turbine market. Capstone has a 30 kW product, Elliott has 45 and 80 kW products, and Northern Research and Engineering Company will have several products in the 30 to 250 kW size range. The targets for small gas turbines are efficiencies above 35% and designs for the use of fuels with less than 25% heating value of that of natural gas.

The future of the technology in India depends mainly on three barriers: capital costs, regulation and availability of natural gas. In India, the initial markets are likely for cogeneration and premium power i.e. the uninterrupted power systems. Only when the economics is favorable such as government regulation, the micro turbine technology will penetrate the mass market for backup power as an alternative to diesel gensets. This change can be expected from statistics of the NTPC more so because of abundance of natural gas. India has 527 trillion cubic feet of shale gas which will last for another 200 years and has 38 trillion cubic feet of proven shale gas which will last for 29 years as per a US report. The U.S based Capstone in 2005 deployed Biogas-Fueled C30 micro turbines in West Bengal to generate power using a micro grid system. The CHP setting will allow a dairy company to utilize all the thermal energy and one third of the power. The remaining will be sent to a nearby village. A company called Turbo Tech India based in Bangalore is one of the first indigenous companies to manufacture micro turbines for small scale power generation in India.

VI. Conclusions

Micro turbines presently are a state of the art technology that are expected to play a major role in the DG sector mainly due to their relatively small size, low operations and maintenance costs and relatively low capital costs. Also the current development programs include micro turbines from a power output of 30 -250 kW. The advantages of incorporating this technology are innumerable such as high power to weight ratio leading to reduced fabrication costs, lower noise and vibration levels, lesser moving parts, relatively low NOx emissions, multi fuel capabilities and low use of lubricating oil which reduces the possibility of maintenance and lubrication. However, the drawbacks of the MTs such as lower efficiency as compared to the reciprocating engines and reduced efficiency at part loads have to be addressed as well if micro turbines are to be sought as a successful alternative for small scale power generation.

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