Microturbines

Lecture #9

- Microturbines were developed by the industry through improvements in auxiliary power units originally designed for aircrafts and helicopters and customized for customer-site electric user applications.
- Microturbines from 30 kW to 400 kW were designed for small scale distributed power either for only electrical power generation or in distributed electrical power generation or in combined cooling or heat and power (CCHP) systems.
- Microturbines can burn a variety of fuels including natural gas, gasoline, diesel, kerosene, naphtha, alcohol, propane, methane or digester gas. The majority of commercial devices presently available use natural gas as the primary fuel.

Microturbine Advantages

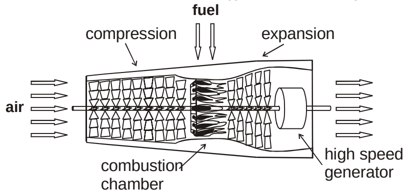
- Very low weight per horsepower, resulting in light generator sets;
- Pure rotary motion as opposed to stroking, resulting in less vibration, low noise when compared to diesel generators, high mechanical performance and very high reliability;
- No need of liquid cooling system required;
- Some microturbine run on air bearings with very low maintenance;
- Very fast response to load variation since they do not need to build up pressure such as in steam turbines or have high momentum such as in reciprocating engines;
- Operate on a variety of fuels;
- Combustion usually runs on excess of air, resulting on very low emissions, and
- Even low power microturbines can provide recoverable heat for water and space heating, the larger units can even be used for industrial purposes or for combined cycle with other turbines.

Most Typical Applications

- Peak shaving and base load power (grid parallel);
- Combined heat and power;
- Stand-alone power;
- Backup/standby power;
- Ride-through connection;
- Primary power with grid as backup;
- Microgrid.

Principles of Operation

- From left to right there is a compressor, then a combustor, a turbine, and a generator sharing the same shaft.
- An auxiliary machine initially starts the whole process by spinning the turbine shaft to introduce air compressed by the blades. The air is then mixed with fuel gas and passed into the combustion chamber of the turbine.
- This mixture is compressed to a point of continuous combustion which drives the set of blades indicated on the right side of the shaft, increasing the speed of the shaft which in turn, admits more incoming air and fuel gas. A high-speed generator is connected on the shaft, which converts this mechanical energy into electricity.



- The combustion assembly might include a single or multiple combustors. The combustion chamber is a reacting system, i.e. a chemical reaction takes place. In the combustion chamber heat is added to the gas at a constant pressure. The density decreases and the specific volume and temperature are increased.
- The combustion chamber takes the internal energy of the fuel, mixes the burning fuel with air at constant pressure and increases the temperature.
- Usually natural gas is used as fuel source. The best natural gas input should also be at 80 psig or higher pressure. As the gas pipeline gets closer to the customers, a regulator station reduces the pressure in the pipeline to about 60 psi or less. Therefore, a pre-compression of natural gas can be required for microturbines.

- The expansion turbine is the power-producing element of the overall set. It consists of turbine wheels each of greater diameter than the previous one. Work is extracted from the hot gas by letting it expand.
- The generator is typically a high-speed permanent magnet machine. The air leaves the turbine through the exhaust outlet. Although the operation seems simple, it must be designed and tailored to the turbine to have the correct speed and pressure combination to avoid back pressure and optimize the overall performance.
- The exhaust gases can be used in process heating applications, or can be used indirectly, with a heat exchanger to produce hot water. Typically microturbines for distributed generation do not operate at very high temperatures, so no steam is produced though large gas turbines can produce steam and may be coupled and combined with other cycles.

- All gas turbines use the same energy source, i.e. an expanding, high-pressure gas produced by the combustion of mixed fossil fuel and air.
- This mixture has the same physical properties regardless of the size of the gas turbine. Therefore, the tips of the turbine blades must move at a speed appropriate to capture the energy from this expanding gas. This means that large size utility turbines with 2.5 meters wheels will spin at 1,800 or 3,600 rpm while smaller turbine with wheels of only 0.15 meters in diameter will have a much higher rotational speed, up to 100,000 rpm.

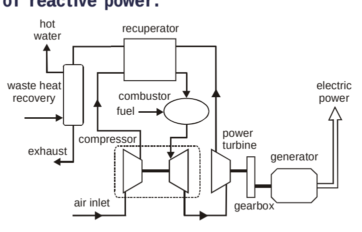
- The control structure of a microturbine will depend whether the unit has either a single- or two-shaft structure.
- The physical arrangement of a microturbine can be used for classification, for example, if they are single-shaft or two-shaft, simple cycle or recovered, inter-cooled or reheated.
- Unrecovered turbines have the compressed air 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 lower capital costs, higher reliability, and more heat available for cogeneration applications than recuperated units.
- Recuperated units use a 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.
- Efficiency gains can be achieved with materials like ceramics, which allow a significant increase in the engine operating temperature.

Principles in Establishing the Control Approach for a Microturbine

- At steady state, the power of the natural gas combustion and air into the turbine is ideally equal to the electrical power removed from the generator. The speed of the generator and turbine is not critical, as the output sinusoids from the generator are rectified. The dc link voltage needs to be supported to ensure that conservation of the power requirements are met. This operation requires good speed control of the turbine.
- During a load transient, the change in power is taken from the rotor speed of the microturbine. However, because these devices are small, there is very little stored energy in the rotating masses and the rotor speed changes very quickly. The speed control of the microturbine sees this speed change and corrects the rate at which the fuel is supplied to the microturbine, correcting the speed until the set point is achieved. The speed of a microturbine needs to be changed quickly to ensure that the generator does not stall. In this manner, the turbine generator set is capable of load tracking.

Split-shaft Microturbine System

- The split-shaft design has a power wheel on a separate shaft and transfers its output to a conventional generator via a gear reducer.
- This system philosophy employs the same technology of the two-pole generator sets running at 3600 rpm or may use an induction generator with a static VAR compensator to assist as source of reactive power.

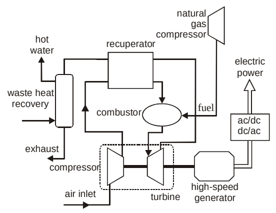


Split-shaft Microturbine System – Cont.

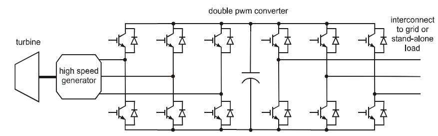
- This is a proven robust scheme and although manufacturers claim it does not need power electronics it requires synchronizing equipment and relays for connection to the electric grid.
- The gear reducer requires maintenance along with the lubrication system. There are two turbines, one is a gasifier turbine driving a compressor and another is a free power.
- In conventional power plants, a two-pole permanent magnet generator is driven via a gearbox, running at constant speed, since it is synchronized to the electric network.

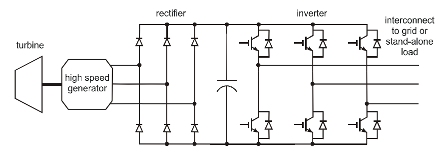
Single-shaft Microturbine System

- **The main input to the regulator is an electric power reference, i.e. the amount of electric power the generator should produce. The main output of a regulator is the fuel rate, i.e. how much fuel will be injected in the combustion chamber. There is a maximum value, with the fuel valves fully open and a minimum value, when the valves are open just to keep the flame alive.**



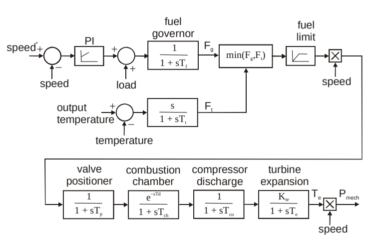
Power Electronic Topologies for PM Generators Used in Microturbines





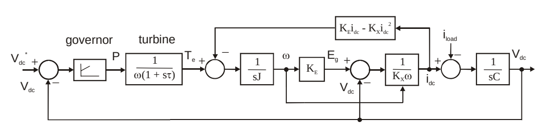
Modeling

- **From speed to mechanical power delivery**



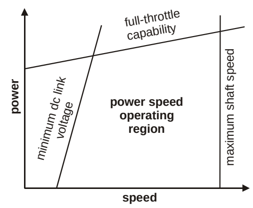
Modeling

- **Combined electromechanical model for a microturbine system**

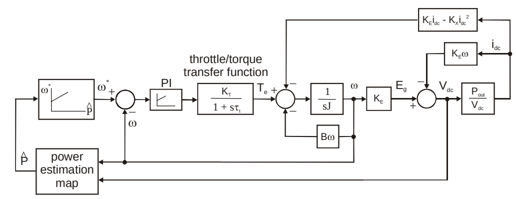


Modeling

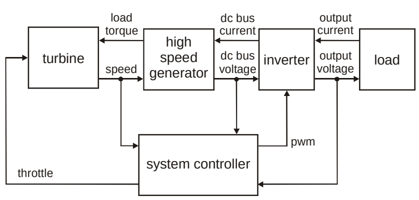
- **Constraints on power and speed of a microturbine**



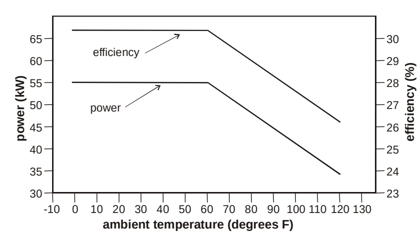
Direct Self Control of a Microturbine



System Control of a Microturbine and Output Inverter



Power, Efficiency in terms of Ambient Temperature



Site Assessment

- Microturbine capital costs currently range from $700-$1,100/kW including all hardware, software, and initial training.
- Adding heat recovery increases the cost by $75-$350/kW. Installation costs vary significantly by location but generally add 30-50% to the total installed cost.
- Microturbine manufacturers are targeting a future cost below $650/kW. This appears to be feasible if the market expands and sales volumes increase. With fewer moving parts, microturbine vendors hope the units can provide higher reliability than conventional reciprocating engine generator technologies.
- Most manufacturers are targeting maintenance intervals of 5,000-8,000 hours. Maintenance costs for microturbine units are still based on forecasts with minimal real-life situations. Estimates range from $0.005-$0.016 per kWh, which would be comparable to that for small reciprocating engine systems.

Site Assessment

- Placement of microturbines is critical to avoid piping and wiring costs. Therefore, ideal locations are near those already existing emergency diesel generators, boiler rooms with available connectivity to natural gas, electricity, and hot water. Often outdoor installations are more cost-effective because audible noise are typically on the level of 70 dBA at 100 meters and it is probably convenient to find an outdoor place in the building with easy connections to exhaust and fresh air ducting and close to the utility connections.
- Typical microturbine power and heat output efficiencies for power generation are at around 30% at the moment. The electrical efficiency falls to about half of that when the recuperator bypass is engaged. In this case, the overall thermal efficiency may rise to about 80%. The exhaust gas temperature is typically about 260°C while using the recuperator and 870°C with the recuperator bypassed. Not all of this heat can be effectively transformed into useful energy. For example, the Capstone microturbine can produce hot water at about 90°C when joined with a CHP heat recovery unit.

Questions?