SOLAR HYBRID STEAM INJECTION GAS TURBINE
(STIG) CYCLE

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by

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Abstract

The Steam Injection Gas turbine (STIG) cycle offers a way to use steam at a low temperature matching the gas turbine pressure, in order to augment the power output of the turbine. In conventional STIG, the gas turbine exhaust stream heats water in a heat recovery steam generator (HRSG), and the steam is injected into the combustion chamber. The flow rate of steam is limited by the amount of thermal energy available from the turbine exhaust, typically up to 10% of the compressor flow rate. The solar augmentation of a STIG cycle, using solar concentrators, generates steam in much larger amounts compared to the natural limit of the HRSG in the conventional STIG. In a conventional STIG the sensible heat from the turbine exhaust is used for evaporation, leading to a thermodynamic irreversibility and loss of work potential due to the pinch point problem. In the proposed solar STIG, solar heat is used for evaporation, and the gas turbine exhaust is used primarily for the superheat and economizer sections.

The solar steam should match the turbine pressure, typically in the range of 10—30 bar, leading to saturated steam temperatures of 180—234°C. Solar concentrating collectors for such an application can be simpler and less expensive than collectors used for current solar power plants. We performed a thermodynamic analysis of this hybrid cycle. High levels of steam-to-air ratio were investigated, leading to high power augmentation compared to the simple cycle and to conventional STIG. The peak performance Solar Fraction can reach up to 50% at the highest augmentation levels. The peak overall conversion efficiency from heat to electricity (average over fuel and solar contributions) can be in the range of 40–55% for typical candidate turbines. The peak incremental efficiency (corresponding to the added steam beyond conventional STIG) was in the range of 22–37%, corresponding to peak solar-to-electricity efficiency of about 15–24%, similar to and even exceeding current solar power plants using higher temperature collectors.

The cycle’s water consumption was derived and compared to other power plant technologies. The analysis shows that the water consumption of the cycle is negative due to water production by combustion, in contrast to other solar power plants that have positive water consumption. The size of the needed condenser is large, and a very low cost condenser technology is required to make water recovery in the solar STIG cycle technically and economically feasible.

An annual analysis of the Solar STIG cycle is presented for two sites with moderate and high annual DNI, under two scenarios: Constant power with a varying Solar Fraction (SF), and variable power with a nearly constant SF. Results show typical annual SF in the range of 8-40%, considerably higher than current hybrid solar technologies. The annual solar to electricity efficiency of 15-17%, is similar to the annual efficiency of current parabolic trough plants that operate at much higher pressure and temperature. The variable power scenario improves the SF with only a minor decrease in efficiency.

The CO2 emissions of the cycle were studied in both the peak and annual performance. The results have shown the CO2 emission to be lower or comparable to the combined cycle, and comparable to other hybrid solar technologies such as the ISCC.