AN ASSESSMENT OF HIGH EFFICIENCY COGENERATION, BASED ON ACTUAL OPERATIONAL DATA

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Overview

Cogeneration (or "Combined Heat and Power", CHP). is spreading worldwide more and more. One of the causes of such a success are, of course, the incentives granted by many States, which have at last acknoledged the importance of this technology for the overall energy efficiency.

It is then natural to wonder which of the technologies available for electricity production are best suited to be employed in cogeneration: the answer to this question may provide guidance both to installation designers who have to choose a technology for a specific application, and to policy makers who are responsible for allocating public subsidies.

Methods

More than two thousand generating units, of different technologies (gas turbines, internal combustion engines, steam turbines etc.) were analysed. For each generating unit, "real life" operation data were collected for years 2011 to 2019; based on those data, a few efficiency indicators were calculated as weighted averages. Indicators include: electric efficiency; thermal efficiency; overall efficiency; Power to Heat Ratio (PTOH); Primary Energy Savings index (PES); equivalent operation hours (Heq); load factor.

Electric efficiency is the ratio of electricity produced by the CHP unit in a given year to energy (fuel) consumed to do so.

Thermal efficiency, on the other hand, is the ratio of heat produced by the CHP unit in a given year to energy (fuel) consumed to do so.

Overall efficiency is the sum of the above efficiencies.

Power to Heat Ratio (PTOH) is the ratio of electricity to useful heat, produced by a CHP unit in a given year.

A CHP unit with a high PTOH produces a larger amount of "valuable" energy (electricity) than a unit with a lower PTOH.

A high PTOH indicates that the heat carrier (e.g., steam) was exploited efficiently, as it produced a significant amount of electricity before being further used for thermal purposes.

Primary Energy Savings index, or PES, is an estimate of the amount of fuel that was saved by producing electricity anh heat jointly, as compared to producing them separately.

Heq is the number of hours during which a given generating unit would have been in operation, if it had constantly been kept at maximum load. For each generating unit, the equivalent operating hours (Heq) have been calculated by dividing the annual electricity production by the unit power.

Heq was in turn divided by the actual yearly operating hours (Heff), where available. This yielded the "load factor" (Fc), always less than one.

Statistical correlation among indicators was also investigated for each technology; this includes, i.a.:

- correlation between equivalent operation hours and electric efficiency;
- correlation between equivalent operating hours (Heq) and load factor (Fc);

- correlation between electric efficiency and thermal efficiency.

Results

Internal Combustion Engine (ICE) has, of all technologies, the highest Power to Heat Ratio (PTOH) and electric efficiency. Furthermore, electric efficiency is not significantly dependent on the year of commissioning.

The high value of load factor Fc, together with a low Heq, suggests that ICEs can be -and are- started and stopped rapidly, which keeps the duration of partial load operation very short. In particular, micro ICEs show a very strong, inverse relationship between electrical efficiency and thermal efficiency: this suggests that the amount of heat wasted is low.

Unlike ICEs, gas turbines have an excellent overall efficiency, but a rather low electric one. This seems to be an intrinsic characteristic of these turbines, since the electric efficiency does not depend significantly on the equivalent operating hours (Heq).

PTOH, too, is lower for gas turbines than for IECs.

Gas turbines also seem to have reached technological maturity: electric efficiency is virtually independent of commissioning year.

Steam turbines feature lower efficiencies and PTOH, and tend to suffer from load variations: the small-scale ones show a strong direct correlation between equivalent operating hours (Heq) and electric efficiency. This is consistent, incidentally, with another strong direct correlation: that between load factor (Fc) and equivalent operating hours (Heq). Apparently, frequent starts and stops (which are the most probable cause of low Heq) are associated with low load.

Conclusions

Internal Combustion Engine appears to be the technology which is best suited for high efficiency cogeneration: it is able to continuously adjust to heat load variations, while maintaining high PTOHs and efficiencies (although low power ICEs tend to perform better on the overall efficiency than on the electric one). ICE is to be regarded as a mature technology by now, as it shows no significant increase of electric efficiency since 2011 (micro ICEs even show a slight decrease).

Statistical analysis confirms that the amount of heat wasted is low in all operational conditions; this is yet another proof of overall high performance for this technology.

Gas turbines are somehow less performant: they reach lower electric efficiency and Power to Heat Ratio PTOH. No efficiency improvement is to be expected from a more regular operation, or from technological progress.

Steam turbines are less than satisfying, due to their low efficiencies and PTOH, and poor aptitude to variable load operation. Statistical analysis shows that frequent starts and stops may hinder the full exploitation of the turbine (low load factor Fc). This suggest (or confirms) that steam turbines need long times to reach full load after start up, which is an evident operational drawback as compared to gas turbines or internal combustion engines.