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TITLE: Metrology For Improved Power Plant Efficiency

Abstract

Guiding principles of the European energy and climate policy are security of supply, economic efficiency and environmental protection. As electric energy cannot be stored in significant amounts it has to be generated at the time of use. Consequently, a mix of so-called basic, medium and peak load power plants is necessary in order to balance consumption and production. Although an increase in the contribution of renewable energy is necessary and a matter of high priority, large scale power plants, which currently provide around 40% of generated electricity, will continue to play an important role within this mix and will remain indispensable for the next few decades. It is therefore of outstanding importance to increase the energy efficiency of such power plants by improved thermal, flow, dimensional, mechanical and electrical metrology often in hostile environments.

Joint Research Projects (JRPs) submitted for this topic should aim to address the development of reliable and accurate in-situ temperature, thermophysical, and mechanical properties, and flow rate measurements for improving power plant efficiency, plus on-site measurement of electrical power output of generating plants.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP 2008[i], section on "*Grand Challenges"* related to *Energy* on pages 8 and 23.

Keywords

Energy efficiency; power plants (fossil, nuclear); gas turbines; energy distribution networks; on-line temperature and flow rate measurements; modelling of influence parameters; thermophysical and mechanical properties; dimensional measurements; on-site electrical energy measurement; sampling; fluid dynamics.

Background to the Metrological Challenges

The need to improve energy efficiency and reduce energy consumption is recognised in a number of European Directives (e.g. 2006/32/EC: Directive on the promotion of End-use efficiency and Energy Services [1]) and national government policies dealing with energy (e.g. "National Energy Efficiency Action Plan [2]" of the German government). The European Commission's Policy on Energy Efficiency [3] shows the importance of this goal and how the EU is promoting efficiency. Across Europe industry has a common problem of how to measure, with meaningful accuracy, energy loss and identify process improvements within a defined budget and production constraints.

In Europe steam power plants are an important source of electricity generation and whilst a considerable number of them are due for replacement during the next decade, even with anticipated increased use of renewable energy sources, it is generally expected that in 2020 around 40 % of electricity will still be produced by conventional power plants [4]. The average efficiency of steam power plants across Europe is 36 %, and up to 46 % for the most modern ones. By increasing the steam temperature of the next-generation power plants from the current 540-600 °C to 700 °C an improvement in efficiency to around 50 % is possible, resulting in CO_2 reductions per MWh of generated electricity of about 25 % [5]. To increase the efficiency of gas turbines to above 60 % an increase of the typical gas inlet temperature from currently 1300 °C to 1500 °C is necessary [6]. Across the whole world the situation is even more demanding with the mean efficiency of coal power plants of around 30 %. Typically 0.48 kg coal is necessary to produce one kilowatt hour and this is associated by an emission of about 1.116 kg CO_2. For a 700 °C power plant operating at 50 – 55% % efficiency the required coal consumption could be reduced to about 0.288 kg coal with a resulting emission of 669 kg CO_2 [7]. Overall, for a typical coal power plant a 1 % increase in efficiency will reduce the coal consumption by $16x10^6$ kg per year reducing the CO_2 emission by 43 $x10^6$ kg per year [8].

Improving the efficiency of conventional power plants raises a number of significant metrological challenges.

Temperature measurement
Thermometers used in power plants or in thermal energy distribution networks are not and cannot be calibrated directly, as the operation conditions (e.g. flow-rates up to 5000 m³/h, temperatures at least 280 °C to above 1500 °C, pressures up to 25 MPa) are and will not be realized in any calibration laboratory in the world. The challenge lies in establishing metrologically sound and accepted models of the influence of process conditions on temperature metering with the aim to reduce the uncertainty from 3 °C to 1 °C and a further important challenge is the development of drift free (<1 K/year) and vibration-resistant temperature sensors for use at these operating temperatures.

For a future hard coal power plant the requirements to the control system will be (5-7) % power change within one minute for the secondary load control and up to 10 % within 10 s for the primary control. This requires considerable effort to optimise the positioning, contacting and the dynamic behaviour of the temperature sensors.

A further aim is an optimised dynamic “two-shifting” behaviour of a power plant in order to compensate for power-grid loads. These grid loads are caused by both consumer behaviour as well as the increasing amount of power generation by renewable energy sources, e.g. wind or solar energy, which makes the power output inevitably dependant on weather conditions.

Thermophysical property measurement
Increasing the steam and gas temperatures requires novel materials with improved durability to thermal load and corrosion. Corrosion resistant and thermal barrier materials are essential for operation at temperatures up to 720 °C and water vapour pressures of about 35 MPa for steam power plants. To increase the efficiency of gas turbines to above 60 % an increase of the typical gas inlet temperature from currently 1300 °C to 1500 °C is necessary [6], which sets high demands on the thermal barrier protection materials, as this temperature is significantly higher than the melting temperatures of the base material. This requires improved measurement techniques to investigate flue gas corrosion and the high-temperature oxidation behaviour of the most promising Ni-based alloys and predict their

behaviour for working lifetimes of at least $2x10^5$ hours [9]. In addition the measurement of emissivity, which governs the radiative heat exchange with the environment, is exceedingly challenging at elevated temperatures.

Flow measurement
Energy flow normally equates to fluid flow at some point. Energy is generated by steam, transported as hydrocarbon fluid and consumed through heating and cooling fluids. Measurements are required within industry to quantify inefficiencies, measure improvements and to meet regulation. These measurements require to be carried out at extremes of viscosity, temperature, pressure, and on multiphase and multi component mixtures. Conditions are often outside the scope of conventional techniques and sensors. Measurement of energy flow has to encompass novel integration of sensors for flow, temperature, pressure, composition and fluid parameters operating in field and industrial conditions at economic cost.

The lack of precise flow rate measurements currently limits the efficiency of power plants and thermal energy distribution networks. For example, to fulfil safety regulations in nuclear power plants the permitted thermal power output is reduced to a value 2 % below the nominal maximum power to account for the uncertainty of 2 % of the flow rate measurements. Reducing the flow rate measurement uncertainties to 0.5 % would directly enhances the power output by the same amount. Additionally, for all types of power plants the uncertainties in flow rate measurements lead to non-perfect steering and control mechanisms. Recent studies indicate that efficiency enhancement due to optimized control and operation modes based on precise flow rate measurements sum up to an efficiency gain of approximately 2 %.

Flow meters used in power plants or in thermal energy distribution networks are not and cannot be calibrated directly, as the operation conditions (e.g. flow-rates up to 5000 m^3/h, temperatures at least 280 °C to above 1500 °C, pressures up to 20 MPa) are and will not be realized in any calibration laboratory in the world. The challenge lies in establishing metrologically sound and accepted models of the influence of process conditions on flow metering with the aim to reduce the uncertainty of flow metering from around 2 % to approx. 0.5 %.

Dimensional and mechanical measurement
Beside the thermal effects, the dimensional and mechanical quality of the large gears within the turbine gearboxes used for power generation has an important influence on the efficiency in power transmission. In particular the pitch deviations are the main influencing factor and at present no economical method exists for the pitch calibration on large gears of such a high teeth number common in turbine gearboxes.

On-site electrical power output measurement
A final need relates to the actual determination of the effect of all measures taken to increase the efficiency of power plants via on-site measurements of the electrical power output of the plants. This is a significant challenge – at present the required traceable three-phase high voltage electrical power measurement is not available in Europe.

Scientific and Technological Objectives

Proposers should aim to address all of the stated objectives below. However where this is not feasible (i.e. due to budgetary or scientific / technical constraints) this should be clearly stated in the JRP protocol. The objectives are based around the PRT submissions from various institutes. As experts in the field, JRP proposers should establish the current state of the art, which may lead to amendments to the objectives - these should be justified in the JRP proposal.

- Develop reliable temperature and flow rate measurements for hostile environments in power plants
- Develop measurement techniques and tools for in-situ measurement and monitoring of thermal emission and other relevant thermal and thermophysical properties for improving power plant efficiency
- Reliable and accurate on-site measurement of electrical power output of generating plants

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the “end user” community (eg letters of support) is encouraged.

Where a European Directive is referenced in the proposal, the relevant paragraphs of the Directive identifying the need for the project should be quoted and referenced. It is not sufficient to quote the entire Directive per se as the rationale for the metrology need. Proposals must also clearly link the identified need in the Directive with the expected outputs from the project.

In your JRP submission please detail the impact that your proposed JRP will have on the following Directive of the European Commission:

“Energy end-use efficiency and energy services Directive” 2006/32/EC [1]

You should also detail other Impacts of your proposed JRP as detailed in the document “Guidance for writing a JRP”.

As this topic includes “in-situ” measurements direct cooperation with the power industry is essential. Please indicate how this interaction will be achieved to ensure their needs are addressed and that where appropriate and necessary access to in-situ testing can be obtained.

In response to the need for standardised measurement techniques you should detail how your JRP results are going to:

- Feed into the development of documentary standards and guidelines through CEN, other standards developing bodies or other appropriate bodies
- Transfer knowledge to the power generation industry, regulators and policy makers.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] Directive 2006/32/EC of the European Parliament and the Council of 5 April 2006 on energy end-use efficiency and energy services, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:114:0064:0064:EN:PDF

[2] Bundesministerium für Wirtschaft und Technologie (BMWi), November 2007, (http://www.bmwi.de/BMWi/Navigation/energie,did=223436.html)

[3] European Commission's Policy on Energy Efficiency, (http://ec.europa.eu/energy/efficiency/index_en.htm)

[4] Federal Ministry for the environment, nature conservation and nuclear safety, Germany, Neues Denken - Neue Energie Roadmap Energiepolitik 2020 (http://www.bmu.de/energieeffizienz/downloads/doc/43103.php)

[5] VGB PowerTech e. V; http://www.vgb.org/fue_projekt297.html

[6] US Department of Energy, Advanced turbine program

[7] VGB PowerTech e. V; Facts and Figures Electricity Generation 2008 (http://www.vgb.org/en/data_powergeneration.html)

[8] BINE Informationsdienst – Energieforschung für die Praxis, www.bine.info basis Energie 17 ISSN 1438-3802

[9] Siemens AG, (http://w1.siemens.com/annual/08/pool/04_produkte_loesungen/03_energy/03_fossil_power_generation/pof_energy_turbines.pdf)

[i] European Metrology Research Programme. Outline 2008 Edition - November 2008 http://www.euramet.org/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin/docs/EMRP-outline2008.pdf&t=1248796946&hash=9da9ceb781370f04c322ac48068deca5