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ENERGY MEASUREMENT AND STANDARDS – AN OVERVIEW

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Abstract: The establishment of a sustainable energy supply as well as of achieving efficient energy consumption furnish one of the grand challenges and technological mega trends of today and the decades to come. Energy research and development and even field measurements for novel and renewable energies, for transmission and distribution as well as for large-scale energy storage are significantly lacking in appropriate measurement technologies, measurement standards and traceability schemes. An overview is given on the most relevant open questions and challenges to metrology. The known approaches chosen are mentioned. Special attention is drawn to the current metrological research for energy in Europe.

Keywords: Energy measurement, energy efficiency, renewable energies, smart grid, grid reconstruction.

1. INTRODUCTION

Today, humankind faces a steadily increasing consumption of fossil energy along with decreasing resources, an evident anthropogenic climate change and often a depleted environment. Therefore, the development and establishment of a reliable, efficient and sustainable energy supply, transport and distribution that is significantly based on renewable energies as well as an efficient use/consumption including fair metering and billing have become one of the grand challenges to humankind of today and the foreseeable future. Since the Fukushima nuclear power-station disaster in 2011, public opinion and political pressure on energy suppliers and traders towards a fast energy turnaround which is predominantly based on *renewable energies* and will overcome (over the long term) the nuclear era have even increased significantly.

But the exploitation of renewable energies, such as, for example, wind-power and solar energy, is at its very beginning. The same statement applies for electric energy transportation via *High-Voltage-Direct-Current* power lines and distribution by *Smart Grids*. Additionally, an efficient use of energy including savings by promoting energy-efficient buildings and *Green Production* possess high potential for getting through to sustainability. Last but not least, increasing the efficiency of conventional and nuclear power plants requires new technologies and materials that are not yet available or tested.

Almost all fields of energy research and development and even of field measurement are significantly lacking in appropriate measurement technologies, future strategies, measurement standards and traceability schemes.

2. OVERVIEW ON RELEVANT AIMS AND THE RELATED MEASUREMENT CHALLENGES

Practically, the overview is arranged in accordance to the so-called *energy chain* that is comprised of the following components:

- *Energy production/generation* (i.e. transformation of the primarily available energy, e.g. of chemical energy of natural gas, into electrical energy and/or heat)
- *Energy transport and distribution* (it includes necessary energy transformations, e.g. to a different voltage or pressure level)
- *Energy storage* (it includes necessary energy transformations, e.g. from electrical to chemical or mechanical energy)
- *Energy consumption and savings* (i.e. energy transformation to effective and dissipative energy, e.g. from electrical to mechanical energy and heat).

Additionally, measurement and metrology are requested to develop measurement solutions and establish traceability for *E-Mobility* and transaction energy as part of a future integrated (and smart) energy system.

The overview is graphically illustrated with Figure 1.

2.1 Energy production/generation

Research and development in energy production is mainly striving for significantly higher efficiency of both, conventional power plants and renewable energy generation as well as for sustainability (reducing the dependency on fossil energy, dropping the emission of *Green-House Gases* and of arising waste, ensuring the economical and considerate exploitation of land and other resources). But a stable and reliable supply must be guaranteed.

Therefore, for conventional power plants, novel converter technologies based on new and high-temperature-capable materials are to be developed. The planning and operation of wind-power and solar-energy parks requires knowing exactly the effectiveness depending on all relevant influences and other parameters.

Thus, measurement and metrology are challenged to provide the material properties for generators and safety-relevant facilities, low-uncertainty process and control parameters, the energetic and transportation properties of fuel and the conversion characteristics of renewable-energy generators. Furthermore, for portable electronic devices,

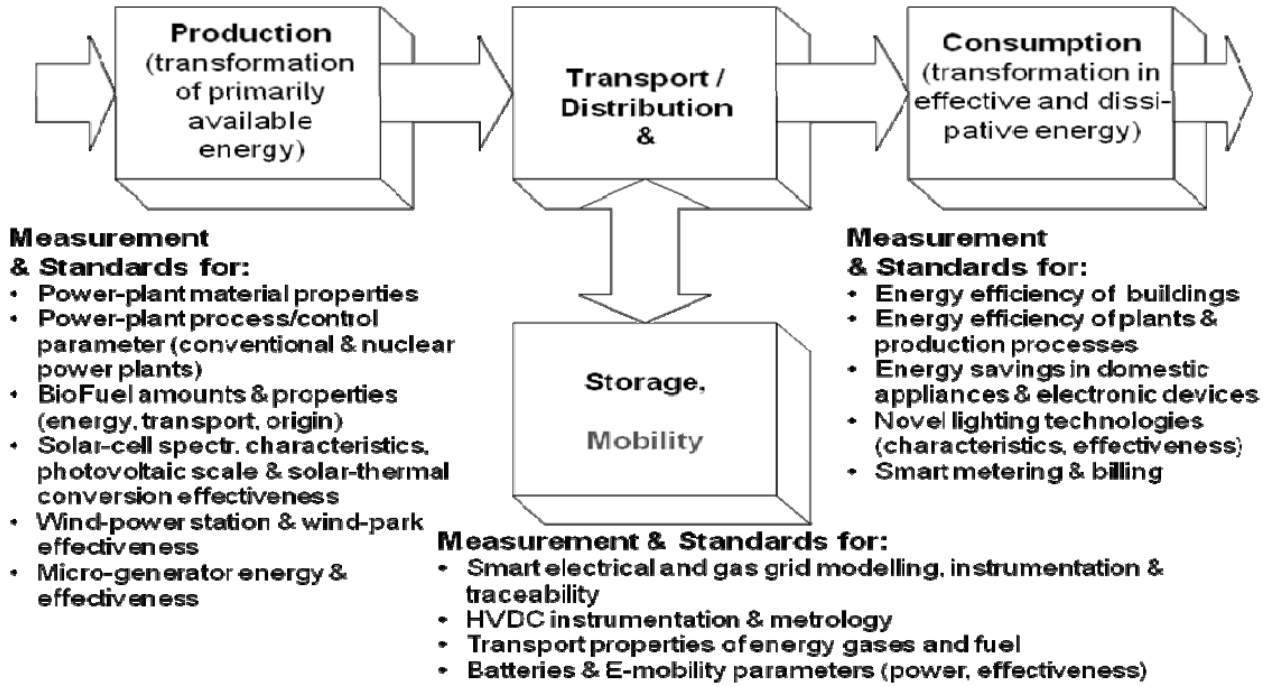

Fig. 1: "Energy chain along with related measurement and metrology challenges – an overview

the capability for correct measurement of the generated electrical energy by novel micro generators (energy harvesting) is to be developed.

Liquid fuel (see also 2.4): Conventional fuels are usually refined from mineral oil. Because of the gap between the foreseeable exhausting oil deposit resources and the increasing fuel demand in the so-called transition countries, to an increasing extend *BioFuels* are produced and utilized. Due to the potential competition with food-stock production and the use of cheap rain-forest areas, this is not problem-free. It challenges measurement and metrology not only to provide reliable energy and transport data but also to provide metrological prove of the source of origin and the compatibility with the facilities and mobiles it is intended to be used for.

BioGases: BioGases are mainly produced from bio-waste/biomass. Thus they do not compete with the food stock. BioGas production requires to a variety of parameters very accurate: methane loss in the production phase, effectiveness of the production plant as well as the energy content and the composition of the gas (gas quality) that is fed to the grid.

Fig. 2: Bio Gas production plant on a German farm

2.2 Energy transport and distribution

Electrical energy: On the large-scale level of electrical power transmission (high-voltage direct-current power transmission, HVDC), complete new technologies (see Fig. 3) are to be developed, including for traceable power measurement at transfer stations.

Fig. 3: Illustration: HVDC technology (Source: Siemens)

The combination of conventional and nuclear large-scale power stations with wind and solar energy requires a "smart"-controlled grid (see Fig. 4) based on accurate and comparable input data. Furthermore, due to the fact that to an increasing extend large-scale electrical drives are combined with thyristor-activation control systems, power quality as well as its measurement and its influence on other measurements has become an important issue.

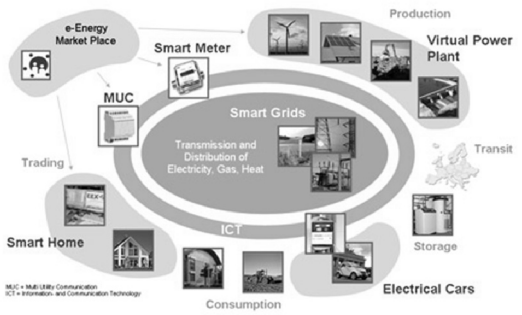

Fig. 4: Illustration of a Smart Electrical Grid (Source RWE)

Transport and distribution of energy gases: Energy gases are usually sold in relation to the energy content delivered. Due to various gas qualities fed in temporal changing amounts into the grid (different origins: North Sea, Russia, other countries, BioGas, LNG) and the operation of usually "under-instrumented" gas distribution grids, necessarily the gas quality delivered to the individual customers must be mathematically reconstructed in a metrological correct way from the gas quality and flow data available (see Fig. 5).

2.3 Energy consumption and savings

In the private sector, the field of energy consumption and savings is comprised of developing energy-efficient buildings concepts, domestic appliances as well as of fair and correct metering and billing of the effectively consumed energy amount. Additionally it includes individual mobility

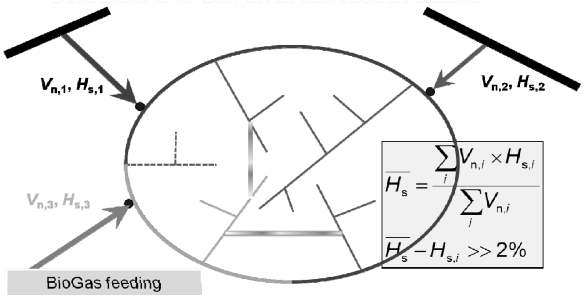

Fig. 5: Distribution of BioGas in the Grid in winter time illustrates the problem of various gas compositions and qualities delivered, Vn,1+Vn,2 = 400 ...19 000 m3, Vn,3= 500 m3; Hs,1= Hs,2= 10,5 kWH/m3; Hs,3= 9,5 kWh/m3 (Source: PTB)

(see 2.2 (liquid fuels) and 2.4). Measurement technology is requested to both guarantee accurate on-site measurements and to take care of data safety and reliability. Metrology has to provide the relevant material data and to establish appropriate traceability schemes.

In industry, the efficiency of production processes including the raw materials and semi-finished products used (energy balance, carbon-dioxide balance, *Green/Sustainable Production*) is made measurable and verifiable. Appropriate procedures should be developed and provided.

For both, the private sector and for industry and public, the development and the use of novel energy-saving lighting technologies, such as, for example OLED technology, offer high saving potentials. But their characteristics and the brightness perceived differ from conventional means. This requires a new approach to their metrological evaluation.

2.4 Energy storage and mobility

Large-scale electrical energy storage: Especially countries and economies with a high fraction of renewable energies (solar and wind energy) have an increasing demand for large-scale energy storage, e.g. by means of pump storage stations. Alternative solutions for regions which do not possess the topographical prerequisites are still missing. Nevertheless, efficiency and easy accessibility of energy storage stations along with correct metering of inbound and outbound energy is required.

Batteries and fuel cells: The main reason for the currently booming research activities in the field of batteries, especially Li-Ion-Batteries, is the intended use in the E-Mobility area. Still this requires much fundamental research in metrology in electrochemistry that can provide relevant contributions to further progress (fundamental properties of substance and of thermo- dynamical relationships, correct measurements of remaining capacities and other relevant properties). Additionally, safety of batteries and fuel cell is a relevant issue.

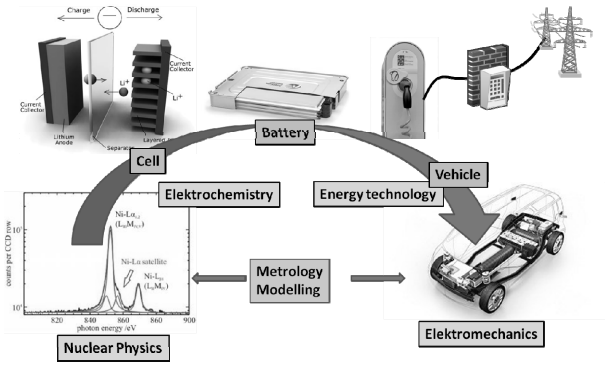

Fig. 6: Metrology may contribute significantly to further development of high-performing batteries in E-Mobility (Source: PTB)

Liquid fuels for mobility: Even electric cars of the future will need so-called range extenders for long-distance drives and cruises that will be based on liquid or liquefied fuels. For the related metrological challenges see 2.2. For "conventionally" driven cars, correct measurement of exhaust gases and particles remains an important metrological task.

Energy-supply and distribution approaches facilitating E-Mobility: The supply grid or loading infrastructure for the future E-Mobility system certainly will be part of the regional or national electrical smart grids. Therefore, similar challenges to measurement and metrology do exist. Furthermore, for electric cars, fast "refuelling" and "rolling-car-refuelling" solutions including appropriate metering will be needed in future (see Fig.4).

Metering of transaction energy: Especially long-distance trains used on cross-national lines have to be equipped with

Fig. 7: Illustration: Fast electrical "refuelling" is an indispensable prerequisite for successful E-Mobility concepts

traceable on-board metering devices for determining the consumed transaction energy, along with remote reading facilities enabling automatic billing.

Fig. 8: Illustration: Electricity metering on rolling stocks is the key to facilitate "fuelling" European High-Speed Trains during their international trips through the continent [2]

3. CURRENT EUROPEAN METROLOGICAL RESEARCH ACTIVITIES

Relevant European metrological research activities are mainly carried out within the targeted programme "Metrology for Energy" within the EMRP [1]. In particular, it is comprised of the following projects:

- Characterization of energy gases [2]
- Metrology for energy harvesting [2]
- Metrology for liquefied natural gas [2]
- Metrology for smart electrical grids [2]
- Metrology for solid-state lighting [2]
- Metrology for improved power-plant efficiency [2]
- Metrology for High-voltage direct current [2]
- Metrology for new generation of nuclear power plants [2]
- Metrology for biofuels [2]
- Emerging requirements for measuring pollutants from automotive exhaust emissions [3].

Furthermore, there are relevant national metrological activities in the following areas:

- Metrology for wind-power stations (PTB) [4]
- Model-based reconstruction of the energy content in under-instrumented gas distribution grids (PTB) [5]
- International photovoltaic scale (AIST, NREL, PTB, TIPS) [6].

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