Measurement Techniques in Power Engineering

Naim H. Afgan

MEASUREMENT TECHNIQUES IN POWER ENGINEERING

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Preface

Current methods for energy development focus on increasing the efficiency of existing power plants and the availability of power and also on designing new plants to operate at higher capacities and efficiencies. One of the best means of reaching this aim is by improving and upgrading the measurement and control systems of power plants. Within this framework, great effort has been focused recently on further development of measurement systems in order to achieve an increase in the availability of power and in the efficiency of power plants.

Modern thermal power stations can achieve better performance by either increasing their size or improving their fuel efficiency. Both of these routes are dependent on acquiring the necessary parameters for the efficient control of combustion, heat and mass transfer, and other physicochemical processes. In their further development, thermal power stations will use better and more sophisticated methods for determining the physical phenomena involved in scaling up the size and rating of power plants.

In many countries, nuclear power represents a substantial portion of the energy capability. The further development of nuclear power will depend on increasing the efficiency and improving the safety of this method, which are the main incentives for the development of appropriate measuring methods and techniques required for control and acquisition of the parameters of the system. In particular, emphasis must be given to the development of a system that will function even under the most severe conditions, such as might occur during an accident. Great effort is being devoted to better understand the heat and mass transfer problems (methods and techniques) related to the transient behavior of two-phase flow.

Fast breeder nuclear power plants are the next generation of energy systems that will play an important role in world energy strategy. Recent status reports on fast breeder reactor development have confirmed their main characteristics and parameters, while further engineering work to prove safety characteristics is still required. Because of the potential hazards posed by fast breeder reactors, a fast response to the main operational functioning of any part of the system is a key feature, and the measurement and control systems are of prime importance. In addition, the development of a measurement system for the fast breeder reactor needs further research and investigation of the physical phenomena relevant to the performance of the system. Because liquid metal is used as coolant for such energy systems, it is very important to have a detailed knowledge of the heat and mass transfer behavior of the liquid metal at both steady and transient conditions.

Direct conversion of thermal into electrical energy will remain the main goal in future development of energy systems. Within this scope the MHD conversion system is envisaged as the most promising. Parameters required to attain the plasma state of the working fluid place new requirements on the measurement and control systems. Since MHD power is presently in a trial state, the development of the respective diagnostic methods and techniques is one of the main targets. In particular, temperature, velocity, and concentration of the constituents are the necessary parameters for designing and operating the MHD system.

Solar energy is one of the most promising alternative energy systems for power generation in the pilot stage. Several solar power systems are under investigation and should prove to be both economic and reliable. Because the efficiency and availability of a solar energy system strongly depend on the performance of the solar collectors, it is very important to adopt standard procedures for testing the collectors. Recently, a number of testing procedures have been adopted that rely on the measuring and acquisition system. Specific requirements are given for the design of a measuring system in order to prove its adequacy for testing solar collectors. Further development of solar power systems depends on achieving a better measuring system together with other characteristics capable of satisfying specific requirements.

This book is a collection of lectures prepared for the Advanced Course organized by the International Centre for Heat and Mass Transfer on measurement in power engineering, held August 29–September 2, 1983, in Dubrovnik, Yugoslavia. It comprises reviews of the present status of measurement methods and techniques used in determining relevant parameters in several types of power systems and also those used in the research and development of individual systems. It should be emphasized that the faculty was composed of scientists and engineers most competent in the subject matter, with experience in the practical application and design of measuring and acquisition systems. The book is intended for engineers interested in the fundamentals and applications of modern measurement methods and techniques used in power engineering.

As the editor of this volume, I would like to express appreciation to my colleagues for their cooperation and willingness to prepare this material for publication in the present volume.

Naim Afgan

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Measurement Techniques in Power Engineering Development

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ABSTRACT

The modern power systems are strongly related to the adequate measuring and acquisition systems in order to achieve its high performance. Also their further developments are depending on the ability to project its improvement as well as the development of a new system. In reviewing design and research parameters relevant in the development of power engineering this paper covers recent thermal power system; nuclear power systems with thermal and fast breeder reactors, magnetohydrodynamic power system and solar power system. Two groups of parameters are considered: design parameter and research parameters. For each group respective methods are listed with specific features describing its main static and dynamic characteristics. This lecture is aimed to be an introduction to the Advanced Course an Measurement Techniques in Power Engineering which is designed to give a good background information for the scholars in the field of Heat and Mass Transfer as well as to teaching instruction for practicioners applying respective methods in the design and research in modern power systems.

1. INTRODUCTION

The need for commercial energy from the beginning of industrial development has been a constant driving force for the development of power engineering industries (1). With Watts invention of the steam engine, the requirement for vapor steam to be produced in the early version of Scoot-boilers has been a pioneer incentive in creating power engineering. Since that time, a constant effort has been devoted to the further development of power engineering. In this respect, thermal power engineering has played an important role. At the beginning, the conversion of primary energy resources, which are available in the form of hydrocarbons, had been the only thermal energy source used to produce commercial energy. At the very beginning of its development, power engineering relayed on the efficiency of energy transformation from its chemical form, as it comes from the earth, to the thermal, mechanical or electrical form as it is used nowadays. These transformation procedures and their efficiency have been the subject of attention for many years and Carnot was the first to recognize the importance and the means for the assesment of the quality of these transformations. With the powerful second law of thermodynamics we have learned that the availability of our energy resources could be increased by raising the upper limit of the thermodynamic parameters within the power system. Throughout its history, the power energy system has been constantly upgrading its performance by increasing the working parameters of the system. Also, the realiability of the system has been limited by the available structural materials which have posed the upper limit for our desire to increase the performance of the system by increasing its thermodynamic paramaters. In order to obtain a full advantage of the respective power energy system the immediate need was to develop an adequate measuring system for the acquisition of parameters which would enable us to measure the performance of the system. As the upper limit for the endurance of the structural materials has posed a boundary for the working parameters of the system, from the very beginning of power system development the necessity for the control and protection of the system from destructing its environment due to overriding these limitations, was realized. This was the second motiv for the development of the measuring system for the acquisition and control of the parameters. The thirs incentive for the development of measurement systems in power engineering was the need for the development of new power energy systems with better performance, larger in size and with new fuel.

Thermal power energy system efficiency is, according to Carnot, cycle efficiency determined by the temperature at which thermal energy is supplied to the working fluid for constant environment temperature. Fig.1 shows Carnot efficiency as a function of T_1. Constant increase in turbine inlet pressure and temperature has been a permanent goal of most of our efforts in the development of thermal power systems. Most modern power stations have achieved the maximum temperature in the cycle of $T_1 = 560^oC$ at the supercritical pressure of p = 240 barrs, with power production ranging at 300 - 800 MW. A close look to the engineering design of this power station will introduce us to the number of specific problem relevant to the acquisition and control systems of the plant. In the first place there is a need for reliable and accurate measurement methods for screening the respective parameters at any specific point within the system. It is obvious that the control of any parameter distribution within the system requires the respective space and time averaging procedure in order to be able to control the system as a whole, as well as to have insight in the performance of its individual parts. This became particularly important in the new modern thermal power station steam generator, where the furnace lateral dimension ranges in the tens of meters and with its height over a hundred meters, posing a new requirement to the determination of the flue gas temperature, concentration of the flue gases, radiation properties of flue gases and radiation heat flus on the furnace wall.

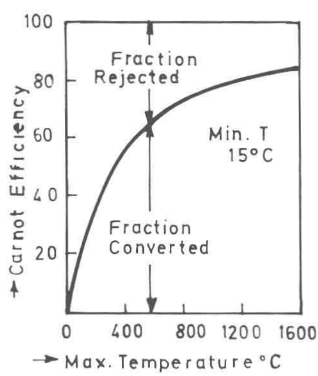

Fig.1 CARNOT EFFICIENCY

We are witnessing that nuclear energy is becoming one of the essential energy sources in power production. Through its development nuclear energy has proved to be an efficient and economic energy source. But its potential hazard to the environment has posed a large burden to engineering design in order to prove its safety through its lifetime. This has imposed a new role to the measurement system for the control of the vital parameters of the system. As the system has to be under control under all conditions, it is obvious that the measurement system has to be designed with specific requirements in order to satisfy safety criterions. In this respect the measurement system in the nuclear power plant has an important role in the general philosophy of nuclear reactor safety. Even the parameters of the system are not very high and its environment is rather mild, severe requirement for the reliability of the measuring system is the new feature not met before in the engineering practice. Inherent nuclear reactor power transient in the most severe accident is imposing specific design feature of the measuring system for any parameter of the system. If we have on mind that under this conditions it is required to have very low probability in failing do detect any transient it becomes very obvious that the designer of measuring system in nuclear power plant is at fundamental importance for the safety of the system.

The fast breeder reactor is the next generation of the nuclear power system. In particular, the liquid metal cooled fast breeder reactor is the most prestigious nuclear power system which will play an important role in the further development of the power energy systems. Since the safety of nuclear power system is the major limitation in its development it is particularly important for the liquid metal cooled fast breeder reactor with its inherent very high transient power trip, to design respective engineering system in order to prevent mall function operation. In this respect the measuring system in this type of reactor is one of the essential parts of the total system which has to be designed to meet respective requirements and criteria.

Even the solar system has not approuched a very high level in its use for power energy production, its importance for the total energy economy is becoming recently more pronounced. As a solar system has to be designed to collect very diluted solar energy,its high performance is one of the mile stones for its economic outcome. Particularly important is its acquisition of insolation data as well as the development of the respective procedure in testing and controling parameters of the system. For this reason a regular procedure which was to be followed in the performance test of any solar energy producting system has been adopted.

The direct conversion of thermal to electrical energy could result in increasing the efficiency of conversion becouse higher temperature can be used in the system with no moving parts. This method provides electrical power at a reduced cost. Magnetohydrodynamics (MHD) is one of the direct conversion system in which much interest has been shown for power generation. A hot conducting gas moves in a magnetic field through a duct equipped with electrodes between which the useful potential is developed. The achievement of adequate conductivity at a temperature consistent with long lives of duct and electrodes for ome of the main problems in

MHD. Recent development in this field has proved that some of the anticipated problems have been solved but further development is needed before it will become a standard power producting system. Special emphasis has been focused to the development of respective diagnostic methodes for the determination of essential parameters of the system. In this frame the most important parameters are: plasma temperature, velocity, concentration of seeds, electrical conductivity of plasma.

2. THERMAL POWER ENGINEERING

The Carnot efficiency of the Clausius - Ranklin cycle in thermal power stations is determined by the maximum pressure and temperature of working fluid. These are two parameters which have to be measured through all the system in order to maintain full control of the performance of the system. Fig.2 shows a typical thermal power station.

Modern thermal power stations have the maximum design steam temperature in the range of 560°C and pressure exceeding the level of 240 barrs. Heat flux of the heat transfer surface is around 50 W/cm^2 with flue gas temperature in the range of 1200°C depending on the fuel. The maximum power rating of modern thermal power boiler is about 1300 MW in liquid fuels and 800 MW in solid low

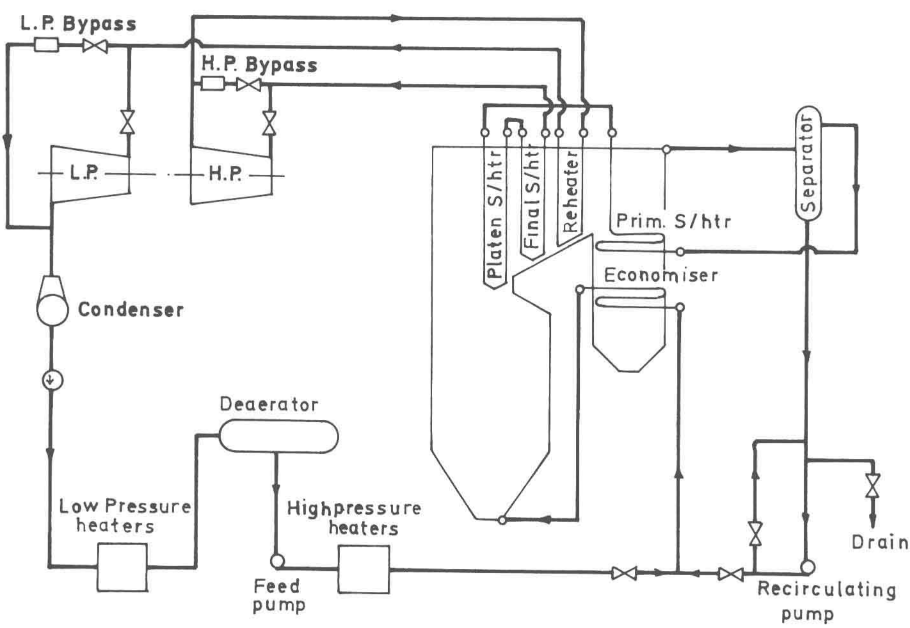

Fig. 2 THERMAL POWER PLANT

caloric fuels (Table 1). The recent development of the modern thermal station is focused to improve its control with the introduction of better controlled systems being capable of following as closely as possible the respective demand and at the same time ensuring an efficient performance of the plant. As the combustion process is the mile stone for efficient performance of modern thermal power stations it is obvious that the new design will also introduce a new concept in the control of the combustion process in the boiler (3, 4). The integration of the new control

Table 1. THERMAL POWER DESIGN PARAMETERS

Parameters	Steady state characteristics		Transient characteristics
	Performance range	Accuracy	Response time
Flue gas temperature	700-1200°C	$\pm$ 5°C	low
Excess air concentration	100-350 ppm	$\pm$ 0.2% F.S.	0,1 sec-200 min
Heat flux	0 - 50 W/cm^2	2% F.S.	0.01 sec
Steam temperature	0 -500°C	0.06-0.6°K	10 sec
Steam pressure	0 - 240 bars	0.25% F.S.	10 sec.

philosophy into the existing control systems to increase the efficiency of the combustion process is probably the fastest growing area of power plant control (5). And probably the most cost-effective means of improving boiler efficience is by using a central system that is capable of minimizing furnace excess air level. The parameters most widely used as the basis for low excess air trim in O_2 and CO. There is some controversy in the control field over which the flue gas constituent in the better indicator of combusting quality. Both variables gone important information about the combustion process and when used in combustion, provide a very accurate picture of firing conditions within the boiler. Some advantages of CO trim that are most often cited include: CO measurement is related directly to the amount of unburned fuel in the boiler and it can be used to control the completness of the combustion process. Also CO control is independent of fuel type. Control is always performed at the level between 100 - 250 ppm CO as shown on Fig.3.

2.1. Design parameter

Flue gas temperature is one of the essential parameter in the design of thermal power stations boilers. It become even more important for low caloric fuel boiler if it is inclined for ash deposit formation and slaging (6). For the most solid fuel boiler furnaces it is adopted that the average heat generation ratio is

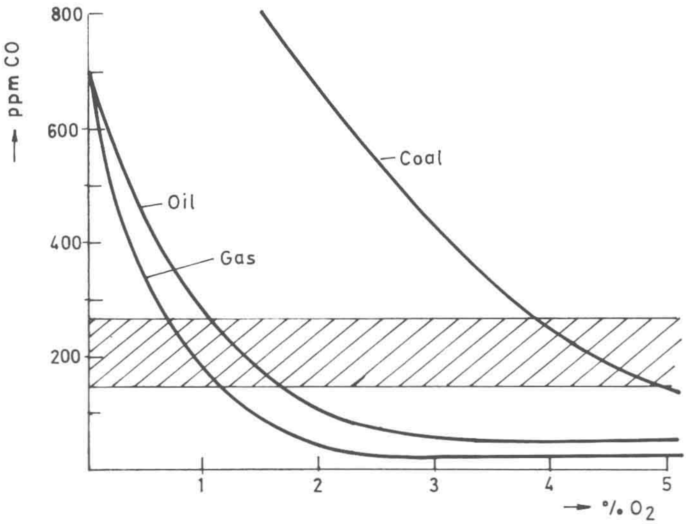

Fig. 3 ALLOWABLE EXCES AIR

in the range of 200 kw/m^3. This condition implies that the furnace outlet fuel gas temperature does not exceed the softening temperature of the mineral constituents in the flying ash particles. As it was shown (Fig.4) the softening temperature of the ash deposit on the heat transfer surface is dependent on the quality of the

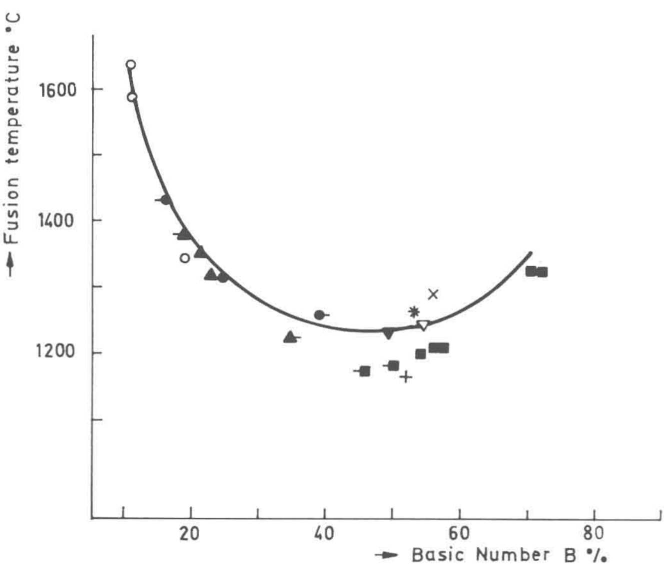

Fig. 4