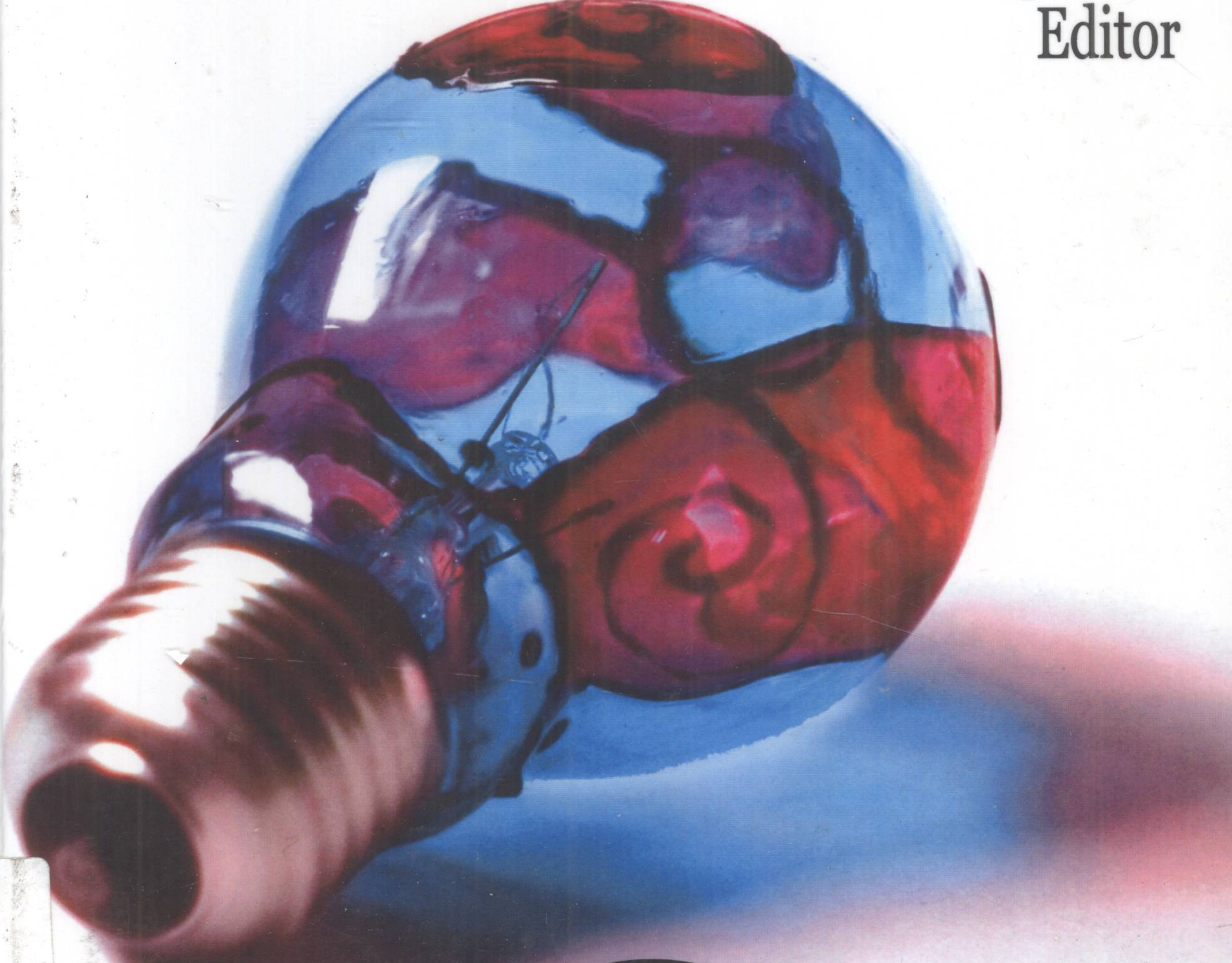
Energy Conversion

New Research

Wenzhong Lín
Editor



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ENERGY CONVERSION: NEW RESEARCH

WENZHONG LÍN
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ENERGY CONVERSION: NEW RESEARCH

PREFACE

This new book is devoted to new research on static and dynamic energy conversion; energy efficiency and management; heat pipes; thermosyphons and capillary pumped loops; thermal management of spacecraft; space and terrestrial power systems; hydrogen production and storage; renewable energy; nuclear power; single and combined cycles; miniaturized energy conversion and power systems; fuel cells and advanced batteries; and and desalination.

Expert Commentary A - In the last decade nuclear energy has gained a widespread renewal of interest as an important contributor to energy security, supply and sustainability. A number of new designs of nuclear power plants (NPP) has emerged recently, in attempts to achieve advances in the following areas: sustainability; competitive economics; safety and reliability; proliferation-resistance and physical protection. Actually, in the framework of the Generation IV International Forum (GIF), a task force has announced in 2002 the selection of six reactor technologies, which would represent the future shape of nuclear fission energy: these reactors operate at higher temperatures than today's reactors, allowing new and attractive applications, such as the thermo-chemical production of hydrogen. In addition to these six concepts for deployment between 2010 and 2030, the GIF has recognised a number of International Near-Term Deployment advanced NPPs available before 2015. Moreover, several international research projects are ongoing, which concern subcritical Accelerator-Driven Systems for radioactive wastes incineration, in conjunction with Partitioning and Transmutation technologies.

Expert Commentary B - A survey on existing literature has shown limited work done on the estimation of diffuse solar irradiation using artificial neural networks. This communication explores the possibility of developing a prediction model, which could be used to estimate monthly average daily diffuse solar irradiation on a horizontal surface from a selection of geographical and meteorological parameters. The parameters include: latitude, longitude, altitude, global solar irradiation, cloud cover and relative humidity. Artificial neural networks method has been employed in the prediction problem. The principle of work of the artificial neural networks (ANN) is like that of the human brain, whereby ANN learns, memorizes and simulates a behavior or a data structure. Results have shown good agreement between the estimated and measured values of monthly average daily diffuse solar irradiation, giving a correlation coefficient of 0.816. An error analysis gave a normalized absolute mean bias error of 0.1% and a normalized root mean square error of 3.3%, which is within an acceptable range of accuracy.

Short Communication - This article proposes a new robust control design of frequency stabilizers installed with Superconducting Magnetic Energy Storages (SMES) and Static Synchronous Series Compensator (SSSC) using H_∞ control. It is well known that the load-frequency stabilization effect of SMES in an interconnected power system is restricted in its located area. The SMES almost has no any frequency stabilization effect in another interconnected area. To enhance the frequency stabilization effect of SMES, the SSSC can be applied as an auxiliary device. SSSC can be used as an energy transfer device of SMES to stabilize frequency in another interconnected area. The proposed technique not only introduces a sophisticated frequency stabilization in deregulated power systems, but also offers a smart energy management control of SMES. In addition, to take the robust stability of the controlled power system against system uncertainties into account, the H_∞ control is used to design robust frequency stabilizers of SMES and SSSC. Simulation results in a two-area interconnected power system confirm the high robustness of frequency stabilizers SMES and SSSC against load disturbances and system uncertainties.

Chapter 1 - Batteries and fuel cells are amongst the most efficient devices for the conversion, storage and delivery of electrical energy. These electrochemical technologies are leading candidates for large-scale energy storage applications which can provide needed flexibility in the choice of primary fuels for energy generation and thereby reduce the demand for petroleum. Much of the recent R&D on advanced rechargeable batteries and fuel cells have been driven by such applications. Batteries and fuel cells can also have a beneficial environmental impact because of their high energy conversion efficiency and low emission rates. A number of studies have addressed the environmental effects of electrochemical technologies, including the ecological and biomedical effects of effluents from electric vehicle batteries, safety issues, and emissions to the atmosphere. International problems, such as acid rain and global warming have received considerable attention in recent years, and it is recognised that electrochemical technologies can play an important role in mitigating these problems. Three electrochemical energy conversion technologies may find widespread applications early in this century: (a) electric vehicles powered by advanced rechargeable batteries and/or fuel cells, (b) fuel cells for electricity generation, and (c) batteries for electric utility load levelling. This chapter focuses on the first two of these electrochemical technologies. First, the status of selected rechargeable battery technologies (*e.g.* lead-acid, iron-nickel oxide, zinc-nickel oxide, metal hydride-nickel oxide, zinc-air, zinc-bromine, sodium-sulphur, lithium-iron disulphide, lithium-polymer electrolyte, *etc.*) that are being developed for electric vehicles is presented. Second, electric road vehicles and their recent advances are discussed. Third, a review on fuel cells for electricity generation is presented, giving special attention to fuel cell vehicles. Moreover, the concept of hybridisation is identified and, in particular, the integration of fuel cells and advanced batteries which provide a full performance capability with quiet, odour-free operation and dramatic reductions in polluting emissions is analysed. The chapter concludes with an estimate of the quantities of gaseous CO_2, SO_2 and NO_x emissions that could be avoided if the described electrochemical technologies are implemented.

Chapter 2 - The treatise presents an extensive simulation and analytical analysis of the energy conversion phenomena in parallel and series hybrid-electric powertrains. Parameters of both hybrid powertrains are evaluated and compared to parameters of the conventional-internal combustion engine powertrain. Simulation approach is based on an accurate and fast forward-facing simulation model that is capable of capturing dynamics of the powertrain components. Moreover, the treatise offers an analytical approach based on the energy balance equations in order to analyze and predict energy conversion efficiency in both hybrid powertrains. The analysis covers broad range of parallel and series hybrid powertrain configurations. Very good agreement between simulation and analytical results gives confidence in the accuracy of the performed analysis and confirms the validity of the analytical framework. Combined simulation and analytical analysis enables deep insight into energy conversion phenomena in hybrid powertrains. It reveals advantages and disadvantages of both hybrid powertrain concepts and their variations running under different operating conditions. The analysis thus indicates guidelines that lead to optimum fuel economy of particular powertrain concept operating according to the specified drive-test cycle. It can be concluded from the presented results that: 1.) parallel hybrid powertrain features better fuel economy than the series one for the applied test cycles, 2.) both hybrid powertrain configurations feature the best fuel economy at light duty application and 3.) electric conversion efficiency has significant influence on the fuel economy enhancement of hybrid-electric powertrains.

Chapter 3 - Global analysis of the power system markets shows that the Load Frequency Control (LFC) is one of the most profitable ancillary services at these systems. This service is related to the short-term balance of energy and frequency of the power systems and acquires a principal role to enable power exchange and to provide better condition for electricity trading. The main goal of LFC problem is to maintain zero steady state errors for frequency deviation and good tracking load demands in a multi-area power system.

This chapter provides an overview for the researcher of control strategies, as well as their current use in the filed of LFC problem. The history of control strategies is outlined. Various control methodologies based on the classical and optimal control, robust, adaptive, self tuning control, VSC systems, digital and artificial intelligent/ soft computing control techniques are discussed. The authors make various comparisons between these approaches and the main advantages and disadvantages of these methods are given. Finally, the investigations on LFC problem incorporating BES/SMES, wind turbines, FACTs devices have also been discussed.

Chapter 4 - Besides high efficiency and gentle environmental emissions, the solid oxide fuel cell (SOFC), as a high temperature fuel cell, has also other many advantages such as fuel flexibility, quiet, size flexibility, high-quality exhaust heat and good controllability etc. These promising advantages make SOFC particularly adapt to be integrated with traditional thermal cycles in order for better performance or some requirements. This work aims to present some typical conceptual integration schemes on SOFC. Two basic integration strategies called thermal coupling and fuel coupling are introduced in this work. For thermal coupling method, the exhaust thermal energy of SOFC is utilized by the thermal cycles through direct circumfluence or indirect heat transfer. For fuel coupling schemes, the hydrogen production cycle or fuel reformer is integrated with SOFC, as well as often together with thermal power system. As the traditional thermal cycles, the Brayton cycle and Rankine cycle are generally integrated with hydrogen production cycle in SOFC hybrid system for the central large-scale power generation. The basic integration strategies are then configured together building the advanced hybrid system. Four advanced conceptual hybrid integration schemes are specially investigated on the combinations of SOFC and nuclear reactor power generation with thermochemical hydrogen production, coal gasification power generation, absorption refrigeration, and thermophotovoltaic power generation, respectively.

Chapter 5 - Under floor heating is one type of heating of buildings' spaces such as residential rooms and sport halls. Under floor heating has some superiorities to other heating systems such as radiators, fan coils and ovens. The most important advantage of this system is higher thermal comfort levels than the others. Thermal comfort is often stated qualitatively by manufacturers; therefore it is difficult to compare the thermal comfort of the under floor heating with other heating systems. Efforts have been done to make sense of thermal comfort as a quantity that leaded to present some formulations for thermal comfort as function of several parameters such as temperature, humidity and mean radiant temperature. In this work, a short review on the history of the under floor heating system, along with its heat transfer mechanism and performance is briefly discussed. A typical room is then considered as test case and the governing equations are solved numerically, and distribution of thermal comfort within the room is computed using PVM model. This simulation is carried out for two heating systems separately: the under floor heating and radiator. The results show that the under floor heating, in spite of the lower energy consumption, is able to make available higher thermal comfort levels.

Chapter 6 - The laminar burning velocities are of fundamental importance for analyzing and predicting the performance of combustion engines, which can be extremely useful in the analysis of fundamental processes and serve as a design aid. The term of laminar burning velocity is generally defined for one-dimensional planar flames in theory, where flames are unstretched. For spherically expanding flames, the stretch imposed on the premixed flame front is well defined. Furthermore, the asymptotic theories and experimental measurements have suggested a linear relationship between flame speeds and flame stretches. Thereby, spherical flames are systematically used to determine the fundamental burning velocity – the unstretched laminar burning velocity by mean of an extrapolation at zero stretch. Meanwhile, Markstein lengths can, in principle, also be deduced to characterize the variation in the local flame speed due to the influence of external stretching, which is of importance in expressing the onset of flame instabilities and the stretch influence on flame quenching as well. Natural gas and liquefied petroleum gas are multicomponent fuels. The use of those as alternative fuels in industry and civil domains has been growing in recent years due to the increasing demand for energy and stringent pollution regulations. The determination of the laminar burning velocities has been received continuous attentions for so many years, but the most of study is implemented for the pure fuels, such as methane, propane, butane etc, as for the multicomponent fuels, natural gas and liquefied petroleum gas, the fundamental data available is still limited in literatures. In view of considerations above, spherically expanding laminar premixed flames, freely propagating from spark ignition sources in initially quiescent natural gas and liquefied petroleum gas mixtures in air, are continuously recorded at various equivalence ratios and temperature, pressure conditions. The stretched flames are analyzed, and following the linear relation between flame speed and flame stretch, the unstretched laminar burning velocities and corresponding Markstein lengths of flames have been deduced. The correlation formula of the unstretched laminar burning velocities, dependent with pressure, temperature and equivalence ratio, diluent ratio, is derived as simple power law relations at the reference temperature and pressure. Furthermore, the stretched laminar burning velocity and the stretch mass burning velocity are defined and derived at different stretch conditions, to quantify the effect of flame kernel thickness. The differences between these two burning velocities are discussed and their responses to stretch due to flow strain and curvature are also quantified by the appropriate Markstein numbers. Because exhaust gas recirculation (EGR) is regarded as an effective way to reduce nitrogen oxides emissions in combustion engine, the laminar flames of diluting fuel/air mixtures are experimentally studied. As a consequence, general expressions are presented to describe the effect of exhaust gas addition on the fundamental burning velocities.

Chapter 7 - Regulated and unregulated emissions of diesel engines with five different sulfur content fuels were studied in this article. The sulfur contents of the five typical fuels are less than 1500ppm, 800ppm, 500ppm for Euro2 , 350ppm for Euro3, and 50ppm for Euro4. Firstly, these fuels were compared using a 1.9 L PASSAT light-duty diesel engine with four cylinders, turbocharged and intercooled, electronic control high pressure fuel injection and diesel oxidation catalyst. Regulated emissions (NOx, HC, CO and smoke) and unregulated emissions (formaldehyde (HCHO), acetaldehyde (MECHO), and sulfur dioxide (SO_2)) of the diesel engine were measured on an engine test bench. Secondly, the five typical fuel experiments were performed on a PASSAT diesel passenger car equipped with the same type 1.9L engine as the former. The test diesel car was driven on a chassis dynamometer over the New European Driving Cycle (NEDC), and PM, NOx, HC and CO emissions from the diesel passenger car under the NEDC were measured.

The results show that the PM and smoke emissions descend continuously and remarkably with decreasing fuel sulfur content, and it shows the PM and smoke emissions have certain relation with fuel sulfur content. The HC and CO emissions have large scale reduction with very low sulfur fuel, NOx emission has no significant change with different sulfur content fuels. The MECHO emission is higher than the HCHO emission, and both continuously descends with deceasing fuel sulfur content and both could not be detected at higher engine load with 50 ppm sulfur fuel. The SO_2 emission ascends continuously with the increasing engine load, and descends with deceasing fuel sulfur contents obviously. This indicates the SO_2 emission has high relation with fuel sulfur content.

Chapter 8 - Two methane hydration processes, constant-pressure and lower-temperature, low-temperature and raising-pressure, were designed and investigated in a 1L stirred tank reactor. By experiment, some conclusions were given as follows: (1) Higher initial sub-cooling was helpful to dissolution of methane gas, hydrate nucleation and crystal growth. (2) In low-temperature and raising-pressure process, storage capacity and hydration rate were $146.3V_g{\cdot}V_H^{-1}$ and $0.321V_g{\cdot}V_H^{-1}{\cdot}min^{-1}$, respectively, which were better results than constant-pressure and lower-temperature process. In addition, configurations of two man-made samples were compared with natural samples from the sea floor. Results showed that configurations of hydrate were related to the hydration process. At the same time, hydrate formation of the sea floor was simulated in the laboratory. Experiment results indicated that hydrate crystal growth had direction, which can provide some references for hydrate process analysis and hydration reactor design.

Chapter 9 - A high accuracy and rapid convergence hybrid approach is developed for transient three-dimensional heat transfer analysis of thick, irregular, functionally graded plates subjected to different boundary conditions. The method essentially consists of the finite element method (FEM) and the differential quadrature method (DQM) for the spatial discretization in conjunction with the finite difference method (FDM) (Crank-Nicholson scheme) for the temporal discretization. Hence, the high accuracy and fast convergence of the DQM for variable coefficients partial differential equations with generality of the FEM for modeling of the arbitrary shaped domain and boundary conditions together with the numerical stability of the Crank-Nicholson scheme are achieved. This results in superior accuracy with fewer degrees of freedom than conventional finite element method (FEM) or finite difference method (FDM).

The in-plane spatial derivatives are discretized using the FEM and the resulting transient variable coefficient partial differential equations are discretized in the transverse direction using the DQM. Finally, the Crank-Nicholson scheme as a stable numerical method is employed to discretize the ordinary system of equations in the temporal domain.

The convergence behavior of the method is shown and to verify its accuracy, the results are compared with the available exact solutions and those obtained using the FDM. Less computational efforts of the method with respect to the conventional FDM are demonstrated. The effects of different parameters on the temperature distribution of the different thick FGM plates such as elliptical and circular plates are studied.

CONTENTS

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Expert Commentary A

INNOVATIVE TECHNIQUES FOR THE SIMULATION AND CONTROL OF NUCLEAR POWER PLANTS

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In the last decade nuclear energy has gained a widespread renewal of interest as an important contributor to energy security, supply and sustainability. A number of new designs of nuclear power plants (NPP) has emerged recently, in attempts to achieve advances in the following areas: sustainability; competitive economics; safety and reliability; proliferation-resistance and physical protection. Actually, in the framework of the Generation IV International Forum (GIF), a task force has announced in 2002 the selection of six reactor technologies, which would represent the future shape of nuclear fission energy: these reactors operate at higher temperatures than today's reactors, allowing new and attractive applications, such as the thermo-chemical production of hydrogen. In addition to these six concepts for deployment between 2010 and 2030, the GIF has recognised a number of International Near-Term Deployment advanced NPPs available before 2015. Moreover, several international research projects are ongoing, which concern subcritical Accelerator-Driven Systems for radioactive wastes incineration, in conjunction with Partitioning and Transmutation technologies.

All these new projects deal with very complex systems, which comprise the nuclear reactor, its energy conversion systems as well as the necessary facilities for the entire fuel cycle. In this context innovative techniques, which are nowadays available from Multi-Physics Modelling (MPM) and Object-Oriented Modelling (OOM), together with the advanced strategy of Model Predictive Control (MPC), could be usefully employed for the simulation and control of such new complex systems. These innovative techniques allow different degrees of detail (from a zero-dimensional, lumped description to a 3-D, distributed parameters geometry) and different modelling scales: from single components (steam generators, control rods, pumps, valves, fuel rods, etc.) or subsystems - like the NSSS (Nuclear Steam Supply System) and the TGFS (Turbine, Generator and Feedwater System) - to the overall nuclear power plant, and possibly till the entire fuel cycle.

The Multi-Physics approach is suitable for the modelling and simulation of dynamical systems, whose behaviour is strongly dependent on the coupling of different and simultaneous phenomena, possibly with significant effects related to their spatial distribution: e.g., this is the case of the core in a nuclear reactor, whose behaviour can be properly described by taking into account the mutual dependence between neutronics and thermal-hydraulics.

Nowadays, several MPM software packages based on the finite element method are available, by which the user in principle can simulate any system of coupled partial differential equations (PDE); the specified PDEs may be non linear and time dependent and act on a 1-D, 2-D or 3-D geometry. These new MPM tools look promising for the dynamic simulation of those nuclear components or sub-systems, like the reactor core, which are subjected to complex and coupled phenomena: actually, it is possible to describe such phenomena by means of the most appropriate models with regard to accuracy degree requested by the specific simulation.

In short, the Multi-Physics Modelling allows more flexibility to evaluate the interaction effects in comparison with conventional tools of analysis; nevertheless, it could become computationally unpractical for very complex 3-D domains. By means of the MPM approach a detailed description of the single component/sub-system of a nuclear power plant is viable, but neither the simulation of transients at the overall system level nor the analysis of the control-relevant dynamics during the NPP normal operation are manageable: to these last two purposes, OOM techniques may answer successfully.

Actually, recent advances in Object-Oriented Modelling of complex dynamical systems allow a declarative, highly modular and a-causal approach that brings new interesting possibilities in the development of system simulators: this means that it is possible to build the overall model for a nuclear power plant by connecting the models of its single components or sub-systems through rigorously defined interfaces or connectors (also referred to as physical ports). Among the new paradigms of the OOM approach, a fundamental role is played by the following: the definition of physical ports as the standard interfaces to connect a certain component model, in order to reproduce the structure of the overall system; the definition of models in a non-causal form, that permits reuse, abstraction and unconditional connection; the mutual independence of the model interfaces (the physical ports) and its internal description, that means the user can adopt the conventional modelling or the innovative MPM techniques to simulate the behaviour of the single component/sub-system. In particular, the internal description of a component/sub-system has to be written independently of its boundary conditions, which are not necessarily declared a-priori as inputs or outputs; this OOM paradigm marks a fundamental difference with conventional block-diagram-oriented (causal) simulation languages, in which each model must have definite input and output signals.

The OOM languages - now available from engineering software based on the above paradigms and originally conceived for conventional, fossil-fired plants - may allow an efficient management of the different degrees of detail needed throughout the design process of a nuclear power plant, and possibly of the related fuel cycle, too: especially, Modelica language brings new possibilities in this field, allowing the fast development of system simulators, which can be tailored to the different needs of the design process, while maximising the re-use of existing information and knowledge. Therefore, OOM simulation techniques can play a key role during the phase of concept development, when suitable dynamic models must be set up in order to evaluate different design solutions, during the initial design stages, when the control strategies and the required instrumentation are evaluated, and during the validation process of the controller tuning up to the plant commissioning phase.

Furthermore, the OOM approach represents a very important tool in the design of NPP control systems, particularly when innovative plants or innovative control strategies are considered. Contrary to conventional, fossil-fired power plants, where it is often deemed inessential, dynamic modelling is of paramount importance in NPPs engineering: a nuclear plant can be actually built and operated only after an extensive licensing procedure, where the safety of the plant during accidental transients is demonstrated. Reliable, accurate and certified simulation packages are well established in this field (e.g. RELAP, TRAC, ATHLET, CATHARE), and very detailed dynamic models of the overall plant are always developed for new NNPs; however, these simulators are unnecessarily over-detailed for control system studies, require very long times for the simulation of a single transient (hours, or even days), and offer little flexibility to integrate the plant model with the control system model and other boundary conditions like a simplified power generator and grid. Conversely, the OOM approach permits light and flexible simulation models, which may gradually evolve during the control system design phases, and eventually allow to perform up to ten thousands simulation runs in sensitivity studies for a new NPP design.

In short, the principal aims of Object-Oriented Modelling are thus: to obtain a NPP model, which is accurate enough to reproduce the control-relevant dynamics during normal operation, validated against the more accurate, safety-oriented models; to integrate the NPP model with the control system model and with other relevant subsystems at its boundaries; to provide a whole range of degrees of detail, so that the correct balance between accuracy and simulation speed can always be struck, depending on the specific simulation needs.

Nuclear power plants are highly complex, non linear, time-varying, and constrained systems, whose control represent one of the most relevant issues to be solved during the design process. The control strategy usually adopted in the current NPPs is based on a classical feedforward and feedback (typically with a Proportional-Integral configuration) scheme. Techniques for the optimal control of nuclear reactors have been extensively studied in the past two decades, but it is still difficult to design optimal controllers for nuclear systems because of variations in nuclear system parameters and modelling uncertainties.

Among the most promising control techniques, MPC methodology has so far received attention as a powerful tool for the control of industrial process systems, and it has been recently applied for the first time to a NPP with very good results. MPC is an effective means to deal with large multi-variable constrained control problems. Its main idea is to choose the control action by repeatedly solving on line an optimal control problem: this aims at minimizing a performance criterion over a future horizon, possibly subject to constraints on the manipulated inputs and outputs, where the future behaviour is computed according to a model of the plant.

For the development of the new generation of nuclear reactors the adoption of MPC methods could be very interesting and useful, especially when several constraints on the physical variables of the various plant components/sub-systems have to be fulfilled; moreover, MPC could be advantageous to guarantee a rapid and smooth power manoeuvring, in view of the economical and safe operation of nuclear power plants as well as of the importance of load-following strategy.

In short, the MPC approach has many advantages over the conventional control strategy, above all because it is possible to handle constraints in a systematic manner during the design and implementation of control; nevertheless, difficulties may arise for guaranteeing closed-loop stability, for handling model uncertainty, and for reducing on-line computations.

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Expert Commentary B

ESTIMATION OF DIFFUSE SOLAR IRRADIATION USING ARTIFICIAL NEURAL NETWORKS

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ABSTRACT

A survey on existing literature has shown limited work done on the estimation of diffuse solar irradiation using artificial neural networks. This communication explores the possibility of developing a prediction model, which could be used to estimate monthly average daily diffuse solar irradiation on a horizontal surface from a selection of geographical and meteorological parameters. The parameters include: latitude, longitude, altitude, global solar irradiation, cloud cover and relative humidity. Artificial neural networks method has been employed in the prediction problem. The principle of work of the artificial neural networks (ANN) is like that of the human brain, whereby ANN learns, memorizes and simulates a behavior or a data structure. Results have shown good agreement between the estimated and measured values of monthly average daily diffuse solar irradiation, giving a correlation coefficient of 0.816. An error analysis gave a normalized absolute mean bias error of 0.1% and a normalized root mean square error of 3.3%, which is within an acceptable range of accuracy.

Keywords: artificial neural networks; diffuse solar radiation; global solar radiation; model.

1. INTRODUCTION

Diffuse fraction plays an active role in thermal, chemical and biological processes on the earth's surface (Maduekwe and Chendo, 1997). In particular, the knowledge of the diffuse fraction is a major requirement in assessing climatological potential of a locality for solar energy utilization (Iziomon and Aro, 1998). Measuring equipment would be the most reliable in provision of diffuse solar radiation data but are available in few places worldwide due to the high cost and maintenance requirements. The diffuse solar radiation component is less