Editorial

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The present special issue is aimed at giving an overview of the potentials of Soft Computing methods (e.g. Artificial Neural Networks, Fuzzy Logic, Evolutionary Algorithms) in nuclear engineering applications. Soft Computing methods are finding increasing use as an alternative to traditional methods in a variety of engineering applications, including monitoring, prediction, diagnostics, control and safety. They are particularly attractive because of their ability to capture the complex non-linear relationships of real systems and processes from the possibly uncertain and ambiguous information contained in the available measured data, without requiring a detailed physical understanding, which is often lacking in real, practical cases.

The nine papers collected in this special issue are extended and revised versions of selected works presented at the FLINS 2006 conference. FLINS, an acronym for Fuzzy Logic and Intelligent technologies in Nuclear Science, is a well established international research forum to advance the theory and applications of computational intelligence for applied research in general, and for nuclear science and engineering in particular. The 2006 meeting, held in Genoa, Italy, on August 29–31, marked a further step forward towards the application of Soft Computing-based approaches in the nuclear industry.

On the other hand, the *International Journal of Nuclear Knowledge Management* (IJNKM) aims at providing a highly professional and authoritative source of information in the field of nuclear sciences, technologies and management, at the same time, establishing channels of communication between nuclear and non-nuclear experts and managers, thus contributing to the reduction of the gap between theory and practice.

Hence, the natural marriage which resulted in the present Special Issue, reporting on recent research in the field of Soft Computing methods applied to nuclear engineering.

The unifying motivation behind the selection of the works hereby contained is that of highlighting the capabilities, reliability and cost-effectiveness of soft computing methods in diverse practical nuclear applications.

The opening paper, by J. Garvey, D. Garvey, Seibert and Hines investigates the issue of a practical use of Soft Computing models for On-Line Monitoring (OLM) of safety critical instrumentation for calibration reduction. Seven case studies, investigating the effects on model performance of model development and data assumptions, are summarised and critically discussed. These case studies form the core of an extensive effort in support of a regulatory review of possible licence amendments for US Nuclear Power Plants (NPPs). Although this study is not an exhaustive review of the many issues involved in OLM, it provides a set of considerations and practical concerns which must be accounted for when testing the performance of Soft Computing models for this application.

The second paper by Zio, Baraldi, Gola, Roverso and Hoffmann continues in the direction set by the first paper, with an investigation of the combined use of Genetic Algorithms (GA) and Fuzzy Clustering, for fault diagnosis in a nuclear system. In the paper, the problem of fault diagnosis is formulated in terms of pattern recognition for transient classification, i.e. a problem of partitioning transient data patterns into pre-defined fault classes. For higher accuracy and reliability, the problem is tackled by constructing an ensemble of pattern classifiers. The development of such an ensemble requires the construction of the base classifiers which constitute the ensemble and the integration of their predictions. In this paper, the first issue is tackled by means of a Multi-Objective Genetic Algorithm (MOGA) for feature selection, aimed at creating a set of base classifiers fed by different Feature Subsets (FSs). The second task of integrating the classifiers' output is performed by a Static Weighted Voting (SWV) combination approach. The overall procedure is applied to a case study regarding the classification of simulated transients in the feedwater system of a Boiling Water Reactor (BWR).

Fault diagnosis is also the topic of the third paper by Roverso. A novel technique is proposed for reducing the variability of fault manifestation through a process of 'intelligent normalisation' of the transient data. Such normalisation is important for the development of Soft Computing models for diagnostics, which must be based on data similar and consistent with what will be observed during the actual on-line monitoring of the plant. In other words, the ‘training’ data upon which the Soft Computing models are built must properly cover the space of operation of the monitored process. The coverage requirement can quickly become a problem if the process to be monitored operates in a wide range of regimes, with large variations of manifestation of the faults of interest in the observable measurement transients. The approach proposed in the paper resorts to Artificial Neural Networks (ANNs) for performing the normalisation of the monitored measurements into a corresponding normalised state. An application to a NPP transient classification problem is provided.

The next paper by Zio and Popescu also deals with the on-line identification of transients in monitored processes. Following a methodology proposed in the literature, six parameters are computed from the current and historical values of the measured signal. Each parameter is meant to hold a particular piece of evidence of the signal trend. Fuzzy logic is then used to capture and integrate the ambiguous information carried by the measured signal, in order to classify the trend of the developing process dynamics as increasing, decreasing or steady-state. More specifically, the trend information carried by each one of the six parameters is evaluated fuzzily by mapping its values into a properly constructed truth curve whose values represent the degrees of truth of the evidence carried by the parameter with respect to the presence or absence of a dynamic trend. Each truth decision curve depends on either one or two coefficients: a genetic algorithm is used to find the optimal values of these coefficients so as to maximise the fraction of correctly identified trends. Then, singletons are used for quantifying the truth values of the six parameters with respect to the presence of a given trend. The max operator is used for the integration of the information of the six parameters. The decision making task for the final trend identification is performed by simply comparing the obtained singleton values with pre-established thresholds indicating steady state or transient behaviours. The trend identification method is applied to a case study concerning one section of the feed-water system of a simulated NPP characterised by the same working conditions of the Forsmark 3 reactor in Sweden.

The paper by Benítez-Read, Rivero-Gutiérrez, Ruan, Ramírez-Chávez, López-Callejas and Pacheco-Sotelo presents the development of a new user interface for a TRIGA Mark III reactor. The aim is that of testing new power control algorithms based on fuzzy logic. The Mexican Nuclear Centre has a TRIGA Mark III research reactor among its key nuclear facilities. A new digital console has recently been installed and is currently operating the reactor. Different algorithms to regulate and control the reactor’s neutron power, based on advanced control theories and knowledge-based expert systems, have been proposed for testing on the new console. For this purpose, a study is undergoing with respect to the analysis of the closed-loop reactor’s response under different control schemes. This will allow the determination of the suitability of a given control scheme and its feasibility for real-time application on the new console. Two of the controllers that have been under study are:

- an exact input–output linearising control, which presents good reference signal tracking characteristics
- a Mamdani type fuzzy controller that efficiently deals with the uncertainties and the slow variations of the plant parameters, mainly due to its intrinsic capabilities of interpolating among operating regions.

The controllers have been shown to satisfactorily bring the reactor power from 50 W (source level region) to 1 MW (full power). The first controller, however, has not been designed to avoid the automatic reactor shutdown (scram) due to small reactor period values, occurring when the power increment rate overpasses a safety limit. On the other hand, the second controller has not yet been exhaustively tested for initial and final power levels other than 50 W and 1 MW, respectively. The next step is the testing and validation of these controllers in real time. To perform such testing, it has been proposed to develop a computing system, similar to the reactor digital console, together with a simulator of the reactor dynamics. The proposed interface windows are designed to look similar to the windows that the reactor operators are accustomed to. Likewise, the system will have the capability to manage nuclear instrumentation for testing in real time.

The work by Sajjadi, Boroushaki, Jafari and Yazdanpanah propounds the use of ANNs for identifying the complex dynamics of a horizontal steam generator in a VVER reactor type, based on data simulated by a RELAP5 thermo-hydraulic code. In particular, it investigates the capabilities of an intelligent structure named by the authors 'Nonlinear Auto Regression with eXogenous inputs' (NARX), which belongs to the family of Recurrent Neural Networks (RNNs). RNNs are attracting significant attention, because of their intrinsic potentials in temporal processing, e.g. time series prediction, system identification and control, temporal pattern recognition and classification, whereas classical feedforward neural networks are, in general, capable of representing only static input/output mappings. NARX structures are characterised by external connections with temporal buffers which feed back the outputs of the network to the input nodes. Training is performed by the steepest descent algorithm, within an off-line batch process, fed by a set of simulated thermo-hydraulic data examples. The proposed algorithm is capable of reproducing the underlying complex dynamics of a horizontal steam generator in a time that is approximately 5000 times faster than a RELAP5 thermo-hydraulic code with comparable errors.

Another application of ANNs is presented in the paper by Cadini, Zio, Di Maio, Kopustinkas and Urbonas. A static, multi-layered, feed-forward ANN is implemented for performing the numerous model output calculations involved in a sensitivity analysis by variance decomposition. Sensitivity analysis is an important tool, which can provide relevant insights into the behaviour of a system model with respect to how much its output depends on the input. Various approaches have been developed for performing sensitivity studies, e.g. first-order differential analysis, Monte Carlo sampling, response surface methodology, Fourier Amplitude Sensitivity Test (FAST) and more. Many of these entail computing the model output several times in correspondence to different input values sampled from proper probability distributions. Often, the computation times required by the numerical solution of the model render these analyses prohibitively costly, so that one has to resort to fast, simplified models or to empirical interpolations of the model response. In this paper, the variance decomposition method for performing sensitivity analysis is adopted. It is a powerful approach which allows the quantification of the effects on the model output of the variability of, not only single inputs, but also of groups of inputs, thus also including their interactions. To efficiently manage the considerable computational demand on the method, related to repeating several model solutions in correspondence to the different sampled input, the authors resort to a properly trained ANN. The proposed approach is applied to a case study of literature regarding the sensitivity analysis of a detailed numerical model for computing the maximum fuel cladding temperature, in case of an accident scenario in a RBMK-1500 nuclear reactor.

The paper by Pereira, Schirru, Lapa, Canedo, Waintraub, Meneses, Baptista and Siqueira illustrates an application of the Particle Swarm Optimization (PSO) technique to four classical nuclear engineering problems: nuclear fuel reload, core design optimisation, surveillance test planning and accident classification. Traditional gradient-based optimisation techniques, e.g. linear-programming and perturbation theory, have been used in the past. However, due to the non-linearity, multimodality and poor (or no) knowledge about the search domain of these complex problems, the use of more robust techniques has been investigated. Among these, population-based metaheuristic PSO techniques have led to promising results. In this paper, a review of such achievements is reported.

The paper by Salazar, Rocco and Zio also addresses an optimisation problem. The work illustrates the use of Multiple Objective Evolutionary Algorithms (MOEA) in combination with Interval Arithmetic (IA) for the robust reliability design of complex systems, such as those employed in nuclear engineering. The motivation of the work comes from the fact that, in real applications, uncertainty affects the values of the decision variables underpinning the optimisation of an engineering system (e.g. with respect to its design, operation and maintenance). Thus, an issue of robustness of the final solution arises with respect to its optimality in the face of the existing uncertainties. Depending on the type of information describing the system, it is possible to identify different formulations of robustness. In this paper, the robustness of system design is defined as the maximum deviation from its specifications that can be tolerated with the designed system still meeting all the requirements. In a previous work, the authors proposed an indirect approach by formulating the problem as a Single Objective (SO) optimisation problem. The approach was based on an evolutionary strategy, whereas IA was used to verify the feasibility of the system design by a single 'interval' evaluation. In practice, however, the situation is complicated by the fact that the Decision-Maker (DM) could be interested in simultaneously optimising two or more objectives, e.g. the reliability and the cost of a given system design. The identification of the optimal solutions of Multiple Objective (MO) optimisation problems is possible, for instance, by adopting a SO formulation in which the objectives are combined into a weighted sum, properly normalised. This approach is technically simple and straightforward. Nevertheless, the DM must, *a priori*, select the arbitrary weights of the weighed combination, in reflection of their preferences on the different objectives, or repetitively solve the optimisation problem with different weight values to obtain a group of alternatives (the so called Pareto set) from which to choose, *a posteriori*, the final solution. An alternative, and more powerful, approach is one in which the concept of dominance is exploited during the optimisation, in order to analyse the multiple objectives and to identify a Pareto set of optimal alternatives. In this paper, the latter MO approach is embedded within an EA scheme. The approach is exploited to obtain the optimal robust design of the Residual Heat Removal (RHR) system of a NPP.

As a final remark, we wish to point out that this special issue would not have been possible without the enlightening motivation of Professor Da Ruan of SCK-CEN, Belgium and the kind support of Professor André Maïsseu, Editor-in-Chief of the Journal, who have given us the opportunity and the support necessary to put together such a collection of interesting work, nor without the outstanding contribution of all the authors and the accurate and timely collaboration of both the authors and the reviewers. To all of them goes our sincere professional appreciation and personal gratitude.