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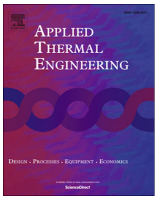

Research Paper

Preferred physical-mathematical model of the cold energy storage system

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HIGHLIGHTS

- Comparative uncertainty is caused by finite number of variables recorded in a model.
- We calculate comparative uncertainty of mathematical model of cold storage system.
- Experimental uncertainty cannot be less than model's comparative uncertainty.
- Validation metric occurs to be very simple and easily interpretable.

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ABSTRACT

The aim of this paper is the introduction of a methodology for the development of an optimal physical-mathematical model for a cold energy storage system (CESS) from the viewpoint of the required number of chosen variables. Selection of the design, technical and technological parameters of a CESS is a complex process of selection based on a mathematical model using multi-criteria optimization, in which many factors must be taken into account to attain minimum uncertainty. Here, in order to solve this problem a chosen universal metric, called the comparative uncertainty, is calculated according to the amount of information contained in the model. The number of recorded variables is calculated according to this metric. For practical cases, the detailed steps, including the choice of class of the exploring phenomenon, calculating the optimum number of dimensionless criteria, and the value of the achievable comparative uncertainty, are presented. The proposed method is a new method for estimating the optimal model. Examples are also introduced.

1. Introduction

This study aims to develop, via a weighted and careful approach, an optimal physical-mathematical model of cold energy storage systems (CESS) from the point of view of the number of recorded variables.

Based on current technology, in general CESS is the technology with the shortest time response to the demands of the world political leaders to protect the environment [1–3]. It is focused on reducing the site peak demand and peak energy usage of air-conditioning or plant process needs, from hours with the highest or middle electrical tariff, to the night when the electricity tariff is the lowest and the coefficient of performance of refrigeration equipment is high. CESS could improve electric utility operations by requiring fewer generation plants and reducing the need to build new plants and distribution systems [1].

In order to select the most applicable CESS for each customer, there is a need to take into account various criteria, including economic costs, environmental impacts, as well as technological and technical specifications of power systems [4–7]. In turn, any financial calculations will be acceptable only through the development of an optimal physical-mathematical model that identifies the most appropriate material, construction and configuration of the CESS. Here, the author finds the minimum value of the estimated experimental or computerized model uncertainty in order to confirm its acceptability or revise it before the experiment. The remaining analysis of CESS is intended to help inventors, developers and manufacturers to determine the most simple and reliable method of choosing of a model with an optimal number of chosen variables.

In spite of many experimental and numerical investigations regarding CESS characteristics, their industrial technical parameters are still unsatisfactory. There is not a reliable, well-tested and accepted methodology for calculating parameters or to study of the feasibility of using CESS. The techniques proposed in

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Nomenclature

$\boldsymbol{e_l}, \ldots, \boldsymbol{e_f}$	number of choices of dimensions for each primary variable
$\boldsymbol{F}$	amount of substance (mol)
$\boldsymbol{I}$	powered by electric current (A)
$\boldsymbol{J}$	luminous intensity (cd)
$l, m..f$	integers of primary variables of SI
$\boldsymbol{L}$	length (m)
$\boldsymbol{M}$	weight (kg)
$\boldsymbol{q}$	secondary variable
r^*	dimensional scale parameter with the same dimension that $\mathbf{U}$ and $\boldsymbol{S}^*$ have
$\boldsymbol{S}$	dimensionless interval of observation/supervision of dimensionless researched variable $\boldsymbol{u}$
$\mathbf{S}^*$	dimensional considered range of changes of the measured dimensional variable $\mathbf{U}$
$\boldsymbol{T}$	time (s)
$\boldsymbol{U}$	dimensional researched variable
$\boldsymbol{u}$	dimensionless researched variable
$\boldsymbol{u}_{\text{exp}}$	dimensionless calculated variable measured during field test
$\boldsymbol{z}'$	number of physical dimensional variables in selected CP
$\boldsymbol{z}''$	number of physical dimensional variables recorded in physical-mathematical model

Greek symbols

$\boldsymbol{\mu}_{SI}$	number of possible dimensionless variables of the International System of Units (SI)
$\boldsymbol{\beta}'$	number of primary physical dimensional variables in the selected CP
$\boldsymbol{\beta}''$	number of primary physical dimensional variables of total number of variables recorded in model
$\boldsymbol{\Delta u}$	dimensionless total uncertainty in determining the dimensionless variable $\boldsymbol{u}$
$\boldsymbol{\Delta}\mathbf{U}$	dimensional alleged uncertainty of the measured dimensional variable $\mathbf{U}$
$\boldsymbol{\Delta u}_{\text{pmm}}$	dimensionless uncertainty of model caused by the finite number of recorded variables
$\boldsymbol{\Delta u}_{\text{exp}}$	dimensionless calculated experimental uncertainty in determining the dimensionless variable $\boldsymbol{u}_{\text{exp}}$
$\boldsymbol{\Theta}$	temperature, K
$\boldsymbol{\varepsilon}$	comparative uncertainty, $\boldsymbol{\varepsilon} = \boldsymbol{\Delta u}/\boldsymbol{S} = \boldsymbol{\Delta U}/\boldsymbol{S}^*$
$(\boldsymbol{\varepsilon}_{\text{min}})_{LMT\theta}$	lowest comparative uncertainty for $\text{CP}_{\text{SI}} \equiv \boldsymbol{LMT\Theta}$
$l, m...f$	exponents of variables
$\ni$	corresponds to dimension
$\equiv$	congruence

Subscripts

pmm	physical-mathematical model
exp	experimental

Acronyms

CP	class of phenomena
SPV	System of Primary Variables

scientific articles are still far from actual industrial applications. Algorithms developed by private firms - manufacturers of CESS - are confidential and therefore are unknown to the public.

In addition, there is no universally accepted recommendation on how to calculate the total efficiency of a CESS. In spite of the fact that there is a Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems [8], it is not used in scientific research. Besides that, at present, the vast majority of manufactures, the amount of which is more than 300 in the world [9], so not provide sufficient technical information to understand real CESS advantages and disadvantages. It does not allow for the establishment of an objective comparison of CESS specific indicators. The companies use different technologies to produce their panels, as well as different means to test and verify their claims.

On this note, a previous study [10] can be mentioned in which there is a comparison of the specific parameters of CESS. The comparison is provided for a number of different technologies and a number of commercial products produced by several companies. It includes, for example, chiller and stored cold water, dynamic and static ice storage CESS, phase change material CESS, and pumpable ice-based storage systems. According to analysis of results, a considerable variation of the values of CESS specific parameters, especially coefficients of performance, confirms the need to develop uniform methodology for calculating CESS efficiency. In addition, it creates a situation in the CESS market that does not allow potential buyers to obtain true technical information to choose the preferred method, technology, and construction of CESS.

In the scientific community the prevailing view is that use of supercomputers, large simulations and large-scale models can reach a high degree of model approximation to the researched object [2,3,11]. For example, a standard input file of Energyplus elaborated by DOE (USA) as a beta-test of a whole-building simulation engine to describe a building has about 3000 inputs. Its preliminary calculated accuracy (uncertainty of, for example, room temperature) is very hard to estimate, because it strongly depends on the accuracy of the modeling inputs. Without measured data to compare and calibrate with, energy simulation results could easily be 50–200% of the actual building energy use. That is why, it is not possible to validate a model and its results, but only to increase the level of confidence that is placed in them [12].

However, human intuition and life experience provide a simple truth. For a small number of variables, the modeler gets a very rough picture of the process being studied. In turn, a large number of accounted variables allows one to deeply and thoroughly understand the structure of the phenomenon. At the same time, with the apparent attractiveness, each variable brings its own uncertainty to the integral (theoretical or experimental) uncertainty of the model or experiment. In addition, the complexity and cost of computer simulations and field tests increase enormously. Therefore, an optimal or rational number of variables specific must be applied to each of studied process.

The above mentioned points reflect only the tip of the iceberg of problems associated with the identification of the most preferred model for the description of the selected object. The general strategies of matching a model and the observed object that have been particularly popular over the last decade, from both a theoretical and applied perspective, are *verification* and *validation* (V&V) techniques [13]. *Verification* is the process of determining that a computational model accurately represents the basic mathematical model and its solution; *validation* is the process of determining to what degree a model is an accurate representation of the real world from the perspective of the intended use of the model [14]. The quality validation may be useful in certain scenarios,