Review Report on PhD Thesis
Stratification in storage tanks for heat pumps
Yogender Pal Chandra

Achieving the objectives set in the doctoral thesis

This PhD thesis successfully meets its objectives by innovatively exploring thermal energy storage through experimental and simulated assessments of thermal stratification. The research distinctly achieves the design and validation of methodologies, models, and a real-time intelligent IoT system effectively addressing the specified aims.

Topicality and the level of analysis of the state of the art

The author provided a comprehensive review of the state of the art in the journal paper "Stratification analysis of domestic hot water storage tanks: A comprehensive review." This review meticulously examines the latest advancements and methodologies in thermal stratification.

Contribution of the doctoral thesis theory to fundamental knowledge

The theoretical contributions of this doctoral thesis enhance our understanding of thermal energy storage (TES) systems. By identifying gaps in stratification indices and developing advanced computational fluid dynamics (CFD) models, the thesis innovatively quantifies thermal stratification. Further, it transcends traditional first law models by integrating dynamic second law models with heat pumps, offering a robust methodology for evaluating TES systems in transient states.

Contribution of the doctoral thesis to applied practice

This doctoral thesis advances applied practice by developing a real-time edge device for integrating heat pumps with thermal energy storage (TES), using exergetic model. However, the provided solution, including the Raspberry Pi and related software modules, is currently tailored for laboratory settings and not yet ready for broader practical deployment.

Selection and suitability of methods and techniques used

The selection and suitability of methods in this doctoral thesis, including experimental setups, computational fluid dynamics (CFD), and second law thermodynamics models, were appropriately chosen to address the complexities of thermal stratification in TES systems. By integrating these traditional methods with machine learning techniques, the thesis bridges a gap, enhancing the predictive accuracy and efficiency of TES systems.

Utilization of methods and techniques for the study

The methods and techniques employed in this thesis, including CFD models and second law thermodynamics, were adeptly utilized to study thermal energy storage systems. The author's application of machine learning models was conscientious, with careful attention to regularization and the avoidance of overfitting, ensuring robust and generalizable results.

Knowledge and orientation of the student in the doctoral thesis discipline

The doctoral candidate exhibits profound knowledge and orientation within the field, as evidenced by their comprehensive review paper, "Stratification analysis of domestic hot water storage tanks," which includes 139 references and has garnered over 80 citations.

Formal level of the thesis

The thesis's formal presentation is its weakest point.

Particularly, its graphical elements don't meet the expected standards. For example, images such as those in Figure 7 on page 13 are noticeably scaled, detracting from their clarity and effectiveness. Additionally, there are instances where the text within figures is so small as to be virtually unreadable, as seen in Figure 6 of the paper "Intelligent data systems for building energy workflow: Data pipelines, LSTM efficiency prediction and more."

Additionally, the text contains formal errors, such as the omission of figure captions and numbering (refer to page 8), and contains confusing formulations, exemplified by the sentence on page 17: “The sooner the data layer collects the data from the experimental setup, it dynamically plots the temperature profile of TES and heat pump parameters.”

The last comment pertains to a notable error found in the journal papers concerning the formulation of mathematical expressions. Specifically, in the paper "Second law performance prediction of heat pump integrated stratified thermal energy storage system using long short-term memory neural networks," is in equation 25 expressed residual sum of squares

$$RSS = \sum_{i=1}^{n} (e)^2 = \sum_{i}^{n} [y_i - (m + bx_i)]^2 \tag{25}$$

Certain symbols in this equation are omitted from the nomenclature table. However, a more severe issue arises in equation 26, where the sum of residuals is equated to a different term that also incorporates regularization

$$RSS(L1) = \sum_{i=1}^{n} (e)^2 = \sum_{i}^{n} [y_i - (m + bx_i)]^2 + \lambda \sum_{j}^{m} W_j^2 \tag{26}$$

This mistake is particularly surprising as it was overlooked during the peer review process, especially considering that the same error recurs in the paper "Intelligent data systems for building energy workflow: Data pipelines, LSTM efficiency prediction, and more" (Equations 22 and 23). Despite the author's apparent understanding of different cost function formulations, these inaccuracies represent a significant formal error that could lead to confusion.

Conclusion

In conclusion, despite formal deficiencies, this doctoral thesis effectively fulfills the requirements expected for a doctoral degree, presenting theoretical and applied advancements in thermal energy storage. The candidate has demonstrated profound expertise and made commendable contributions to the field. I **recommend** that, upon successful oral defense, the candidate, Yogender Pal Chandra, be awarded the deserved Ph.D. title.

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