CHARACTERIZATION OF ANFIS-SC METHOD ON POWER PEAKING FACTOR

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ABSTRACT

Prediction of power peaking factor (PPF) using ANFIS method at TRIGA research reactor has been conducted in the previous study and resulted in good predictive performances. This method could be implemented as a real-time monitoring system for various reactor types. In this paper, the ANFIS-SC trained models will be characterized to investigate the generalization capability of the models against new input data. Three ANFIS-SC trained models adopted from the previous study with 0.45, 0.45, and 0.50 of the cluster radii were chosen for this characterization study. Based on the statistical analysis, the correlation coefficients of the trained models show a weak relation between predicted and actual output. The Means Absolute Error (MSE) and Root Means Square Error (RMSE) were near to zero in the range of 7.2112×10^{-7} – 9.4304×10^{-7}. However, the average output of all the trained models was in the range of 1.8722 - 1.8724 while the average output of the actual PPF is 1.8728. This statistical result shows that the generalization capabilities of the ANFIS-SC method were excellent and could be improved further with a deep learning mechanism for exact prediction performances. Besides, the ANFIS-SC method also can be applied for PPF monitoring at the control room of the nuclear reactor for enhancing the reactor operation as well as for education and training.

ABSTRAK

Ramalan faktor memuncak kuasa (PPF) menggunakan kaedah ANFIS di reaktor penyelidikan TRIGA telah dijalankan dalam kajian lepas dan menghasilkan prestasi ramalan yang baik. Kaedah ini boleh dilaksanakan sebagai sistem pemantauan masa nyata untuk pelbagai jenis reaktor. Dalam kertas kerja ini, model terlatih ANFIS-SC akan dicirikan untuk menyiasat keupayaan generalisasi model terhadap data input baharu. Tiga model terlatih ANFIS-SC yang diguna pakai daripada kajian terdahulu dengan 0.45, 0.45, dan 0.50 jejari kelompok telah dipilih untuk kajian pencirian ini. Berdasarkan analisis statistik, pekali korelasi model terlatih menunjukkan hubungan yang lemah antara output yang diramalkan dan sebenar. Mean Absolute Error (MSE) dan Root Means Square Error (RMSE) adalah hampir kepada sifar dalam julat 7.2112×10^{-7} – 9.4304×10^{-7}. Walau bagaimanapun, purata keluaran semua model terlatih adalah dalam julat 1.8722 - 1.8724 manakala purata keluaran PPF sebenar ialah 1.8728. Keputusan statistik ini menunjukkan bahawa keupayaan generalisasi kaedah ANFIS-SC adalah sangat baik dan boleh dipertingkatkan lagi dengan mekanisme pembelajaran mendalam untuk prestasi ramalan yang tepat. Selain itu, kaedah ANFIS-SC juga boleh digunakan untuk pemantauan PPF di bilik kawalan reaktor nuklear untuk meningkatkan operasi reaktor serta untuk pendidikan dan latihan.

Keywords: TRIGA research reactor, power peaking factor, ANFIS-SC trained models, deep learning mechanism

INTRODUCTION

Power peaking factor (PPF) is one of the reactor safety parameters that require continuous monitoring for safe reactor operation. It can be defined as the local maximum power density to the average power density in a fuel rod. The PPF is important to prevent fuel rods from melting which could lead to severe reactor incidents. Commonly, the PPF was calculated using a neutronic calculation such as MCNP, SRAC-Citation, and GETERA-93 code [1-3].

Besides, artificial intelligence (AI) methods also have been used widely in nuclear applications for the PPF parameter calculation through estimation and prediction as well as for fault diagnosis and control to enhance reactor safety and operations [4]. Although there are sophisticated computational codes for reactor design, safety analysis, and simulate various calculations in the multi-physics application, however, it has several limitations such as requiring complex geometry defining, high computer performances, and time-consuming [5]. These limitations could be eliminated by using AI methods to approximate the problems in simple ways and requires less computation time.

Various studies have been conducted to address the accuracy of the AI methods in predicting the PPF parameters. For instance, the application of a support vector machine for PPF prediction was promising with excellent generalization and fast calculation [6]. Moreover, a cascade fuzzy neural network a neural network and an adaptive neuro-fuzzy inference system (ANFIS) have also resulted in an accurate PPF estimation which could be implemented in the reactor monitoring systems [7-9].

However, published work done by [9] as not addressed the validation procedure to evaluate the model's performances with the new datasets. Thus, in this work, the extension of the ANFIS model's performance characterization will be conducted to investigate the generalization capabilities of the trained models against the unseen datasets on estimating the PPF parameters. The selection of the trained ANFIS models is based on the subtractive clustering approach (ANFIS-SC) as the input partitioning which will be adopted from the previous study. Details on the methodology, results, and discussion of the ANFIS-SC trained models' characterization can be obtained in the next sections.

MATERIALS AND METHODOLOGY

The trained models based on the ANFIS-SC method were adopted from previous work where extensive training and testing procedures have been conducted for three partitioning approaches which are grid-partition (GP), subtractive clustering (SC), and fuzzy C-mean (FCM) to predict the PPF at Reactor TRIGA PUSPATI (RTP). According to [9] four trained models as tabulated in Table 1 with their respective training status were chosen to be tested further in performance validation. These models were selected due to experiencing the good training session and no overfitting can be observed which depicted the models with good fit training status and accurate prediction performances.

Therefore, in this characterization study, three models based on SC were selected to investigate the generalization capabilities of this partitioning approach. This is due to the SC having resulted in high prediction accuracy in predicting the 2nd law efficiency than the GP approaches in [10] work. Hence, this study will be focusing on the SC approach only to identify an excellent ANFIS model for PPF prediction at RTP.

The input data which are neutron flux and control rods position were collected at RTP while the output data was calculated using TRIGLAV code. These input-output datasets consist of the new dataset which has not been used in training and testing sessions previously. The trained models were tested by inserting the new input data to predict the PPF output and were compared with the actual output to evaluate the model's capability in predicting the PPF output with unseen datasets. Three statistical analyses which are correlation coefficient (R^2) as in Equation 1, MAE in Equation 2, and RSME in Equation 3 were calculated to examine the characterization of these models on PPF prediction. Figure 1 depicted the entire methodology for conducting this study.

Table 1. Good fit trained models adopted from previously published work

Model	Partitioning approaches	Cluster Radius/Membership function	Training RMSE (10^{-4})	Status
1	SC	0.40	1.5729	Good fit
2	SC	0.45	1.6224	Good fit
3	SC	0.50	1.8721	Good fit
4	GP	*gaussmf*	1.0928	Good fit

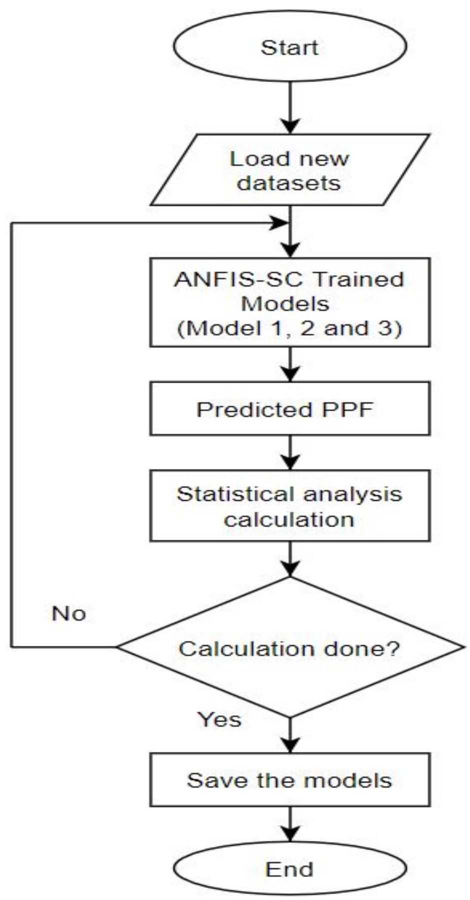

Figure 1. Flowchart for the ANFIS-SC trained model's characterization

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Y_{act} - Y_{ANFIS-SC})^2}{\sum_{i=1}^{n}(Y_{act} - \bar{Y}_{act})^2} \quad (1)$$

$$MAE = \frac{1}{n}\sum_{i-1}^{n}|Y_{act} - Y_{ANFIS-SC}| \quad (2)$$

$$RMSE = \frac{1}{n}\sum_{i-1}^{n} |Y_{act} - Y_{ANFIS-SC}| \quad (3)$$

where;
Y_{act} = Actual PPF
$Y_{ANFIS-SC}$ = Predicted PPF by ANFIS-SC

RESULTS AND DISCUSSION

Figure 2 depicted the actual PPF against the predicted PPF calculated in ANFIS-SC trained models. While Table 2 summarized the statistical analysis of these models. Based on the results, it can be seen that all trained models experience weak R^2 in the range of 0.1844-0.2389. This can be reflected in Figure 3 where the predicted PPF has a significant increasing pattern at the beginning and decreasing pattern at the end of the dataset similar to the reactor power pattern. Hence, the calculated R^2 was low and could not shows the strong relationship between actual and predicted outputs. As for the MAE and RMSE, all the trained models were having a smaller value near to zero in the range of 7.2112 x 10^{-7} to 9.4304 x 10^{-7}. Besides, the average of the predicted PPF value were having differences in the range of 0.02% to 0.03% compared to the actual PPF average.

Table 2. Statistical analysis of the ANFIS-SC trained models

Models	Cluster Radius	R^2	MAE (10^{-7})	RMSE (10^{-7})	Average PPF
1	0.40	0.2218	8.8932	9.4304	1.8722
2	0.45	0.1844	7.2112	8.4919	1.8724
3	0.50	0.2389	8.8219	9.3925	1.8722
				Average Actual PPF	1.8727

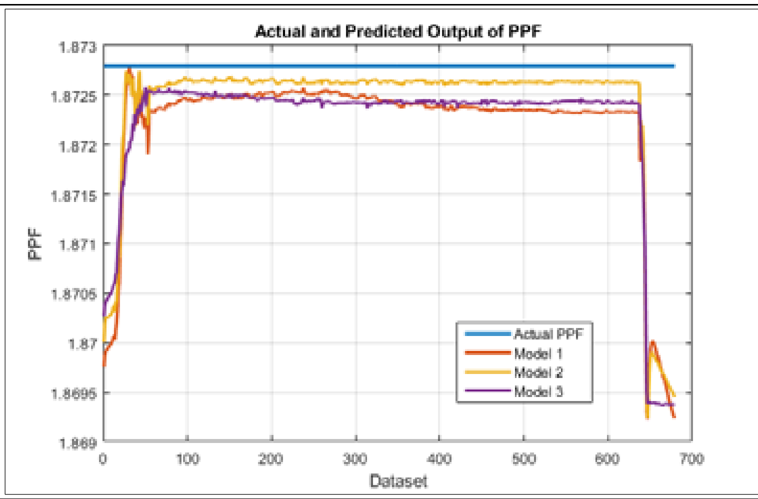

Figure 2. PPF comparison on both Actual and Predicted values

Among all models, Model 2 has the lowest MAE and RMSE which reflected the most accurate prediction of PPF compared to Model 1 and 3. The average predicted PPF of Model 2 was also near to the actual PPF which are 1.8724 and 1.8727 respectively. Hence, this model can be used for continuous PPF monitoring in TRIGA research reactors for enhancing the reactor operation and for training and education purposes. Therefore, with these results, it can be concluded that the trained models of the ANFIS-SC can predict well against the new datasets and proves the good generalization capability of the PPF prediction in the future.

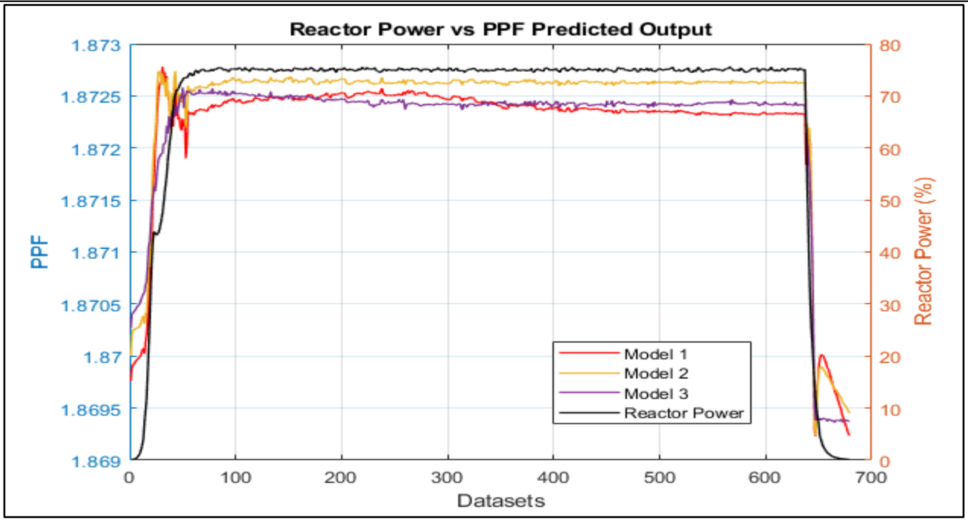

Figure 3. The pattern of Predicted PPF and Reactor power

CONCLUSION

The application of AI for parameter prediction in the nuclear reactor has shown promising results with good accuracy and predictive performances. In this paper, the characterization of the ANFIS models for PPF parameter prediction was conducted to identify the performances of the ANFIS-SC models when dealing with unseen datasets. From the results, the average PPF prediction for both actual and predicted values has differences between 0.02% to 0.05%. While the MSE and RMSE were near to zero and demonstrate accurate predictions. According to the results, all the ANFIS-SC trained models have good generalization capabilities and can predict the PPF parameters accurately. Therefore, in conclusion, the ANFIS-SC could be used for accurate PPF prediction and can be implemented in the real-time monitoring system with 0.45 as the optimum radius cluster at TRIGA research reactors for continuous PPF monitoring.

REFERENCES

[1] Khan, M. J. H., Rana, M. M., & Islam, S. M. A. (2017). Analysis of Power Peaking Factors of 3 MW Triga Mark-II Research Reactor Using the Deterministic Diffusion Code SRAC-Citation. International Journal for Research in Applied Science & Engineering Technology (IJRASET), 5(VI), 390–396.

[2] Mohamad Hairie Rabir, Muhammad Rawi Md Zin, Mark Dennis Usang, Abi Muttaqin Jalal Bayar, and Na'im, Syauqi Bin Hamzah, (2016). 'Neutron Flux and Power in RTP Core-15', AIP Conference Proceedings 1704, pp. 050018-1-050018-11.

[3] Anisur, R. S., & Uvakin, M. A. (2020). Investigation of the power peaking factor K r in the fuel assembly during the maneuvering mode of the VVER-1000 reactor. Journal of Physics: Conference Series, 1689, 12029. https://doi.org/10.1088/1742-6596/1689/1/012029

[4] Suman, S. (2021). Artificial intelligence in nuclear industry: Chimera or solution? Journal of Cleaner Production, 278, 124022. https://doi.org/10.1016/j.jclepro.2020.124022

[5] Serikov, A., Fischer, U., Grosse, D., Leichtle, D., & Strauss, D. (2011). High performance computations of monte carlo radiation transport for ITER fusion neutronics. Workshop on Computational Methods in Science and Engineering, SimLabs@KIT 2010 - Proceedings, 2, 135–148.

[6] Sanchez, P. P., & dos Santos, A. (2021). Prediction of the Power Peaking Factor in a Boron-Free Small Modular Reactor Based on a Support Vector Regression Model and Control Rod Bank Positions. Nuclear Science and Engineering, 195(5), 555–562. https://doi.org/10.1080/00295639.2020.1854541

[7] Back, J. H., Yoo, K. H., Choi, G. P., Na, M. G., & Kim, D. Y. (2017). Prediction and uncertainty analysis of power peaking factor by cascaded fuzzy neural networks. Annals of Nuclear Energy, 110, 989–994. https://doi.org/10.1016/J.ANUCENE.2017.08.006

[8] Pirouzmand, A., & Dehdashti, M. K. (2015). Estimation of relative power distribution and power peaking factor in a VVER-1000 reactor core using artificial neural networks. Progress in Nuclear Energy, 85, 17–27. https://doi.org/10.1016/J.PNUCENE.2015.06.001

[9] Mohd Ali, N. S., Hamzah, K., Idris, F., Basri, N. A., Sarkawi, M. S., Sazali, M. A., Rabir, H., Minhat, M. S., & Zainal, J. (2021). Power peaking factor prediction using the ANFIS method. Nuclear Engineering and Technology (In-Press). https://doi.org/10.1016/j.net.2021.08.011

[10] Gill, J., Singh, J., Ohunakin, O. S., Adelekan, D. S., Atiba, O. E., Nkiko, M. O., & Atayero, A. A. (2020). Adaptive neuro-fuzzy inference system (ANFIS) approach for the irreversibility analysis of a domestic refrigerator system using LPG/TiO 2 nanolubricant. Energy Reports, 6, 1405–1417. https://doi.org/10.1016/j.egyr.2020.05.016