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Hybrid modified evolutionary particle swarm optimisation-time varying acceleration coefficient-artificial neural network for power transformer fault diagnosis

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ABSTRACT

In power transformer fault diagnosis, dissolved gas analysis (DGA) has been widely used to identify the type of the fault. The common methods of DGA are IEC 60599 method, Doenenberg's ratio method and Roger's ratio method. The accuracy of the DGA diagnosis will determine the cost, duration and workload of the maintenance since it can influence the error in the maintenance. Although DGA methods have been used widely, sometimes they still yield incorrect diagnosis results. Thus, many works on transformer fault diagnosis have been proposed previously, which include artificial intelligence methods, to improve the accuracy of transformer fault diagnosis. However, the accuracy of the previously reported works is believed to have rooms for improvement. Therefore, in this work, hybrid modified evolutionary particle swarm optimisation-time varying acceleration coefficient (MEPSO-TVAC)-artificial neural network (ANN) was proposed for transformer fault diagnosis based on dissolved gas data. This is due to these two methods have never been proposed for transformer fault diagnosis in the past. The performance of the ANN was optimised through the proposed MEPSO-TVAC. The superiority of the proposed method was demonstrated through comparison with the existing DGA methods, unoptimised ANN and previously reported methods in literatures. The comparison shows that the proposed hybrid MEPSO-TVAC-ANN obtained the highest accuracy among all methods, which can then be used for power transformer fault diagnosis.

1. Introduction

One of the most important components in power system networks is power transformer, which changes the level of system voltage from one magnitude to another magnitude. Faults in transformer will cause power system outage, resulting in loss of revenue and hardship to consumers. Phenomena which can contribute to transformer faults are corona, partial discharge, sparking, arcing and overheating. Therefore, transformer condition diagnosis, monitoring and maintenance are important.

Transformer fault identification is important in reducing the maintenance cost and repair time to restore the power supply. The most widely used transformer fault identification method is dissolved gas analysis (DGA). DGA is analysis based on the amount of dissolved gas in transformer oil, which is taken directly from the transformer tank [1]. Examples of dissolved gas in transformer oil are hydrogen (H_2), carbon monoxide (CO), acetylene (C_2H_2), ethylene (C_2H_4), methane (CH_4) and ethane (C_2H_6) [2,3]. The existing DGA methods include IEC 60599 method, Roger's ratio method and Doenernberg's ratio method. Although DGA methods are widely used, the diagnosis sometimes lead to incorrect fault type identification and the analyses are heavily relied on experience personnel and experts. Therefore, many works have been proposed to improve the performance of the existing DGA methods.

The proposed methods of improving the performance of the existing DGA methods include consideration of artificial intelligence and optimisation techniques [4–10]. Artificial neural network (ANN) has been one of the methods widely implemented in transformer fault diagnosis improvement [2,11–15]. It is also widely used in the improvement of power system monitoring, security, stability and fault detection method [16–23]. ANN can handle data which have highly nonlinear relationships and it can also generalise solutions of a new data set [24]. Mainly, the dissolved gases and fault type from DGA data are used as the input and output in the training stage of neural networks. The limitation of using ANN is the parameters and properties of the ANN must be

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chosen properly so that the performance of the ANN can be optimised.

Wang et al. in their works have developed a combined ANN with expert system tool (ANNEPS) for transformer fault diagnosis [4]. The performance of the ANNEPS was compared with one of the existing DGA methods, the Roger's ratio method (RRM). It was shown that ANNEPS detected more correct fault case compared to RRM as ANNEPS can solve the problem of "no decision" case in RRM. ANNEPS is also more accurate than individual expert system and ANN alone in detecting the transformer fault. However, the work did not mention how the properties of the ANN were selected. Hence, the optimum performance of the ANN used in the work might not be achieved.

Malabanan and Nerves proposed a hybrid ANN and artificial immune system (AIS) in power transformer condition assessment based on DGA [7]. There are two sets of data used, which the first set consists of three inputs and the second set consists of four inputs. The inputs are various gas concentrations, gas ratio and gas rates. The trained network made 32 correct diagnosis out of 40 samples in the first set while 25 out of 30 samples in the second set. Comparison of the proposed ANN-AIS method with other conventional DGA methods shows that the accuracy of the proposed method is better. However, the work did not mention how the properties of the ANN were selected. Hence, the optimum performance of the ANN used in the work might not be achieved.

Shintemirov et al. have implemented bootstrap and genetic programming (GP) algorithm for power transformer fault classification [5]. Equalisation of data sample for various fault type can be achieved by using bootstrap pre-processing. GP was utilised for the purpose of categorising features for each fault type based on the data used. To validate the proposed method, the accuracy of GP combined with ANN, support vector machine (SVM) and K-nearest neighbour was compared. The proposed GP-KNN yields 92.11% accuracy in the power transformer fault classification, which is the highest among the other two techniques. However, the work did not mention how the properties of the ANN were selected. Hence, the optimum performance of the ANN used in the work might not be achieved.

Huang in their works, proposed genetic-based wavelet networks (GWNs) in fault identification of power transformer based on DGA [8]. GWN is a network consists of three layers, which are summing, weighting and wavelet layers. The presented GWNs were tested on an electrical utility diagnostic data. By comparing with conventional methods, such as fuzzy diagnostics method and standard genetic algorithm-tuned wavelet network, GWNs achieved the highest accuracy, which is 93.02% and also less construction time. However, no comparison of the achievement of this work was made with other works.

In [9], Yang proposed self-organising polynomial networks (SOPNs) in identifying transformer fault based on DGA. SOPN was a modelling approach with various layers of functional nodes of low order polynomials. The data samples were obtained from an electrical utility. However, some data samples were obtained by Monte Carlo simulation due to the lack of data. There were two types of SOPN used, which were different in input features selected, such as certain gas ratios. The results show that SOPN achieved accuracy of 97.68%, which is the highest compared to other conventional methods. However, the results from the proposed methods were compared with conventional DGA and ANN only and no comparison was made with other works.

Other intelligence methods have also been implemented in power transformer fault diagnosis in the past based on DGA. This includes support vector machine (SVM) [10,25]. In this work, three types of SVM were used, the binary decision tree, one-against-one and one-against-all. Different data samples were used in different method of SVM. From the diagnosis results, SVM with one-against-one method made 22 correct diagnoses out of 24 samples, or 92% accuracy, which is the highest among other two SVM techniques. However, the performance of the SVM used in this method might not be optimised properly.

ANN has also been combined with optimisation methods in the past. In one of the related works, combination of evolutionary programming with ANN (EPANN) was proposed in detecting the incipient faults in power transformer [26]. An ANN model with two hidden layers was used while the parameters of learning rate and momentum constant were optimised by using evolutionary programming. By comparing ANN alone with EPANN, EPANN yields 95.97% accuracy, compared to 85% accuracy from ANN alone. Thus, EPANN has successfully improved the performance of ANN in identification of transformer fault. However, the results from the proposed methods were compared with conventional ANN only and no comparison was made with other works.

Although works on utilising ANN in transformer fault diagnosis have been widely performed in the past, works on optimising the performance of ANN using optimisation methods are less likely to be found in literatures. Parameters of the ANN, such as the number of neurons and hidden layers, must be selected properly to yield the highest accuracy. Therefore, in this work, hybrid modified evolutionary particle swarm optimisation-time varying acceleration coefficient (MEPSO-TVAC)-artificial neural network (ANN) was proposed for transformer fault diagnosis based on DGA. The performance of the ANN was optimised through the proposed MEPSO-TVAC. This method is denoted as MEPSO-TVAC-ANN. The superiority of the proposed method was shown by comparison with the existing DGA methods, unoptimised ANN and previously reported methods.

The reason of proposing MEPSO-TVAC in this work is the robustness of the existing PSO methods is significantly improved through the modified equation of the velocity of each particle. The movement of particle is diversified, the searching behaviour and exploration capability of particles are enhanced and premature convergence can be avoided. The introduction of TVAC has further improved the performance of the proposed method through a better exploration of the particle towards a better optimum solution.

In this paper, Section 2 describes the existing DGA methods, which include IEC 60599 method, Doenernberg's ratio method (DRM) and Roger's ratio method (RRM). Section 3 describes the implementation of ANN based on dissolved gas input and fault output. Section 4 explains the proposed modified evolutionary particle swarm optimisation-time varying acceleration coefficient (MEPSO-TVAC). Section 5 describes the proposed hybrid MEPSO-TVAC-ANN method. Section 6 reports the results and discussion of the proposed method, existing DGA methods and unoptimised ANN. Finally, Section 7 concludes the achievements of the work.

2. Existing DGA methods

2.1. Doenernberg's ratio method (DRM)

DRM is based on the ratios of certain key combustible gases as the fault type indicators. The ratios have been defined as Ratio 1 ($R1 = CH_4/H_2$), which is the ratio of CH_4 gas to H_2 gas, Ratio 2 ($R2 = C_2H_2/C_2H_4$), Ratio 3 ($R3 = C_2H_2/CH_4$) and Ratio 4 ($R4 = C_2H_6/C_2H_2$). This method requires significant levels of the gases to be present. The fault diagnosis for DRM is shown in Table 1.

2.2. Roger's ratio method (RRM)

RRM also works similar to DRM except that there are 3 ratios being used. The ratios are Ratio 1 ($R1 = CH_4/H_2$), Ratio 2