ARTICLE IN PRESS

Swarm and Evolutionary Computation xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Swarm and Evolutionary Computation

journal homepage: www.elsevier.com/locate/swevo

Estimation of transformer parameters from nameplate data by imperialist competitive and gravitational search algorithms

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ARTICLE INFO

Keywords:
Power transformers
Imperialist competitive algorithm
Gravitational search algorithm
Swarm optimisation
Equivalent circuit

ABSTRACT

Accurate determination of parameters in power transformer equivalent circuit is important because it can influence the simulation results of condition monitoring on power transformers, such as analysis of frequency-response. This is due to inaccurate simulation results will yield incorrect interpretation of the power transformer condition through its equivalent circuit. Works on development of transformer models have been widely developed since the past for transient and steady-state analyses. Estimating parameters of a transformer using nameplate data without performing a single experiment has been developed in the past. However, the average error between the actual and estimated parameter values in the past work using Particle Swarm Optimisation (PSO) and Genetic Algorithm (GA) is considerably large. This signifies that there is a room for improvement by using other optimisation techniques, such as state of the art methods which include Heterogeneous Comprehensive Learning PSO (HCLPSO), LSHADE-EpSin, Imperialist Competitive Algorithm (ICA), Gravitational Search Algorithm (GSA) and others. Since ICA and GSA have advantages over GA and PSO, in this work, estimation of transformer parameters from its nameplate data was proposed using ICA and GSA. The results obtained using ICA and GSA was compared to those using GA and PSO to determine the parameters of transformer equivalent circuit. The results show that GSA performs the best as it gives the lowest average error compared to PSO, GA and ICA. Therefore, the proposed technique using GSA and ICA can give a better accuracy than PSO and GA in estimating the parameters of power transformers. The proposed method can also be applied to estimate parameters of three-phase transformers from their nameplate data without disconnecting them from the grid for testing.

1. Introduction

Power transformer is one of the most important components in power system networks. When there is a transformer failure, the effects are very significant, which include power outage and costly repairs. Each transformer has its own transfer function, which is widely used to analyse its internal condition without dismantle its part. This transfer function can be measured using analysis of frequency-response (FRA) or determined using equivalent circuit of a transformer. Therefore, accurate estimation of parameters in power transformer equivalent circuit is of great importance because it can influence the condition monitoring method of power transformers [1–5]. Since the past, many works have been performed to construct transformer modelling for transient and steady-state analyses [6–10] and to analyse physical phenomena occurring in power transformers [11–14]. Estimating transformer parameters from nameplate data without physical experimental testing using optimisation methods has been developed in the past [1,15–18]. Optimisation methods have become popular among power system applications recently [19–21].

Mohamed et al. developed a method to determine the parameters of one-phase transformer equivalent circuit from its nameplate data with the absence of experiment test using evolutionary computations techniques [1]. In this work, PSO and GA were employed to minimise the objective function, which is the sum of square error of the transformer nameplate data. The square error is calculated as the difference between the actual nameplate data and estimated data. The results show that GA and PSO managed to determine the equivalent circuit parameters of transformers with good accuracy. It was also found that the convergence rate of PSO is faster compared to GA. PSO and GA have been widely used since the past as optimisation algorithm in various applications, including power engineering [22–29].

Meister et al. presented the use of least squares method to estimate

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http://dx.doi.org/10.1016/j.swevo.2017.03.003
Received 17 October 2016; Received in revised form 14 March 2017; Accepted 31 March 2017
2210-6502/

the model parameters of a transformer [30]. This method employs polynomial function approximations to track the transformer model parameters by minimising the distance between the approximation and real functions. Third degree polynomial was found to be corresponded to optimum estimation of the parameters of magnetizing flux of Joule losses and leakage flux while polynomial of second degree can represent the core losses-related parameter. However, the model that has been developed cannot be generalized for other similar transformer ratings. For example, when this model was applied for other similar transformer ratings, there is a large error between the estimated parameter values and the experimental data. This is due to the equation of Joule losses, dispersion flux, magnetizing flux and core losses are not the same for different units of transformer with similar ratings.

Based on Soliman et al. work in [7], an alternative method over conventional short and open circuit tests to determine the N-windings transformer parameters at power frequency in online mode was developed. The method was based on linear least errors square algorithm, which used digitized samples of the input voltage and current and the output voltage and current of the transformer windings. From this method, the transformer parameters that have been successfully estimated are the winding and core parameters.

Thilagar et al. have also performed three-winding transformer parameter estimation using genetic algorithm (GA) [31]. They formulated the objective function to be minimised as the sum of square error percentage between the measured and estimated primary voltage and input power. From the results, the performance of transformer parameters estimation obtained using GA at different load points is quite satisfactory. From this research, it was found that GA could provide a very accurate solution by finding the global optimum solutions whereas conventional optimisation techniques converged to local optimum solutions.

Subramanian et al. estimated an equivalent circuit parameter of a three-winding Transformer using GA and Bacterial Foraging Algorithm (BFA) [15]. The estimated equivalent circuit parameters using BFA have been used to generate load test data. The estimated parameters of the transformer using BFA and GA were compared with the measurement data. It is concluded that BFA gives better performance in optimisation over GA because BFA has estimated the transformer parameters with lower error than GA. The proposed method using BFA gives advantages such as lower mathematical burden, high quality solution, accurate estimate, less computational time and fast convergence.

In the past, PSO and GA have been applied to estimate transformer parameters from nameplate data without experiment tests [1]. However, the average error between the actual and estimated parameter values is between 10% and 24%, which is considerably large. This signifies that there is a room for improvement by using other optimisation techniques, such as Imperialist Competitive Algorithm (ICA) and Gravitational Search Algorithm (GSA). In [32], ICA shows considerable improvement over GA in finding the optimum solution in less computational time with the same population size and iterations. On the other hand, GSA has the ability to find near global optimum solution and provides better results than other nature-inspired algorithms [33].

Since ICA and GSA have advantages over GA and PSO, in this work, a method using ICA and GSA to determine single-phase transformer equivalent circuit parameters from its nameplate data without experiment test is proposed. ICA and GSA were applied to fulfil the nameplate data by minimising an objective function. The proposed technique was tested on three single-phase transformers with different ratings and also comparison with the previously reported works. From comparison between different methods and the previous work in [1], the method that can estimate the parameters of transformer equivalent circuit with the lowest error compared to the actual values can be identified. Hence, the proposed method could be used as an alternative method to determine the power transformer parameters from its nameplate data without measurement in practice.

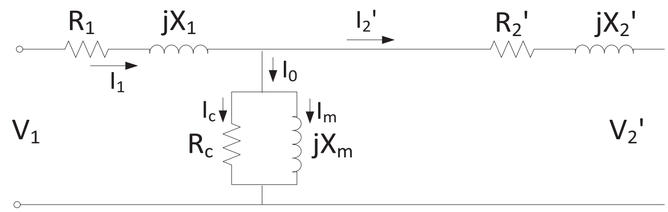

Fig. 1. Equivalent circuit of a transformer by referring to the primary winding.

2. Transformer equivalent circuit and optimisation techniques

2.1. Transformer equivalent circuit

Fig. 1 shows a two-winding transformer equivalent circuit under stable condition by referring to the primary side, where

R_1 = Primary winding resistance
R_2' = Secondary winding resistance referred to primary side
X_1 = Primary leakage reactance
X_2' = Secondary leakage reactance referred to primary side
R_c = Resistance corresponding to core losses
X_m = Magnetizing reactance
I_1 = Primary current
I_2' = Secondary current referred to primary side
V_1 = Terminal voltage on the primary side
V_2' = Secondary terminal voltage referred to primary side
I_0 = No-load current

In this work, the optimum parameters of the transformer are determined using ICA and GSA. The parameters to be determined are R_1, X_1, R_2', X_2', R_c and X_m. The objective function to be minimised by the optimisation methods is the summation of square error between the actual value and estimated value of all transformer nameplate nominal parameters, which are I_1, I_2' and V_2'. It can be written as

$$E = (I_{1actual} - I_{1est})^2 + (I_2'_{actual} - I_2'_{est})^2 + (V_2'_{actual} - V_2'_{est})^2 \quad (1)$$

where $I_{1actual}$, $I_2'_{actual}$ and $V_2'_{actual}$ are the actual nominal nameplate values while I_{1est}, $I_2'_{est}$ and $V_2'_{est}$ are the estimated value using optimisation methods. The actual values are determined from the actual open-circuit and short-circuit tests on the transformer.

2.2. Imperialist Competitive Algorithm (ICA)

ICA is a new evolutionary algorithm for optimisation which is inspired by imperialistic competition [34–40]. Imperialism is the policy of extending the power and rule of a government beyond its own boundaries. The imperialist states compete to increase the number of their colonies by taking possessions of each other colonies and expanding their empires across the globe. This competition will result in a development of the powerful empires while the collapse of weaker ones. In this algorithm, the assimilation policy is modelled by moving the colonies toward the imperialists. Imperialist and colonies are used to represent the possible solutions for an optimisation problem. In ICA, the most important step to reach the optimum global solution is imperialistic competition, which the weakest colony in the weakest empire is picked and having a competition between all empires to possess this colony. The more powerful the empire, the more likely it will possess this aforementioned colony.

For ICA, the algorithm is laid down based on the concept of imperialism. Imperialist states will compete strongly in order to increase the number of colonies possessed by each imperialist and