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An application of artificial bee colony algorithm with least squares support vector machine for real and reactive power tracing in deregulated power system

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ABSTRACT

This paper presents a new method for real and reactive power tracing in a deregulated power system by introducing the hybrid artificial bee colony (ABC) algorithm and least squares support vector machine (LS-SVM), namely as ABC-SVM. The idea is to use ABC algorithm to obtain the optimal values of regularization parameter, γ and Kernel RBF parameter, σ^2, which are embedded in LS-SVM toolbox and adopt a supervised learning approach to train the LS-SVM model. The technique that uses Superposition method is utilized as a teacher. Based on power flow solution and power tracing procedure by Superposition method, the description of input–output for training and testing data are created. The generators' contributions to real and reactive loads in the test system are expected can be traced accurately by proposed ABC-SVM model. In this paper, IEEE-14 bus system is used to illustrate the effectiveness of the proposed ABC-SVM model compared to that of Superposition method. The comparison with the cross-validation (CV) technique and other hybrid technique to obtain the hyper-parameters also has been presented in this paper.

1. Introduction

Throughout the world, the electric power industry is moving towards a deregulated framework where the consumer will have a choice among electric providers to obtain electricity. The aim of deregulation is to optimize the system welfare by introducing competitiveness among participants so this situation can be evolved to become an efficient industry. There are three models that are actively discussed as alternatives to the current vertically integrated monopoly. They are the pool model, bilateral contract model and hybrid model which is the integration of pool and bilateral contract model [1].

Since the last decade, there are lot of techniques and algorithms proposed to trace the power flow and loss allocation, especially in pool based markets. The method that uses proportional sharing method (PSM) proposed by Bialek is one of the well-known methods in literature [2]. The additional fictitious nodes are introduced to overcome the lossy system. This will make the system messy and the matrix for obtaining distribution factors becomes larger which is proportion to the number of transmission lines of the system. The searching technique that adopts PSM to trace real and reactive power can be found in [3] where it is named as nodal generation distribution factor (NGDF). Nevertheless, this technique faces a major problem if implemented on the large test system.

The concept in [4] is based on generator domains, commons and links. These elements need to be defined first before power flow from individual generators can be allocated to which loads. The concept is simple and intuitive for large system. However, the size and shape of a common is subjected to change radically even with a small change in the direction of line flows. Modification of PSM has been done in [5] to trace the real and reactive power transfer by introducing decoupled power flow to overcome the lossy system problem. This approach also introduces equivalent model of a line for reactive power tracing. The effects of line charging to original generators and loads are integrated. However, the actual contribution from individual generators to loads has been ignored. The method called Graph method [6] also adopts the concept of PSM in their tracing method. The method that uses power distance concept which adapted in the linear programming model to allocate the power transfer has been proposed in [7]. Nevertheless, this method only can be used for solving DC model only. The linear programming model to determine the optimal contract with respect to generation/load at all buses has been proposed in [8]. The line flow factors concept has been developed to evaluate the power transaction in bilateral power market.

The hybridization of commons [4], graph [6] and PSM has been proposed in [9]. Even though the results are improved form the

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non-hybrid methods, the method is quite time consuming. The modification of PSM is presented in [10] in reactive power cost allocation. Basically, this method is similar to the method in [5] where the actual contribution of reactive generation is not accounted. The extraction factors matrix technique has been proposed in [11] for calculating load contributions to line flows and losses. This technique is applying PSM for upstream tracing to find out the proportions of the line flows caused by each load. The advantage of this method is no exhaustive search is applied where load shares in line flows are calculated just using one matrix and the additional fictitious nodes are avoided to handle losses. Nevertheless, the extraction matrix is very complex even for the small test system.

The uses of circuit theory in power tracing algorithms are also introduced in [12–16]. Ref. [12] proposed a method that applies superposition theorem to trace the power flow and loss in deregulated system. The integration of *Y*-bus matrix with the equivalent impedance of load bus is performed before this integration matrix is inversed into *Z*-bus matrix. Then, the superposition theorem is applied so that the current injection can be allocated to individual generators.

The method that uses basic circuit theory and partitioning the *Y*-bus matrix to decompose the voltage of load buses as a function of the generators' voltage has been proposed in [13]. This partitioning technique also has been extended in [14–16]. The method form [13] is reevaluated to represent each load current as a function of generators' current and load voltages named as modified nodal equations method (MNE) [14,15]. However, from the results obtained, there are some conditions where the tracing at certain lines or load could be greater than the power produced by its generation. This is due to the existence of counter flow in the tracing results. In [16], partitioned *Y*-bus is applied to design a voltage participation index (VPI) together with the concept of current adjustment factors (CAFs) for the reactive power tracing algorithm. CAFs are a transformation of complex matrix coefficients for adjustment of non-linearity of the network due to real and imaginary factor interactions. The problem of CAFs is it will be very complex if implemented for large system. The extension of Lo and Alturki [16] also has been proposed in determining the real and reactive power loss allocation in pool market [17].

Due to the meshed and nonlinear nature of power system, the applications of Artificial Intelligence (AI) and optimization to power system become popular to explore, especially in power tracing problem. Mustafa et al. [18] incorporated an Artificial Neural Network (ANN) to identify power source to sink relationship in deregulated power system. The Graph method [6] is used as a teacher to train the neural network. The reactive power allocation using modified nodal equation and ANN has been proposed in [19]. The concept of partitioning of the *Y*-bus method [12] is adopted in their tracing algorithm. However, as pointed previously, simulation results show that the reactive power allocation at a certain load can be greater than the reactive power supplied. Moreover, incorporation of ANN into tracing paradigm leads heavy computation time especially at the training stage.

Optimization technique also has been explored in solving the power allocation problem [20–22]. The authors proposed a tracing compliant that minimizes overall deviation from the postage stamp allocation. Nevertheless, this approach treats the power tracing problem as a linear constraint optimization problem. Thus the non-unique results are obtained and the optimization operation is very time consuming. In order to select the correct tracing results, PSM is utilized as benchmarked.

Support vector machine (SVM) is an efficient technique for solving problems in nonlinear classification as well as regression [23]. SVM has been proved to provide better resolutions to boundary and good in generalization performance compared to ANN. SVM has been adopted and applied in various fields such as solving tax prediction issues [24], electricity load forecasting [25,26], security forecast [27], fault classification [28] and many more. It has been said to be very successful and efficient in unfold the prediction problems with small samples, nonlinearity, high dimensional and local minima [29].

Basically, the hybrid models of optimization techniques with SVM have been proposed in literature [26,30,31]. The main objective is same which is to obtain optimal results of the hyper-parameters of SVM. But the design of the developed hybrid model is different where it depends on various fields of problems which want to solve. Yang [26] has proposed the hybridization of LS-SVM with bacterial colony chemo taxis (BCC) in solving short term load forecasting. BCC is applied to determine the optimal parameters of LS-SVM. From the study, it shows that BCC-LS-SVM achieves higher prediction accuracy in a faster manner compared to LS-SVM with grid search as well as ANN. Huang and Wang [30] proposed GA to determine the parameters of SVM including feature selection for classification problem. Their approach significantly improves the classification accuracy with fewer input feature for SVM compared to grid search algorithm. Aydin et al. [31] proposed multi-objective artificial immune algorithm to obtain the optimal parameters of SVM which is basically based on clonal selection algorithm. The method is applied to fault diagnosis of induction motors and anomaly detection.

From the extensive literature reviews, it can be seen that the proposed methodology that adopts the hybridization of ABC and LS-SVM into real and reactive power tracing problem is unique and has not being applied. The new real and reactive power tracing method uses Superposition method as a teacher and incorporates ABC-SVM to calculate the contributions of individual generators to the system loads is proposed in this paper, which are described in the following sections.

2. Superposition method as a teacher

Superposition method was proposed by Teng [12] where it is based on basic circuit theories including KCL, KVL and superposition law. Same with other tracing methods, this method also requires obtaining the solved load flow prior the tracing can be applied. After converged power flow solution, the power tracing is started by obtaining the contribution of voltages and currents which are using the superposition law concept, equivalent impedance and equivalent current injection. Generators in the system are treated as equivalent current injection which injects the current into the system by using the following expressions [12]:

$$S_{n,G} = (P_{n,G} + jQ_{n,G}) \tag{1}$$

$$I_{n,G} = \left(\frac{P_{n,G} + jQ_{n,G}}{V_{n,G}}\right)^* \tag{2}$$

where n is number of generator, $V_{n,G}$ is the generator bus voltage, $P_{n,G}$ is the real power and $Q_{n,G}$ is the reactive power for the generator bus.

For a load bus i, the corresponding equivalent impedance, $Z_{i,L}$ can be obtained using the following expression:

$$Z_{i,L} = \frac{V_{i,L}}{I_{i,L}} = \frac{|V_{i,L}|^2}{P_{i,L} - j(Q_{i,L} - Q_c)} \tag{3}$$

where $V_{i,L}$, $I_{i,L}$ and $S_{i,L} = [P_{i,L} - j(Q_{i,L} - Q_c)]$ are the voltage, current and apparent power of load bus i including the effect of injected MVAR that obtained from the converged load flow solution respectively. The equivalent impedance for each load now is integrated into *Y*-bus matrix where the vector of bus voltages, $\boldsymbol{V_{BUS}}$ can be obtained as follows: