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# Power distribution network reconfiguration for power loss minimization using novel dynamic fuzzy c-means (dFCM) clustering based ANN approach

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ABSTRACT

In this study, a three-layer artificial neural network (ANN) is proposed to reconfigure power distribution networks to obtain the optimal configuration in which the active power loss is minimal. Then, the proposed ANN is reduced in size by transforming the input space with kernels using a proposed modified dynamic fuzzy c-means (dFCM) clustering algorithm to obtain a novel framework. The proposed framework and ANN both are implemented on the two IEEE 33-bus and IEEE 69-bus power distribution networks. The ANN and framework both are trained using the training set consisting of only 64 training samples. The simulated results are compared to the results obtained by performing a selected traditional method which is the switching algorithm. The comparative results explicitly verify that using the proposed framework for distribution networks reconfiguration has some benefits such as a very short process time that is far shorter than the others, a very simple structure including only a minimal number of neurons and higher accuracy compared to the others. These features show that the proposed framework can be effectively used for real-time reconfiguration of power distribution networks.



## Introduction

A power distribution network and a transmission system are the two important parts of an electric power generation and distribution system. The power loss in the distribution network is more than that in the transmission system because the currents available in the distribution part are generally much greater than that in the transmission part. In electric power generation and distribution systems, about 10% of the produced electric power is lost in distribution networks, so minimizing the electric power loss is one of the important problems related to electric power generation and distribution systems [1,2]. In practice, there are two methods for minimizing the power loss in a distribution network. The two methods are the reconfiguration of the distribution network and capacitors placement. The reconfiguration of distribution networks can be also adopted to achieve the other goals such as better voltage profile and better charge balance [3,4]. The limitations of a power distribution network such as radial structure, the capacity of the feeders and the acceptable voltage range of different buses should be practically satisfied for the reconfigured network. In fact, power distribution networks reconfiguration is one of the important problems related to the power systems, so that, there are many recent researches addressing this issue [5–9]. For the distribution networks having a large number of the power switches, the reconfiguration is a multi-objective issue including a non-linear mapping between the input data and the desirable outputs [10,11]. The algorithms presented in the literature for reconfiguring the distribution networks can be divided into the several categories including mathematical optimization methods, switch exchange methods, optimized flow pattern (OFP), and artificial intelligence algorithms [12,13]. A simple method which uses the branches of the network graph and their limitations for network reconfiguration was reported in [1]. A summarized version of the mentioned method was presented in [2]. The summarized method detects the feeding path of each charge, and then, a simple sub-tree is used for each path reconfiguration. The defect of the mathematical optimization techniques is to consume a long time for calculation, so when these methods are implemented on a real distribution network, increase in the size of the network leads to a serious problem. The switch exchange method (SEM) was introduced in 1988 [14]. The method estimates the power loss in each state of the positions of the power switches. The OFP is an innovative method which was introduced for the first time by Shirmohammadi in 1989. This method is also known as sequential switch opening method (SSOM). Application of genetic algorithm

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(GA) for the reconfiguration of power distribution networks was first reported in [15]. A research about providing load patterns, and then carrying out the feeders reconfiguration using patterns detection was presented by Hoyong et al. [16]. A similar ANN approach for power network reconfiguration was proposed in [17]. Hopfield network was used for the reconfiguration of distribution networks by Tang et al. [18]. The major defect of the methods presented in [17,18] is that they can be implemented only for small size distribution networks. The process proposed by Hoyong et al. [16] together with classifying the loads into residential, commercial and industrial types was used for networks reconfiguration in [19].

The clustering techniques are used to classify different sets of physical parameters and events [20,21]. A number of clustering techniques such as local maxima search and search neighborhoods are defined and reported in the literature [21]. Some clustering techniques such as deterministic annealing intensively depend on the data pattern while some other techniques such as generic clustering algorithm do not have this defect. Clustering techniques such as connected-cell search and k-means clustering are called "hard" because they determine and assign a data point to a cluster. The assigned data point either lies in a cluster or not, so the clusters which have overlapping area cannot be effectively distinguished [21]. To address this defect, fuzzy clustering techniques were presented. In a fuzzy clustering, data points are represented by a membership degree which indicates the dependence of a data point to a cluster. Thus, a data point may simultaneously lie in more than one cluster, so an affective detection of overlapping clusters can be performed [21]. An important type of the fuzzy clustering techniques is called fuzzy c-means (FCM) [22–24]. A modified version of the FCM algorithm in which the clusters are dynamically found was presented in [21]. The modified FCM which has high capability for specifying the non-uniformly distributed clusters is called dynamic FCM (dFCM).

A survey in the literature shows that there are other types of fuzzy clustering dynamic algorithms that inside evolving systems such as dynamically evolving clustering (DEC) [25], hyper-ellipsoidal clustering for evolving data stream (HECES) [26], online evolving fuzzy clustering algorithm based on maximum likelihood estimator [27], density-based clustering for evolving uncertain data stream [28], evolving soft subspace clustering [29], evolving clustering method (ECM) [30] and adaptive learning evolving clustering method (ALECM) [30]. DEC uses cluster weight and distance before generating new clusters that is unlike other approaches that consider either the data density or distance from existing cluster centers [25]. In HECES, sliding window model is used to handle incoming stream of data to minimize the impact of the obsolete information on recent clustering results, and shrinkage technique is used to avoid the singularity issue in finding the covariance of correlated data [26]. In the algorithm proposed in [27], the distance from a point to center of the cluster is computed by maximum likelihood similarity of data. The density-based algorithm presented in [28] gives a method for discovering clusters in evolving uncertain data stream, and probability distance was introduced as a similarity measure. The evolving soft subspace clustering proposed in [29] leverages on the effectiveness of online learning scheme and scalable clustering methods for streaming data by revealing the important local subspace characteristics of high dimensional data. ECM is a kind of efficient online clustering method, which evolved the clusters automatically from data streams. It is a distance- and prototype-based clustering method. The distance of a new incoming sample to the closest cluster center cannot be larger than a threshold value; otherwise a new cluster is evolved [30]. First defect of ECM is that when performing incremental learning from scratch, it is quite not appropriate to set the predefined threshold for a good performing adaptation. As second defect, ECM is quite sensitive to different data orders. To overcome the two mentioned defects, ALECM was proposed in [30] that uses the on-line learning capability by adjusting and evolving the clusters automatically with new incoming samples.

There are also some researches on ANN pruning reported in the literature. Self-adaptive evolutionary constructive and pruning algorithm (SAECPA) that is a structural algorithm was reported in [31]. SAECPA considers an ANN in which one hidden neuron is linked towards single input node, then using cluster pruning (CP) and survival selection (SS) the ANN is pruned. Another method that uses equation synthesis and correlated activation pruning (CAPing) was introduced in [32]. Equation synthesis involves the incremental increase in the number of connections of the trained ANN until satisfactory prediction is achieved. CAPing involves the identification of nodes that have similar effects on the desired output. Comparison of the inputs to these nodes can lead to useful dependency relationships. A method for designing ANNs for prediction problems based on an evolutionary constructive and pruning algorithm (ECPA) was also proposed in [33]. The proposed ECPA begins with a set of ANNs with the simplest possible structure, one hidden neuron connected to an input node, and employs crossover and mutation operators to increase the complexity of an ANN population. Additionally, cluster-based pruning (CBP) and age-based survival selection (ABSS) were proposed as two new operators for ANN pruning. The CBP operator retains significant neurons and prunes insignificant neurons on a probability basis and therefore prevents the exponential growth of an ANN [33].

In this study, an ANN is proposed for distribution networks reconfiguration to obtain the optimal configuration in which the active power loss is minimal. Then, the proposed ANN is reduced in size by transforming the input space with kernels using a proposed modified dFCM clustering algorithm to obtain a novel framework. The proposed framework and ANN both are implemented on two power distribution networks. The simulated results are compared to the results obtained by performing the switching algorithm [34]. The comparative results explicitly show that the proposed framework has higher performance compared to the others.

This paper is organized as follows. Fuzzy clustering and the FCM algorithm are discussed in Section "Fuzzy clustering and FCM algorithm". Section "Dynamic fuzzy c-means algorithm and cluster validity" deals with the proposed dFCM algorithm and the concepts of cluster validity. Distribution network reconfiguration is formulized in Section "Distribution network reconfiguration and the proposed ANN and framework" and the proposed ANN and framework are presented. Simulated results of implementing the ANN and framework on two distribution networks are presented in Section "Simulated results". Finally, Section "Conclusion" concludes the paper.

## Fuzzy clustering and FCM algorithm

Clustering is the process of grouping or dividing a series of data from unlabeled patterns into a number of groups which are called clusters, so that, the similar patterns are allocated to one cluster. Each pattern can be shown with a vector which has different parameters and properties. Clustering technique includes two basic criteria which are adjacency measurement and grouping. Adjacency measurement shows the similarity between two points and grouping is used to find an appropriate target function and the related algorithm. Each clustering method determines the similarity between the patterns by calculating the distance between the related patterns. For patterns with metric properties, different types of distance measurement such as Euclid distance or Mahalanobis can be used [21]. Fuzzy clustering is a technical method to allocate data points to different clusters using fuzzy logic which