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# Fault Identification-based Voltage Sag State Estimation Using Artificial Neural Network

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**Abstract**

This paper presents an artificial neural network (ANN) based approach to identify faults for voltage sag state estimation. Usually ANN cannot be used to abstract relationship between monitored data and arbitrarily named fault indices which are not related at all logically in numerical level. This paper presents a novel approach to overcome this problem. In this approach, not only the networks are trained to adapt to the given training data, the training data (the expected outputs of fault indices) is also updated to adapt to the neural network. During the training procedure, both the neural networks and training data are updated interactively. With the proposed approach, various faults can be accurately identified using limited monitored data. The approach is robust to measurement uncertainty which usually exists in practical monitoring systems. Furthermore, the updated fault indices are able to suggest the difference of the impact of various faults on bus voltages.


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*Keywords:* Voltage sag state estimation; artificial neural network; fault indices; power quality; state estimation.

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## 1. Introduction

Recently, the increased awareness of power quality (PQ) issues has led to more research focused on PQ state estimation (PQSE) which covers different types of analysis in PQ area. Voltage sags as one of the most critical power quality problems has attracted great attention in the last decade due to the substantial financial losses to many utilities and industries and frequent disruptions to industrial processes and malfunction of electronic equipment caused by voltage sags [1]. Driven by the need to compare the PQ performance among utility companies or among various feeders, voltage sag state estimation (VSSE) was developed to estimate sag characteristics at unmetered nodes and used for sag assessment. Accurate state estimation of voltage sags allows the operators to be aware of the network performance and develop appropriate network enhancement strategy [2].

Various techniques have been explored for VSSE in literature. Fault position based methods determine the voltage sag magnitude at buses in the network for faults occurring in previously selected fault positions [3]. Since most likely, these methods are not designed to pinpoint the exact fault position, probability based methods have been investigated for VSSE in literature [4]. With the condition identified by the monitoring data, the characteristics of voltage sags at non-monitored buses can be estimated by finding a set of fault positions which are likely to cause the residual voltages. For every possible fault position identified, the residual voltage at all non-monitored buses can be determined by simulating the fault at such a position. The residual voltage can be calculated as a weighted average of all potential residual voltages. Monitor reach area (MRA) method, as one of the most popular and preferred sag monitoring method, is widely used to register voltage sags by faults [5]. MRA defines the region of the network where a monitor is able to register voltage sags caused by faults. A single MRA matrix represents the area of the network where a monitor can detect and capture the voltage sags originated by faults with specific characteristics, such as type, location, and fault resistance, and taking place under particular system conditions such as network topology and generation schedule. The MRA matrix is built for each type of fault and for a number of given voltage thresholds. In this approach, a considerable number of MRA matrices should be built in order to study a reasonable number of fault scenarios. Furthermore, a series of voltage thresholds should be selected and set in advance before being used to build MRA matrix. The effectiveness of sag performance estimation at non-monitored buses obtained from MRA based methods is greatly dependent on the comparison between the actual voltages and the voltage thresholds. Especially with the presence of measurement uncertainty which is very common in practical operation, the information derived from the comparison between the deviated measured voltage residuals and fixed voltage thresholds may mislead and result in inaccurate estimation.

Artificial neural network (ANN), inspired by biological nervous system, is an interconnected assembly of simple processing elements, units or nodes, which allows the network to adapt to and store a set of training patterns through the inter-unit connection weights. ANN is widely applied to various areas such as prediction, curve fitting and clustering etc. It has been also used for solving problems in various areas of power system, ranging from system planning to operation as well as analysis/modeling [6].

This paper proposes a fault position based VSSE method, which employs ANN to register faults, i.e., to associate faults with the voltages at monitored buses. The proposed approach adopts a novel approach for training neural network in ANN. Different from general ANN based methods, the proposed approach updates/modifies the training data simultaneously as the neural network evolves. Given limited monitored data, the proposed approach is able to identify the faults accurately, and allow the voltage sags at unmonitored buses being estimated. The approach eliminates the necessary of setting voltage thresholds in MRA based methods, and has the merit of being robust to measurement uncertainty.

## 2. Problem Description

### *2.1. VSSE by Identification of Fault Location*

Sag monitoring system-level monitoring and estimation are concerned in the study. It intends to estimate the overall power quality of the entire system. This approach requires monitoring usually at a large number of sites and estimating the voltages at sites without monitors. Since it is economically unfeasible to monitor many sites, only a