Engineering Applications of Artificial Intelligence 57 (2017) 50–60

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

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

Development and evaluation of a prototype for remote voltage monitoring based on artificial neural networks

Alex S. Silva[a], Ricardo C. dos Santos[a,*], Fernando B. Bottura[b], Mário Oleskovicz[b]

[a] Center of Engineering, Modelling and Social Science, Federal University of ABC, Av. Dos Estados 5001, CEP 09210-580 Santo André, Brazil
[b] School of Engineering of São Carlos, University of São Paulo, Av. Trabalhador São-carlense, 400, CEP 13566-590 São Carlos, SP, Brazil

ARTICLE INFO

Keywords:
Power quality
Remote voltage monitoring
Hardware implementation
Artificial neural networks
Smart grid

ABSTRACT

This work presents a new solution for remote voltage monitoring in distribution systems based on Artificial Neural Network (ANN). The main advantage of this method is the possibility of monitoring the voltage amplitude in different locations of the distribution system, by using only signals from the utility substation. Initially, the proposed scheme is designed to monitor the voltage amplitude in a specific location of the distribution system. Thus, a methodology to define and evaluate ANNs, as well as to validate the proposed scheme is presented. As a next step, five additional locations are chosen to be monitored and the extended proposed scheme is defined and validated. Alternative Transients Program (ATP) is used to simulate the distribution system and Matlab is used to specify ANNs. Finally, a hardware prototype is developed in order to validate the proposed scheme for practical applications. The development environment LabVIEW and its data acquisition platforms (real-time and non-real-time) are used for the hardware implementation, while real signals are used in the evaluation process. Results from simulations and experiments are compared, proving the effectiveness of the scheme presented in this paper.

1. Introduction

Currently, a large number of papers have been published and researches have been carried out to address power quality (PQ) issues. In this context, voltage sag has a special interest, since it is the most frequent event in distribution systems and may lead to failure or malfunctioning of sensitive equipments (Dugan et al., 2003). Therefore, often voltage sags can result in substantial economic losses (Heine et al., 2002).

To ensure that correct actions will be taken on the distribution system an efficient scheme considering measuring equipments should be used. However, it is not economically feasible to install such equipments in the whole system, which would be the best-case scenario. Given the importance of minimizing the capital cost and providing an accurate monitoring scheme for the distribution system, many works discussing optimal locations for PQ monitors can be found (Juarez et al., 2009; Eldery et al., 2004; Dong-Jun and Seung-Il, 2008; Avendano-Mora and Milanovic, 2012). Moreover, considering PQ issues, different ANNs based techniques (Devaraj et al., 2007; Singh et al., 2012; Almeida and Kagan, 2011; Deihimi and Momeni, 2012) and hardware implementation technology (Tisan and Cirstea, 2013; Jung and Kim, 2007; Rodriguez et al., 2013; Himavathi et al., 2007) have been used to achieve the expected reliability indices.

Seeking to optimize the number of PQ monitors in distribution networks, the formulation proposed in Juarez et al. (2009) is based on the use of analytical expressions which are valid for any location and that can ensure the complete observability of the power system for any type of fault (balanced or unbalanced). In Eldery et al. (2004) to avoid data redundancy the number of PQ monitors was reduced, resulting in a more efficient monitoring system. A cost function is formulated and the appropriated constraints are defined. The optimization problem is stated and the minimum number and locations of PQ monitors is determined. Reference Dong-Jun and Seung-Il (2008) presents a monitor positioning algorithm to determine the optimal location and number of PQ monitors for a given distribution system. A two-fold monitor placement method is proposed in Avendano-Mora and Milanovic (2012), where a generic formulation of the optimal placement is developed to facilitate robust sag monitoring immune to uncertainties associated with the occurrence of faults. Also, a simplified and more flexible formulation (still accurate) that requires fewer monitors is developed.

In terms of ANNs applied to PQ issues, reference Devaraj et al. (2007) develops an ANN based approach for contingency ranking. Regarding the results presented, this approach takes a short time for

* Corresponding author.
E-mail address: ricardo.santos@ufabc.edu.br (R.C. dos Santos).

http://dx.doi.org/10.1016/j.engappai.2016.10.012
Received 30 May 2016; Received in revised form 10 October 2016; Accepted 20 October 2016
0952-1976/

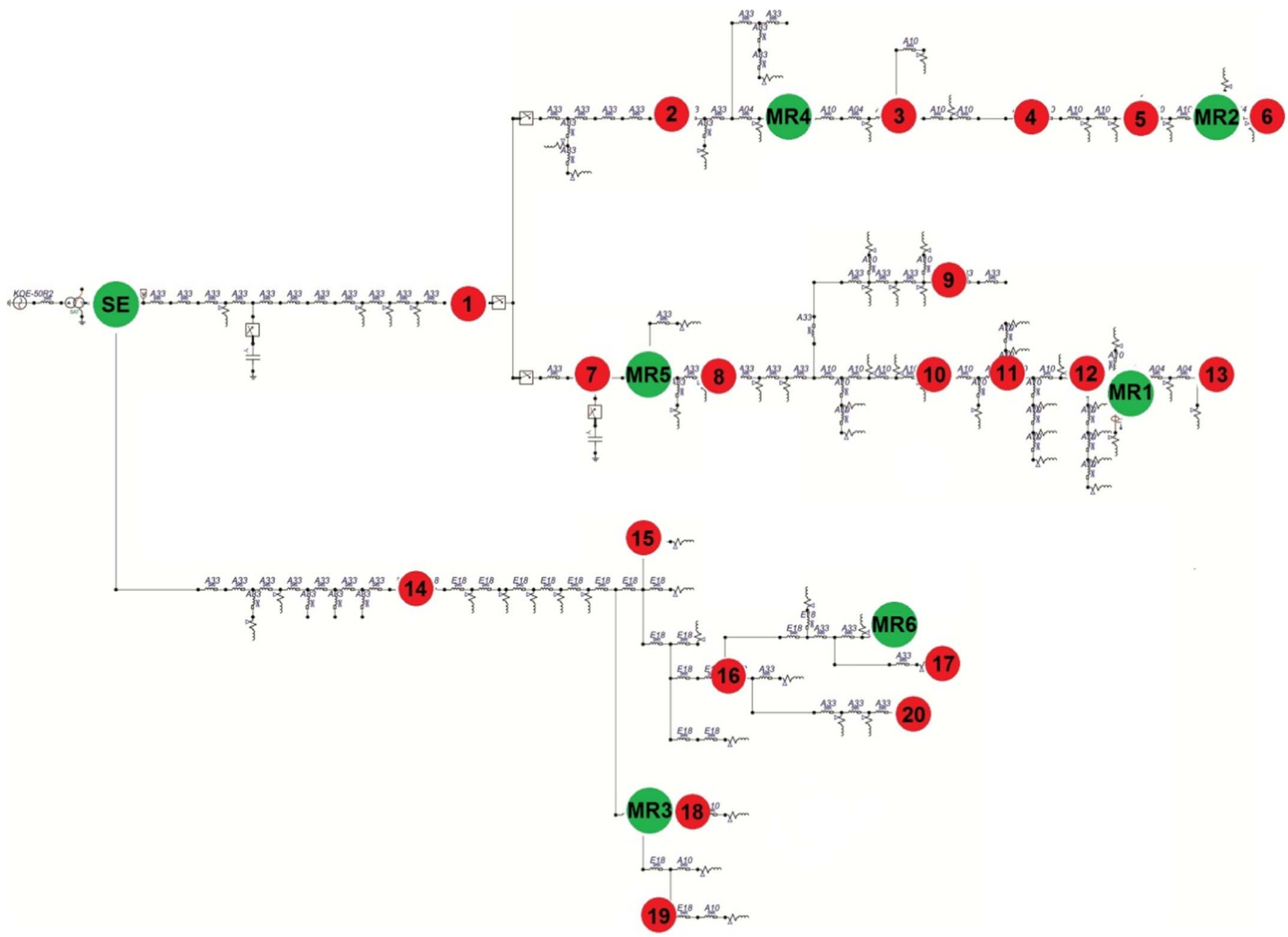

Fig. 1. Adopted distribution system: Main feeder in the substation (SE), measurement locations (MR1 to MR6), and fault locations 1–20.

Table 1
AC source.

Parameters	Value
Amplitude (Vmax) (phase to ground)	71,851.699
Frequency (Hz)	60
Phase (°)	0 degree

Table 2
Mutually coupled RL impedance.

Parameters	Value
Zero-sequence resistance (Ω/m)	20.805
Zero-sequence inductance (mH/m)	203.721
Positive-sequence resistance (Ω/m)	4.062
Positive-sequence inductance (mH/m)	52.5397

training and offers a good performance when considering IEEE 30 bus system. Furthermore, in this work, tests showed that several small networks are better in performance than a large neural network. In Singh et al. (2012) a measurement system of transient disturbances based on ANN is presented. Considering the results obtained, the ANN was able to detect and measure different voltage sags and swells. Reference Almeida and Kagan (2011) proposes a different approach to estimate the voltage values at buses without any PQ monitors, by using information from PQ monitors strategically placed in some buses of the distribution system. This approach reduces the number of meters and hence the cost of the monitoring system. In this approach genetic algorithms and fuzzy logic are used to monitor voltage sags and swells. In Deihimi and Momeni (2012) the authors propose an on-line neural voltage sag waveform estimator for a non-monitored load with sensitivity to voltage sags. In this work the ANN based estimator placed at a monitored location was able to estimate voltage sag waveforms of a non-monitored location.

Table 3
Saturable power transformer.

Parameters	Value
Transformation ratio (a)	3.809524
Nominal primary current (Ip)	131.215970 A
Nominal secondary current (Is)	499.870363 A
Phase shift	30 degree
Primary resistance	0.054695 Ω
Secondary resistance	0.79376 Ω
Primary inductance	1.628 mH
Secondary inductance	23.6258 mH
Magnetization resistence	1 MΩ

With respect to hardware implementation technology, reference Tisan and Cirstea (2013) presents a method for FPGA (Field Programmable Gate Array) implementation of Self-Organizing Map ANNs with on-chip learning algorithm. The advantages of this proposal are high reconfiguration capability and operation under real-time constraints. In Jung and Kim (2007) is presented a hardware implementation of a low cost intelligent ANN controller for non-linear