Conventional Optical Fiber Current Measurements Improved by a High Accuracy Artificial Neural Network Algorithm

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ABSTRACT

This paper relies on an experiment using a conventional fiber optical current measurement system with new concept for signal processing using Artificial Neural Networks. To achieve the high accuracy results, a class 0.1% current standard was used as reference for the ANN processing. Also a large data collection was conducted to assure the high variability of the measurement process behavior, including changes in temperature and other non-linear effects. The results show 0.2% maximum error for the developed system, demonstrating the robustness and high accuracy of the proposed method, being capable of mitigate some drawbacks of FOCS system, like non-idealities compensation.

Keywords: Fiber Optics Current Sensors, FOCS, Signal Processing, Temperature Compensation, Artificial Neural Networks, ANNs.

1. INTRODUCTION

Accurate modeling of physical systems behavior, considering all important variables, often unknowns, represents the master difficulty for scientists that desire reliable and accurate transfer function of the phenomenon under study. This is not different to Fiber Optical Current Sensors – FOCS [1], [2] which, despite of some modern design approaches, still needs attention for old and well known optical problems which affects the sensor signal output, being the two main error sources: the fiber optic sensor temperature dependence [3] and the sensor theoretical model mislead due to non-idealities not included in.

Lack of knowledge about the measuring process and the environment where the measurements are conducted represent examples of this modeling misleading. Thus very often these optical problems produce unacceptable errors, making the measurement system unusable.

To overcome these effects on the FOCS measurement results, this article shows an Artificial Neural Networks - ANN [4], [5] signal processing technique applied to a FOCS system. This method compensates the influences of temperature and non-idealities without the necessity of previous deep knowledge or exact formulation of the physical phenomena. The only knowledge needed become the unknowns that carry the highest error sources. Once this problem is solved, those chosen unknowns must be measured.

The proposed methodology was tested on a real FOCS system in which an ANN was built to process the outputs of the FOCS system, obtaining the wanted electrical current signal through the removal of the temperature effects, fiber birefringence's and other minor real non-idealities.

Even though with the presence of these measuring challenges, FOCS has many benefits over conventional systems that includes: a free of explosion device, a high dynamic measuring range, low weight, electronically compatible with the modern IEC 61850 protocol and with the new electric power Smart Grid - SG standards requirements [6].

This article is an improved extension of a previous research work, [7] where the calibration standard accuracy was high about +-1%. In this new experiment the calibration standard accuracy is about +- 0.1%, ten times better than the old experiment [7], bringing the applicability of the method to rigorous areas, such as the Electrical Power Systems. In this field, accuracy classes for various types of measurements are disposed on the IEC 60044-1 standard [8]. So, the classes 0.1, 0.2s, 0.2, 0.5, 0.5s, 1, and 3 are designated as an approximate measurement of the current transformer's accuracy.

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2. THE FOCS CALIBRATION SYSTEM

The used FOCS (Figure 1) is a classical polarimetric readout system where a linearly polarised wave is rotated in presence of a magnetic field (Faraday Effect) and the output is analyzed by a polarization beamsplitter, with the principal axes oriented at 45° respected to the input. Thus, two signals I_x and I_y are supplied from the photodectors to a summing amplifier and to a differential amplifier. Finally Vx+Vy and Vx-Vy are acquired by the data acquisition system and sent to the ANN algorithm.

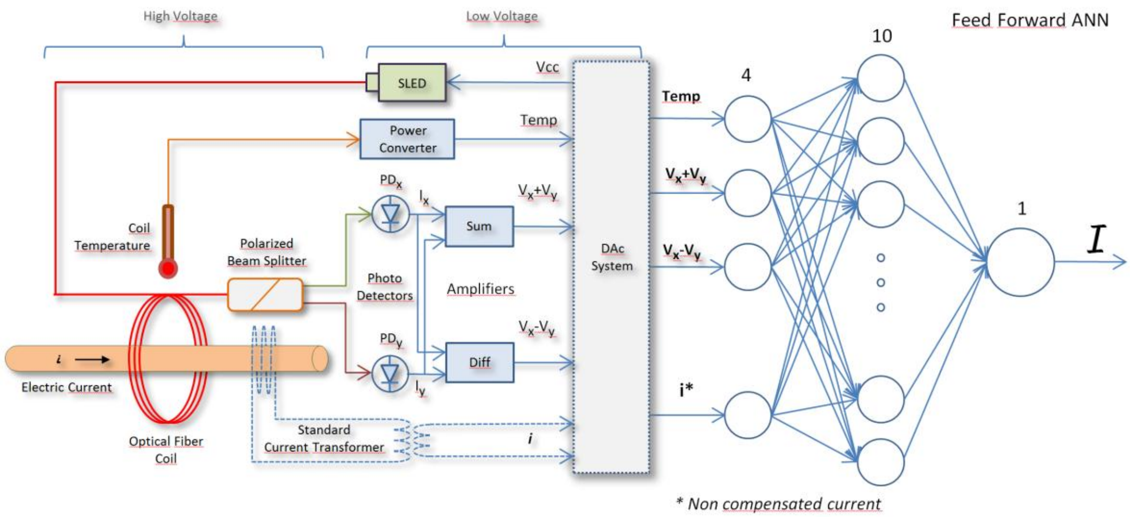

Figure 1 – Fiber optic current sensor system using artificial neural networks signal processing algorithm.

3. THE ANN SIGNAL PROCESSING

According to [4], the Artificial Neural Networks - ANN are signal processors well suited for fitting problems which includes sensor calibration applications, and also being capable to mitigate the systematic errors and at the same time reduces the random portion of errors due to their generalization capacity.

Figure 1 presents the architecture of the ANN applied to the developed FOC system, and the main characteristics are summarized by: multilayer feed forward network architecture, four neurons in the input layer, and ten neurons in the hidden layer and one neuron in the output layer. All neurons of this configuration implement linear transfer functions as neuron output function activator.

Different from previous work [7], at this time, the inputs of the ANN processor are the signals V_x+V_y, V_x-V_y, the non-compensated current (calculated by an analytical formula) and the temperature of the coil. The output of the ANN did not change, however the only change was the current standard that belongs to the 0.1% accuracy class.

With these inputs and outputs arranged, the Levenberg-Marquardt backpropagation algorithm was applied during the training process, according to [4], where such algorithm is well recommended for calibration problems.

Once the training process is done, the ANN algorithm is ready to work integrated to the FOCS prototype built for this experiment, presenting then, high accuracy measurements on real time. This integration is only possible due to the implementation simplicity of ANN after the training process, because the transfer function generated by the training procedure is described as successive sums and multiplication of matrices, [4]. And this kind of computation is easily done by any modern computer.

4. CALIBRATION PROCEDURE

The process of system calibration relies on the data collection of four variables, mentioned above, in a controlled environment. So, six runs of data acquisition were performed in two different temperatures, 22°C and 52°C. To guarantee the modeling generalization and accuracy, the following procedure was adopted:

1- Three runs with coil temperature of 22°C varying the reference current from 200A to 1200A and going back to 200A with 200A steps to get hysteresis effects.
2- Three runs with coil temperature of 52°C varying the reference current from 200A to 1200A and going back to 200A with 200A steps, also to get hysteresis effects.

For the training session of the ANN, it was adopted a random wrapping of the data samples to improve the ANN process generalization. After, this wrapped data set was split in three different subsets. The first, with 70% of this sample set was separated to train the network. The second with 10% was adopted for the training validation and the remaining 20% was applied to test the ANN after training.

After all, the results were checked to assure the correctness of the calibration. Figures 2 and 3 show a comparison between the error distribution along the measuring range of the analytic solution and the ANN signal processing. According to these figures, the ANN processor removed successfully the systematic errors, resulting in a mean error value of 0.007%, against the mean error value of -0.013% for the analytic formula.

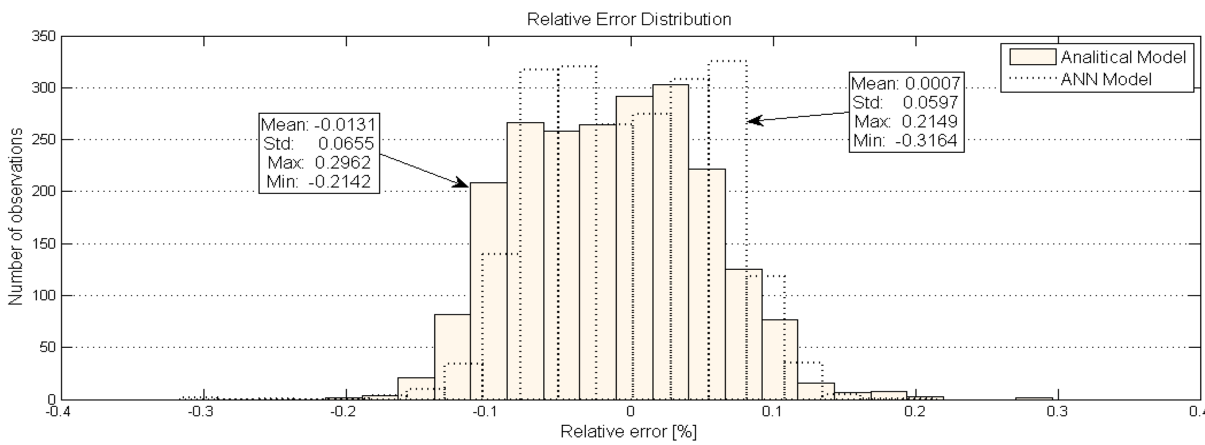

Figure 2 – Calibration curve presenting a liner behavior along the measuring range.

Furthermore, the random errors were slightly minimized and normalized for all measuring range, what also proved the characteristic of ANN generalization of the measurement process, as seen in Figure 3.

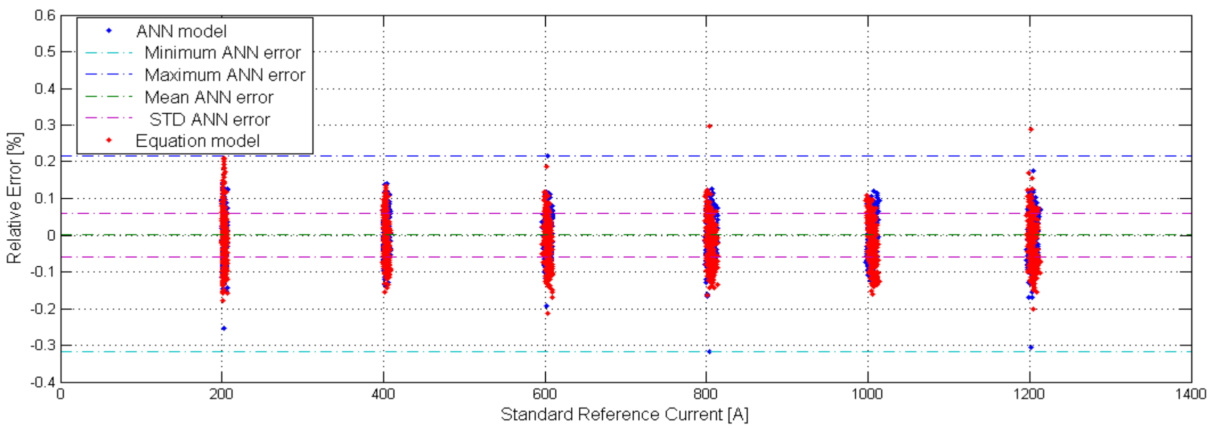

Figure 3 –Relative error distribution comparison between the ANN and the analytical formula.

5. CONCLUSIONS

ANN algorithms for FOCS signal processing represent a new and modern approach to overcome old and recurrent problems. ANN are feasible, realistic and fulfill all the requirements needed for an accurate and real time processing, being perfect to be used in many real applications including electrical power systems. The results showed that the ANN have capability of improve the accuracy of the measurement system even in different temperatures and in a wide electrical current range.

Its mathematical characteristic associated to the human neuron can memorize the behavior of a real data and find a mathematical transfer function that processes real data without the necessity of know all the non-idealities and non-linearity's of the real physical optical system. During the training process, systematic errors are removed from the measurements and the random errors are minimized by the intrinsic characteristic of the ANN as optimal estimator for functions.

The experiment conducted in this paper uses a current standard of 0,1% in a metrological calibration procedure and the results shown that the error of the FOCS prototype was about a maximum of 0,2% in a temperature range of 21°C to 52°C.

Also, the computational efforts are minimized, due to the matrix nature of the ANN mathematics, what decreases the hardware necessities and additionally increases the sensor time response.

Concluding the applied FOCS system with ANN signal processing was capable to measure electrical currents from 200A to 1400A range with accuracy of 0.2% under temperature variations, enabling this prototype to be used as a measurement device class 0.2 on high voltage power systems.

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