Study Committee A3

Transmission and Distribution Equipment

Paper 10133_2022

APPLICATION OF MACHINE LEARNING AND ANOMALY DETECTION FOR ON-LINE DEFECT IDENTIFICATION IN WALL BUSHINGS IN HVDC SYSTEMS

Marcos E. G. ALVES[1], Gabriel S. P. GOMES[1], Murilo M. PINTO[1], Daniel C. P. ARAUJO[1], Bruno F. SARDINHA[1], Sérgio O. FRONTIN[1], Luís R. LOPES[1], Marcio da COSTA[1], Daniel P. SANTOS[1], Rogério A. FLAUZINO[2], Mário L. P. ALVES[3], Priscila M. B. FERREIRA[3], George A. M. LACERDA[3], Denis P. do NASCIMENTO[3]

RADICE TECHNOLOGY[1], USP[2], FURNAS[3]

Itaipu Transmission Systems

The energy generated at 50 Hz in Paraguay is transformed and rectified into direct current, at the Foz do Iguaçu Substation, and transmitted to the Ibiúna Substation, where it is converted to alternating current at a frequency of 60 Hz and sent to the National Interconnected System.

The developed methodology was applied to real operational data collected from 600 kV and 300 kV HVDC wall bushings at Eletrobras Furnas' Ibiúna converter substation, part of the first large HVDC system in Brazil.

Motivation

- Bushings are among the most important components in electrical systems. In converter substations, bushings are used in valve room walls.
- The same hardware and software resources used for monitoring transformer AC bushings is not feasible for this type of bushing.
- Statistical data on defects and failures specific to these types of bushing are not found in literature. However, bushings are the 3rd most common cause of power transformer failures (14%). In power transformers 500 ≤ kV <700, bushings are in the 1st place (30%);
- In partnership with Furnas, Radice/Treetech developed a pilot for monitoring condenser bushings of converter transformers in HVDC systems;
- The motivation of this R&D project is the on-line monitoring of condenser wall bushings in HVDC systems.

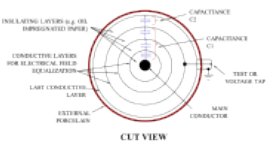
Objectives

Development of Online Monitoring for HVDC Wall Bushings:

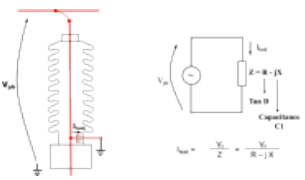
- Detailed design of Hardware and Firmware sensor dedicated to the online detection of changes in dielectric parameters of the insulation of the bushings;
- Detailed Mechanical Design suitable for the best conditions of installation and operation of the IED;
- Software module integrated to Sigma's online monitoring platform, including driver development, diagnostic algorithms, screens, among others.

Condensive Bushings

Constructive Form of a Condenser Bushing



Equivalent circuit of an energized condenser bushing



Study Committee A3

Transmission and Distribution Equipment

Paper 10133_2022

APPLICATION OF MACHINE LEARNING AND ANOMALY DETECTION FOR ON-LINE DEFECT IDENTIFICATION IN WALL BUSHINGS IN HVDC SYSTEMS

Marcos E. G. ALVES[1], Gabriel S. P. GOMES[1], Murilo M. PINTO[1], Daniel C. P. ARAUJO[1], Bruno F. SARDINHA[1], Sérgio O. FRONTIN[1], Luís R. LOPES[1], Marcio da COSTA[1], Daniel P. SANTOS[1], Rogério A. FLAUZINO[2], Mário L. P. ALVES[3], Priscila M. B. FERREIRA[3], George A. M. LACERDA[3], Denis P. do NASCIMENTO[3]

RADICE TECHNOLOGY[1], USP[2], FURNAS[3]

Data Evaluation Methodology

Extraction and Normalization

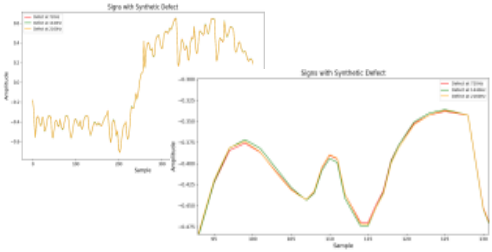
The following signal characteristics were extracted:

- Sum of values;
- Mean;
- Standard deviation;
- Median;
- Maximum Value;
- Minimum Value.

In addition, data normalization was applied to prevent attributes with higher values from impacting the model error more and being privileged during training.

Model Validation

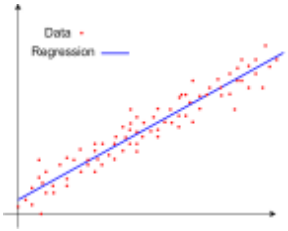
Three signals were created to simulate increases of 5%, 10% and 25% in the values of the Fourier components corresponding to the 12th, 24th and 36th harmonics, respectively.



Supervised Learning

Regression Model

Linear regression models are used to predict the value of a variable based on the value of another variable.



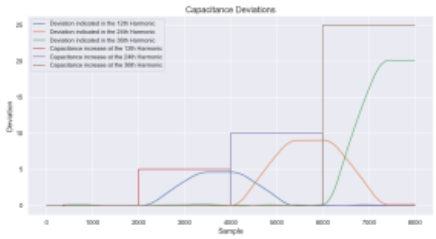
Tests Results

0-2000 samples: No defects, as expected

2000-4000 samples: ~5% defect in the 12th harmonic

4000-6000 samples: ~10% defect in the 24th harmonic

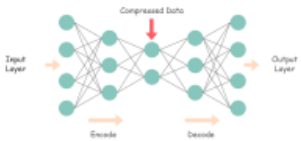
6000-8000 samples: ~20% defect in the 36th harmonic



Unsupervised Learning

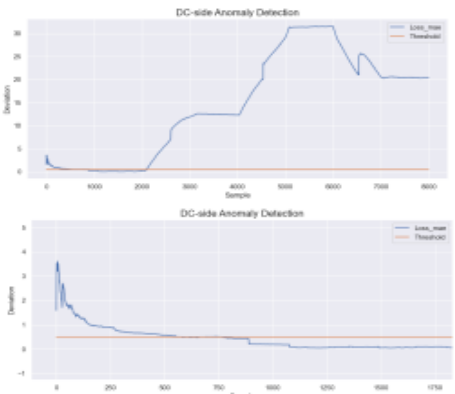
Anomaly Detection with Autoencoders

Autoencoders are neural networks trained to reproduce its inputs to its outputs.



Tests Results

From samples about 750 to 2100 the model stabilized without anomalies. From sample 2100 onwards, the model showed a persistent anomaly.



Study Committee A3

Transmission and Distribution Equipment

Paper 10133_2022

APPLICATION OF MACHINE LEARNING AND ANOMALY DETECTION FOR ON-LINE DEFECT IDENTIFICATION IN WALL BUSHINGS IN HVDC SYSTEMS

Marcos E. G. ALVES[1], Gabriel S. P. GOMES[1], Murilo M. PINTO[1], Daniel C. P. ARAUJO[1], Bruno F. SARDINHA[1], Sérgio O. FRONTIN[1], Luís R. LOPES[1], Marcio da COSTA[1], Daniel P. SANTOS[1], Rogério A. FLAUZINO[2], Mário L. P. ALVES[3], Priscila M. B. FERREIRA[3], George A. M. LACERDA[3], Denis P. do NASCIMENTO[3]

RADICE TECHNOLOGY[1], USP[2], FURNAS[3]

HVDC Bushing Monitoring

The HVDC Wall Bushing Monitor electronic hardware is comprised of Protection and Conditioning, A/D Converters, Isolation, Processing and Communication circuits.

Prototype Installation

Evaluation of prototype's performance in continuous use for real applications.

Conclusion

- The R&D project developed an on-line monitor for HVDC wall bushings and a methodology using two independent Artificial Intelligence models;
- To prove the model's effectiveness, a simulated defect based on expert knowledge was inserted into an actual measurement taken in fieldwork;
- Both models performed well, confirming the feasibility of AI techniques to identify anomalies in HVDC bushings;
- Prototype and methodology validations is currently underway in a real application at Ibiúna substation.

This report presents the main results to date of the R&D project PD-00394-1708/2017, entitled "Monitoração On-line de Buchas de Parede de Alta Tensão em Corrente Contínua (HVDC)", proposed and financed by Furnas Centrais Elétricas and regulated by the ANEEL Program "Research and Technological Development for the Electric Sector."