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Fuzzy Measurement Algorithm for Fault Detection in the Hydrogenerator

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Introduction

Hydrogenerators are exposed to severe stresses and loads of electrical, mechanical, hydraulic and thermal nature, resulting in a large number of potential failures

Fault detection involves the detection, location, and identification of faults.

Three types of unbalances (mechanical, hydraulic and magnetic) can occur in hydrogenerators.

There are two main reasons for the existence of magnetic unbalance: shorted turns in the windings of the rotor poles and geometric asymmetry of the air gap.

Introduction

A novel fuzzy-measurement algorithm (FMA) for the improvement decision making and measuring processes in metrology is proposed in this study.

The algorithm will enable multiple criteria automated assessment based on measurement results in order to avoid potential subjectivity and varied approach based on different expert opinions and nonconforming standards.

Fuzzy-Measurement Algorithm

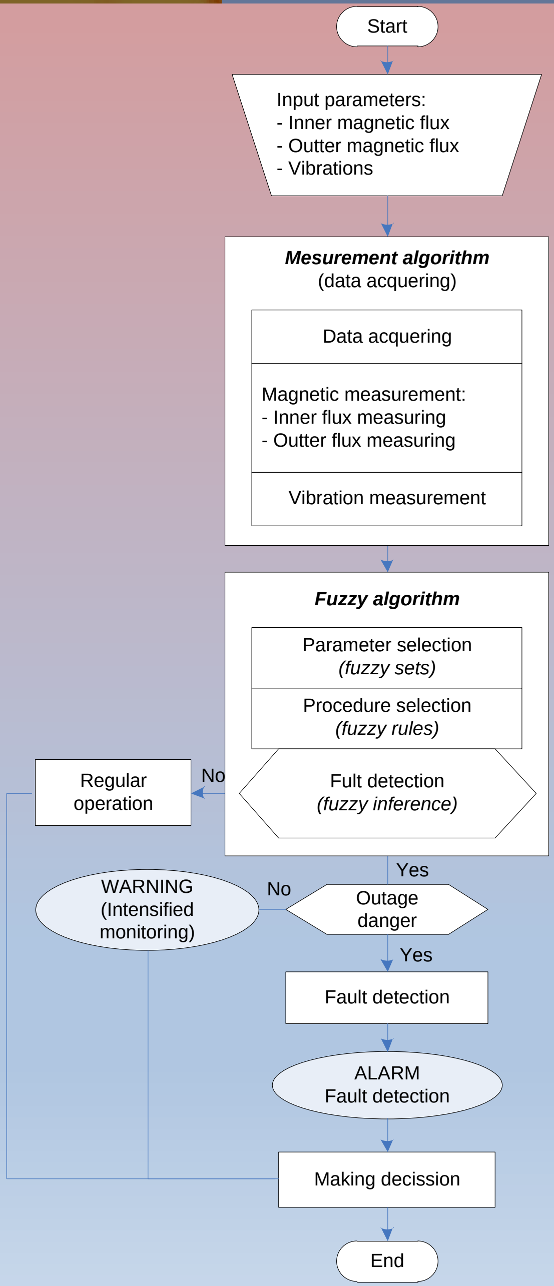
The algorithm was developed to unify complex and diverse measuring methodologies, standards and fuzzy logic control (FLC) into a single entity – a comprehensive methodology for decision-making process.

The proposed algorithm is based on measurement of the main radial magnetic flux in the air gap, leakage radial magnetic flux on the stator housing and mechanical vibrations on the upper guide bearing of hydrogenerators.

The fuzzy model was developed on the principles of the proposed algorithm (FMA).

Fuzzy rules and membership functions were derived from the knowledge and experience gained in situ and in the laboratory environment as well as measurement standards.

Fuzzy-Measurement Algorithm



The algorithm consists of two separate parts. The first one takes into accunt magnetic and vibration measurements and the second one is useful for fuzzy approaching in the making decision.

Fuzzy Logic and Making Decision

Fuzzy set A of universe X is defined by function $f_A(x)$:
$f_A(x) : X \rightarrow \{0, 1\}$,

$$f_A(x) = \begin{cases} 1, \text{if } x \in A \\ 0, \text{if } x \notin A \end{cases}$$

Fuzzy set A of X is defined by function $\mu_A(x)$ called the membership function of set A:
$\mu_A(x)$:X→[0,1], universe

$$\mu_A(x) = 1 \text{ if } x \text{ is totally in } A$$

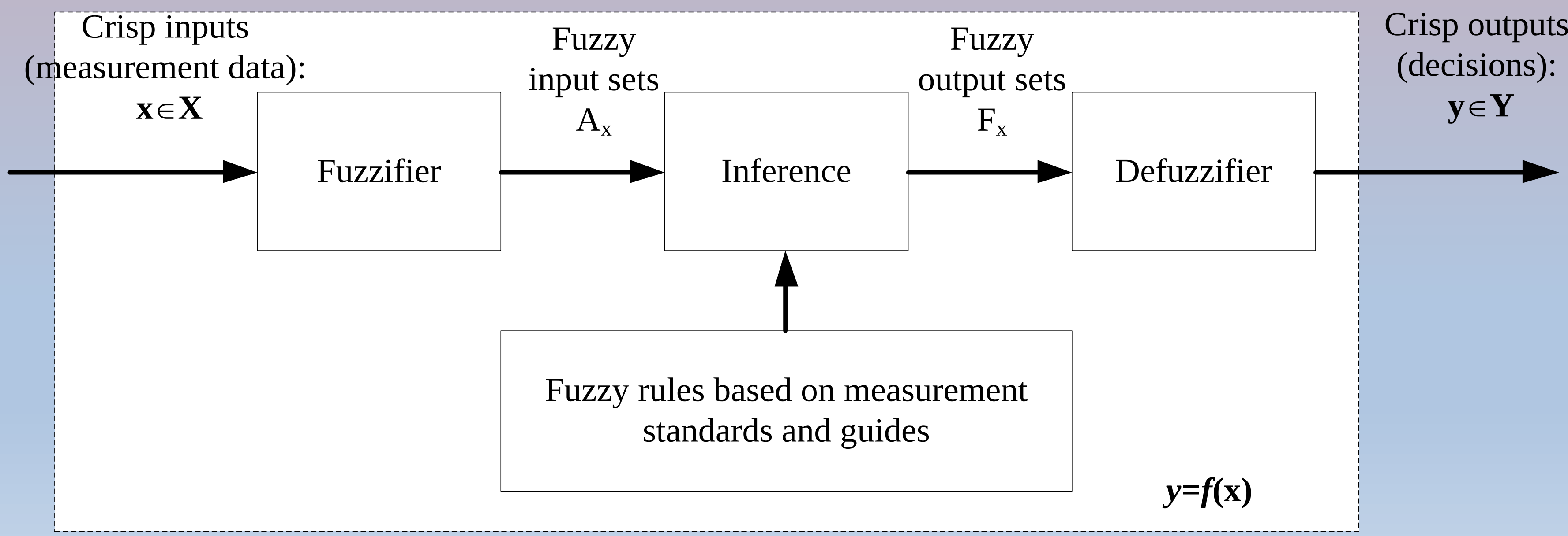
$$\mu_A(x) = 0 \text{ if } x \text{ is not in } A$$

$$0 < \mu_A(x) < 1 \text{ if } x \text{ is partly in } A$$

Fuzzy Logic and Making Decision

FLS is composed of four main components: fuzzifier, fuzzy rules, inference engine, and defuzzifier:

FLS Type-1



The following membership functions are used:

Triangular-shaped membership function:

$$f(x;a,b,c)=\begin{cases}0, & x\le a\\ \dfrac{x-a}{b-a}, & a\le x\le b\\ \dfrac{c-x}{c-b}, & b\le x\le c\\ 0, & c\le x\end{cases}$$

Gaussian curve membership function:

$$f(x;\sigma,c)=e^{\frac{-(x-c)^2}{2\cdot\sigma^2}}$$

Generalized bell-shaped membership function:

$$f(x;a,b,c)=\frac{1}{1+\left|\dfrac{x-c}{a}\right|^{2\cdot b}}$$

Π-shaped membership function:

$$f(x;a,b,c,d)=\begin{cases}0, & x\le a\\ 2\cdot\left(\dfrac{x-a}{b-a}\right)^2, & a\le x\le\dfrac{a+b}{2}\\ 1-2\cdot\left(\dfrac{x-b}{b-a}\right)^2, & \dfrac{a+b}{2}\le x\le b\\ 1, & b\le x\le c\\ 1-2\cdot\left(\dfrac{x-c}{d-c}\right)^2, & c\le x\le\dfrac{c+d}{2}\\ 2\cdot\left(\dfrac{x-d}{d-c}\right)^2, & \dfrac{c+d}{2}\le x\le d\\ 0, & x\ge d\end{cases}$$

The following membership functions are used:

Trapezoidal-shaped membership function:

$$f(x;a,b,c,d)=\begin{cases}0, & x\le a\\ \dfrac{x-a}{b-a}, & a\le x\le b\\ 1, & b\le x\le c\\ \dfrac{d-x}{d-c}, & c\le x\le d\\ 0, & d\le x\end{cases}$$

Z-shaped membership function:

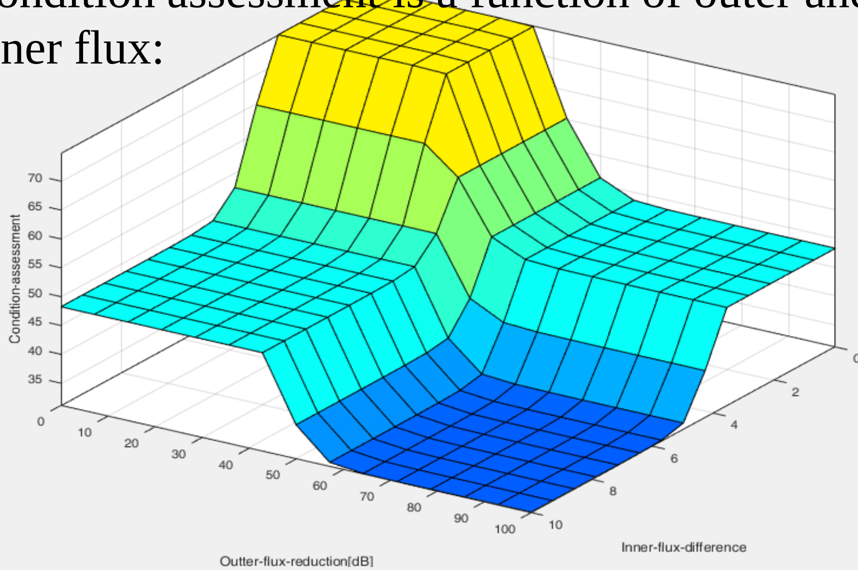
$$f(x;a,b)=\begin{cases}1, & x\le a\\ 1-2\cdot(\dfrac{x-a}{b-a})^2, & a\le x\le \dfrac{a+b}{2}\\ 2\cdot(\dfrac{x-b}{b-a})^2, & \dfrac{a+b}{2}\le x\le b\\ 0, & x\ge b\end{cases}$$

S-shaped membership function:

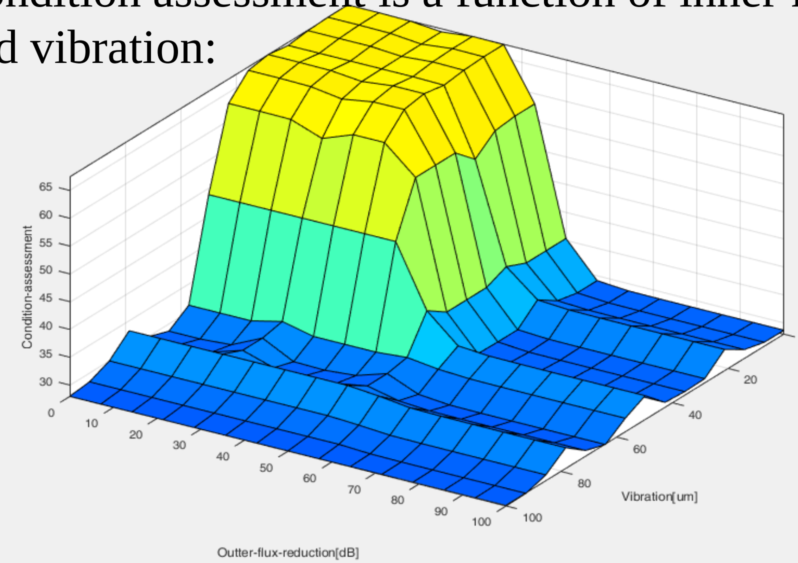
$$f(x;a,b)=\begin{cases}0, & x\le a\\ 2\cdot(\dfrac{x-a}{b-a})^2, & a\le x\le \dfrac{a+b}{2}\\ 1-2\cdot(\dfrac{x-b}{b-a})^2, & \dfrac{a+b}{2}\le x\le b\\ 1, & x\ge b\end{cases}$$

FMA validation

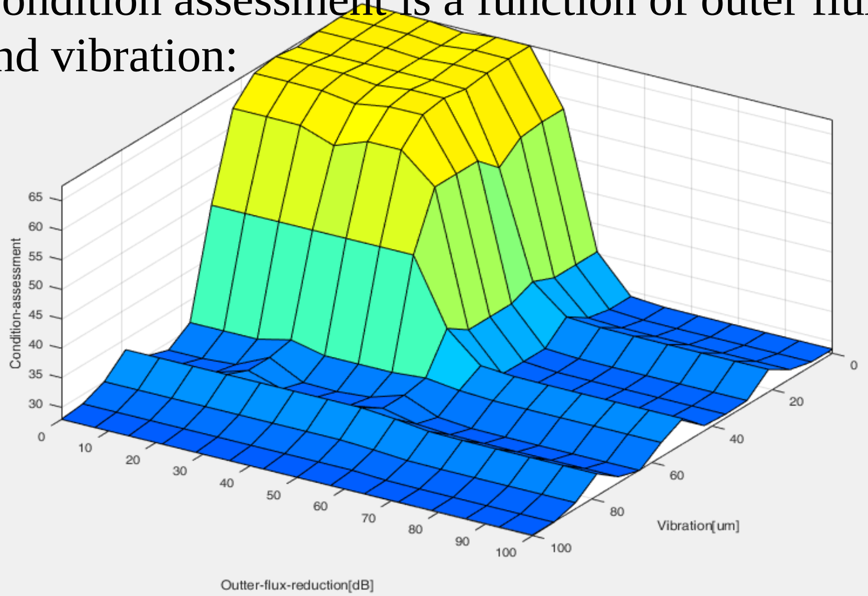
Condition assessment is a function of outer and inner flux:



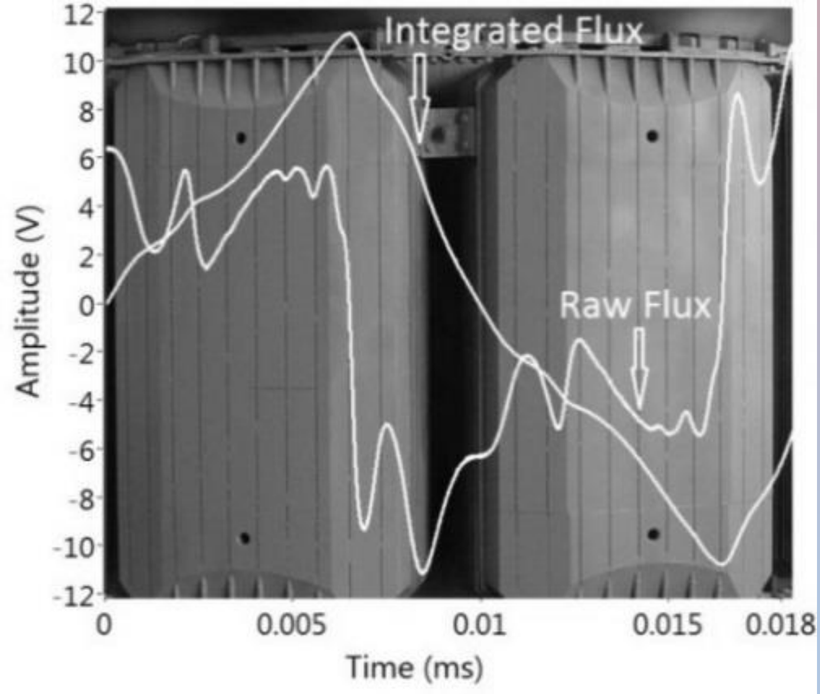
Condition assessment is a function of inner flux and vibration:



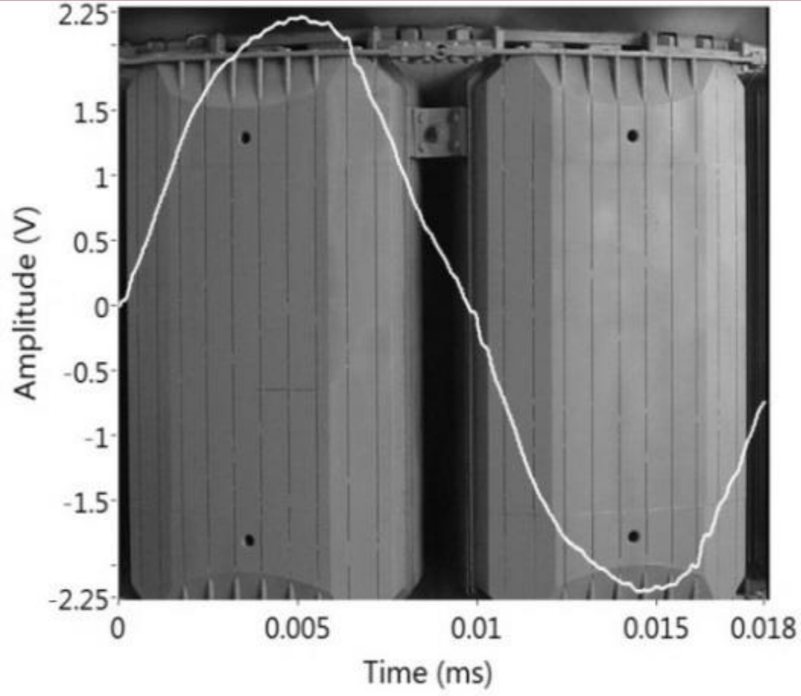
Condition assessment is a function of outer flux and vibration:



FMA validation



Change in magnetic flux in the air gap of the full load generator.



Change of leakage magnetic flux of stator (raw flux). of the full load generator.

Conclusion

This study presents a novel fuzzy measurement algorithm for fault detection in the hydrogenerator with the aim to combine the advantages of fuzzy logic with the advantages of improved measurement methods for measuring vibrations and inner and outer magnetic fluxes in the hydrogenerator.

Two types of fuzzy logic systems were considered (Mamdani and Takagi-Sugeno) and then applied.

The last part of the study discusses the validation of the proposed fuzzy-measurement algorithm that was carried out using appropriate software (MATLAB) and results obtained in real exploitation (in situ).

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