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Fuzzy Logic Based Approach for Condition Monitoring of Hydro Generator

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Abstract: In this study, a fuzzy logic based criterion for the refurbishment and uprating of hydro generator is presented. The criterion is based on the various factor influencing the performance and condition of hydro generator. A new approach that integrates the generator components attributes and their value range into a fuzzy membership functions to determine the strategy for the rehabilitation of hydro generator. With the formalized expert tool, the combination of various inputs with the respective membership functions with the help of if-then rules give the diagnostic technique. The major components of generators have been used as inputs, each having three membership functions in the proposed methodology and out put is generator condition and action required. The technique to identify the hydro generator condition utilizes stator core, stator winding and rotor as inputs and diagnostic as output. A case study demonstrates the potential of the proposed technique.

Key words: Fuzzy logic, fuzzy sets, member ship function, stator core, winding, rotor, refurbishment, uprating

INTRODUCTION

The concept behind the generation of electricity from water is based on conversion of potential energy of water at head to rotate the turbine runner which in turn is coupled to the rotor of the generator. Two key points in case of generation by hydro are volume of water flowing and head where volume means flow rate available and head is the difference in elevation between the upstream and downstream of the river. Hydroelectric is a renewable source of energy and cheapest form of energy.

Besides being emission free source of energy hydropower infrastructure has been instrumental in supporting wetlands, flood mitigation, navigation, irrigation and recreation. etc. The hydroelectric generating facilities and the components are one of the most robust, durable and reliable structures ever produced by the engineers. The robustness of these plants allows the owner to operate these even beyond their optimum economic life, without any major investment on upgrading. The conversion of electricity from water is almost >90% efficient way of converting the available energy into electricity which is higher than thermal which constitute the major source of electricity.

Besides, the ability of hydropower facility to operate both as base load unit as well as peaking unit and its load following characteristics makes it unique. The hydro electric generator is the main component used to convert the mechanical energy of turbine shaft into electrical energy by utilizing Faraday's laws of electromagnetic induction which states that whenever flux linking with a coil changes, emf is induced.

The synchronous generator which has revolving or rotating magnetic field winding wound on the rotor and the armature wound on the stationary stator, the voltage will be induced across the armature or stator windings. D.C current is used to energize the rotating magnetic field on the rotor. The study explains the basic operation of synchronous generator incase of three phase machines, the armature windings or stator windings are placed at 120°C apart. The generator like any other electrical component is subjected under different operating condition due which deterioration and wearing takes place resulting in premature aging as a result of this, the reliability of the component decreases. Table 1 shows the percentage of failure of generator with respect to the component.

Stator winding: The stator windings are most important component of the generator, failures related to stator windings are the main reasons for majority of failures in the generator. Basically, stator windings are copper

Table 1: Percentage of failure of generator's components

Components	Percentage of failure
Stator	70
Rotor	12
Bearing	12
Excitation	3
Others	3

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conductors which are equally distributed in the stator core slots, to engage symmetrical linkage with the flux produced by the rotor. To minimize the effect of any eddy currents these stator windings are made up of many number of copper strands which are insulated from each other. Most of the failures in stator windings are related to insulation failures which could be due to ineffective cooling system, thermal cycling, thermal strength of insulating material and operation under abnormal conditions, etc. (Fig. 1).

Stator core: The basic function of stator core in a generator is to house the stationary stator winding and provide path for electromagnetic flux or carry electromagnetic flux. The stator core is built of thin laminations insulated from each other to reduce eddy current losses; the dimension of these sheets varies from electrical grade, 3-4% silicon or grain oriented and 0.3555-0.483 mm thick steel (Banshwar and Chandel, 2010).

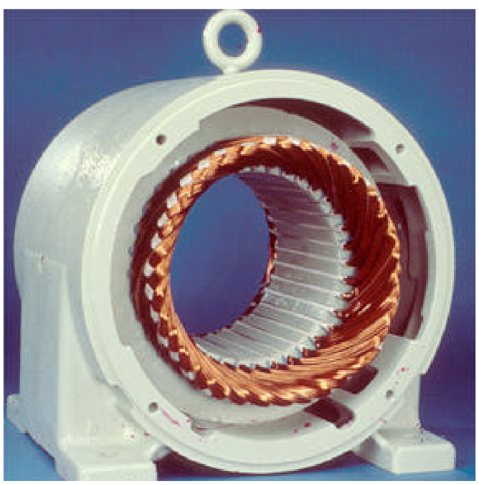

Fig. 1: Generator stator winding

These thin plates are called by various names like laminates or core plate or sheets etc. The stator core of a generator contains tens of thousands of sheets, stacked in group of 10-24 and tightened using key bars. The core handles magnetic flux densities in the stator teeth and core-back or yoke area (Fig. 2).

The alternating magnetic field produces changing voltages and currents which are sources of core losses, besides losses the alternating effect leads to vibration which is one of the main reasons for core failures. Besides vibration, the inter-laminar insulation breakdown can also bring down the core. Based on design imperfection and operational condition, potential reasons for core failures could be summarized as:

- Application of inadequate pressure during the piling of core plates
- Use of resilient material excessively which will relax later leading to imperfection in design
- Over heating of stator core which will eventually lead to thermal aging of the generator
- Excessive eddy current flow and consequently leading to breakdown of inter-laminar insulation due to over heating by eddy currents

Rotor: The rotor is the dynamic component of generator. Due to rotation, rotor should be highly stressed out and hence should have good amount of strength to carry copper windings and operate under mechanical and thermal loading. A rotor generally consist of spider attached to the shaft, a rim constructed of solid steel or laminated rings and field poles attached to the rim. Rotor is the most susceptible to operating incident such as motoring or negative sequence currents, etc. it is also subjected to very high centrifugal forces during normal operation. The rotor winding has slots around its circumference placed symmetrically and rotor windings are placed in these slots between the poles. The rotor is

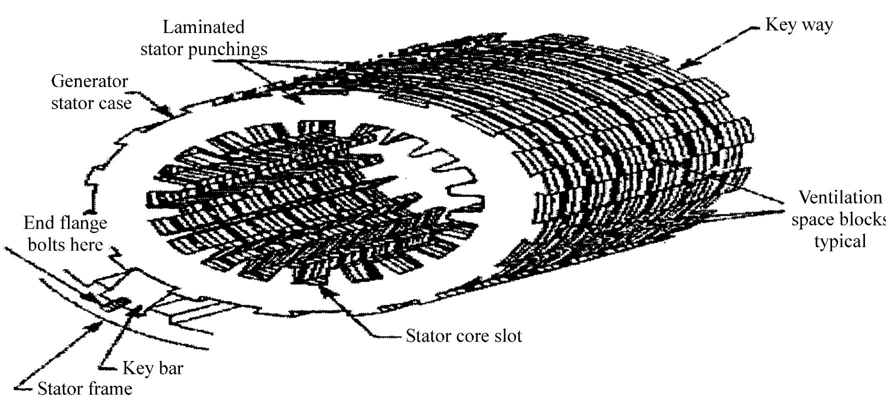

Fig. 2: Generator stator core

Fig. 3: Generator rotor (Rahi *et al*., 2009)

made of essentially one piece steel forging; now a days two piece rotor are no more common. The material used in rotor forging is usually, high permeable magnetic steel to carry the flux produced by the rotor winding. Under operation, very high stresses occur if these stresses are not properly compensated then performance of rotor is slowly derated, finally leading to major failure.

The rotor is coupled to prime mover which in turn rotates the rotor. In hydro generation facility the prime mover is the turbine which is coupled to the generator, the turbine in turn is rotated by the energy of falling water. While inspecting the rotor, the researchers have to check the condition of rotor winding insulation, pole impedance, rotor vibration and whether coupling with the turbine is tight enough or not (Fig. 3).

Multi criterion analysis: Under multi criterion based analysis of hydro-electric generator's condition, each of the generator's components are analyzed where each component have subcomponents. The weighting of each component in the final analysis depends on the weight age or score it receives by visual inspection, failure and maintenance history and electrical tests and measurements to determine soundness of each component.

This analysis could start after it is determined that the decision to upgrade or uprate completely depends on condition of generator. It is economically beneficial to do multi criterion analysis for running unit during major overhaul of the generator so that the researchers avoid any outages particularly for the upgrading feasibility study. Incase, the generator is out of service the decision to restore it back to service by whether repairing or upgrading and uprating should be taken after carefully studying the trend of generator for past few years. The service reliability, cost of maintenance and operation in past against the economic benefits of upgrading and up

Table 2: Input stator winding parameters

Parameters	Weightage
Design and fabrication	0.30
Maintenance and operation history	0.25
Visual inspection	0.15
Test and measurements	0.30
Total score	1.00

Table 3: Stator core parameters

Parameters	Weightage
Design and fabrication	0.30
Maintenance and operation history	0.25
Visual inspection	0.15
Test and measurements	0.30
Total score	1.00

Table 4: Rotor parameters

Parameters	Weightage
Design and fabrication	0.30
Maintenance and operation history	0.25
Visual inspection	0.15
Test and measurements	0.30
Total score	1.00

Table 5: Range of input membership functions

Membership function	Range
Excellent	0.00-0.4
Good	0.35-0.7
Poor	0.65-1.0

rating should be analyzed before taking any major decisions in short a cost/benefit analysis of all the alternatives available should be done to show that implementation of alternatives are economically viable.

In this analysis, each component is analyzed on four different platforms, under each kind the present condition of component compared to its designed specifications, will have major weightage on the analysis (Rahi *et al*., 2007). The weightage or scoring on analysis of each component is based on importance of the component and its present condition for reliable service of the generator and cost to the owner incase of failure of the component leading to both outage and repair. The scores or the weightage for upgrading each component could increase incase there is a better technology available compared to the technology and material used in the component under analysis. The three major criterions that will be studied in case of hydro electric generator are:

- Stator core
- Stator winding
- Rotor

The analysis has been shown in Table 2-6 for each of these three parameters. Membership functions for all the three inputs and one output has been generated and their range have been assigned keeping in view the weightage

Table 6: Range of output membership functions

Membership function	Range
Routine maintenance	0.0-0.35
Refurbishment	0.3-0.75
Poor	0.7-1.00

given for each parameter as shown in Table 2-4. The degree of membership function has been selected as shown in Table 5 and 6 for input and output, respectively.

MATERIALS AND METHODS

Fuzzy logic provides mathematical strength to the emulation of certain perceptual and linguistic attributes associated with human cognition (Rahi, 2010; Banshwar and Chandel, 2010).

The theory of fuzzy logic is based upon the notion of relative graded membership and so are the functions of persuasion and cognitive processes. Fuzzy system are quite alike the conventional systems but the main difference is that the fuzzy system contain fuzzifiers which convert input into their fuzzy representations and defuzzifiers which convert the output of the fuzzy process logic into the crisp solution variables. The fuzzy sets are a special type of set that admits to partial membership. These fuzzy sets allow its member to have different grades of membership. The utility of fuzzy sets lies in their ability to model uncertain or vague data, so often encountered in real life (Table 7).

For simplicity and to contain the size of the study only two inputs and one output with each having three membership functions have been shown in Fig. 4. Mamdani type fuzzy inference system relating inputs to outputs have been formed as shown in Fig. 5.

If-then rules: The following rules have been framed to correlate he various inputs among each other and correspondingly to get output in individual as well as defuzzified crisp average from the FIS (Fig. 6).

Rule viewer: Rule viewer of Fuzzy logic tool box gives pictorial representation of these rules and defuzzified value by using Centroid method (Fig. 7).

Algorithm proposed: The proposed condition monitoring system is designed such that utility personnel can recognize the condition of hydro generator and at the same time informs of the corrective measure to be taken for the restoration of its healthy operation and enhanced rating. The procedure involved in the development of the tool is described as follows:

Table 7: The configuration of fuzzy logic

AND method	Level
OR method	Max.
Implication	Min.
Aggregation	Max.
Defuzzification	MoM/Centroid

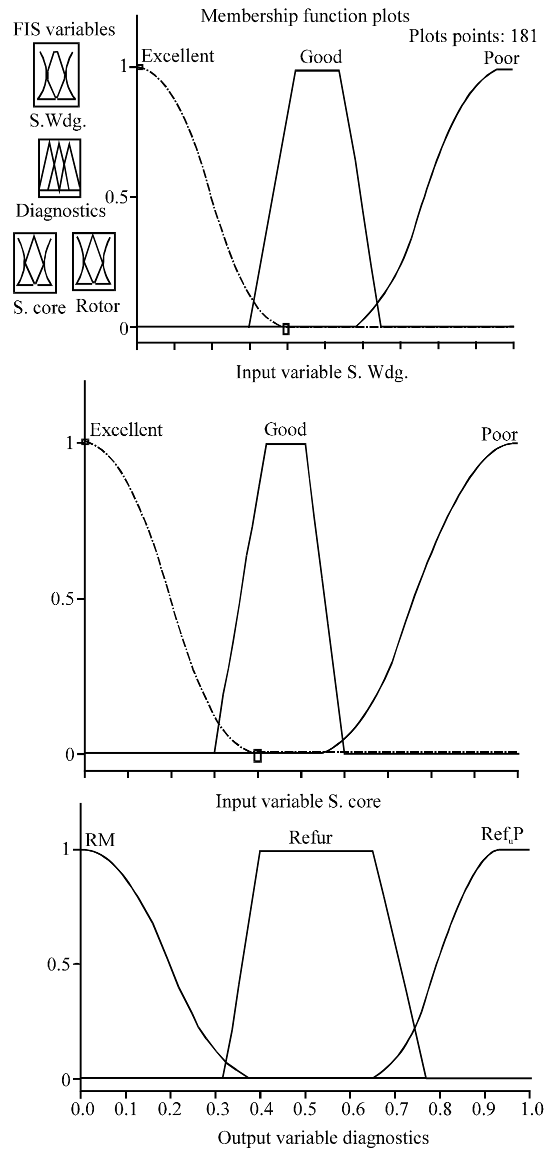

Fig. 4: Input and output membership functions of FIS

- Define the inputs and identify the membership functions
- Define the output and identify the membership functions for the same
- Fuzzy rules are then developed based on the fuzzy variables. These rules depend on the condition of individual component/input of the generator
- Find the defuzzified or crisp value of the out put and accordingly take the decision

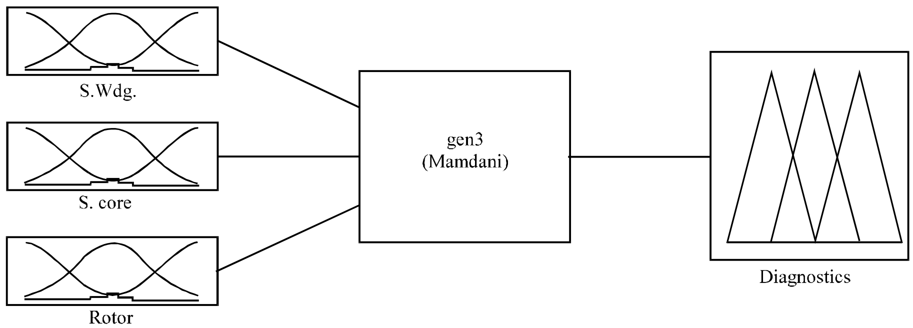

Fig. 5: Mamadani type FIS for hydro generator

1. If (S.Wdg. is Excellent) and (S.Core is Excellent) and (Rotor is Good) then (Diagnostics is RM) (1)
2. If (S.Wdg. is Excellent) and (S.Core is Excellent) and (Rotor is Poor) then (Diagnostics is Refur) (1)
3. If (S.Wdg. is Excellent) and (S.Core is Good) and (Rotor is Excellent) then (Diagnostics is RM) (1)
4. If (S.Wdg. is Excellent) and (S.Core is Good) and (Rotor is Good) then (Diagnostics is Refur) (1)
5. If (S.Wdg. is Excellent) and (S.Core is Good) and (Rotor is Poor) then (Diagnostics is Refur) (1)
6. If (S.Wdg. is Excellent) and (S.Core is Poor) and (Rotor is Excellent) then (Diagnostics is Refur) (1)
7. If (S.Wdg. is Excellent) and (S.Core is Poor) and (Rotor is Good) then (Diagnostics is Refur) (1)
8. If (S.Wdg. is Excellent) and (S.Core is Poor) and (Rotor is Poor) then (Diagnostics is Ref_UP) (1)
9. If (S.Wdg. is Good) and (S.Core is Excellent) and (Rotor is Excellent) then (Diagnostics is RM) (1)
10. If (S.Wdg. is Good) and (S.Core is Excellent) and (Rotor is Good) then (Diagnostics is Refur) (1)
11. If (S.Wdg. is Good) and (S.Core is Excellent) and (Rotor is Poor) then (Diagnostics is Refur) (1)
12. If (S.Wdg. is Good) and (S.Core is Good) and (Rotor is Excellent) then (Diagnostics is Refur) (1)
13. If (S.Wdg. is Good) and (S.Core is Good) and (Rotor is Good) then (Diagnostics is Refur) (1)
14. If (S.Wdg. is Good) and (S.Core is Good) and (Rotor is Poor) then (Diagnostics is Ref_UP) (1)
15. If (S.Wdg. is Good) and (S.Core is Poor) and (Rotor is Excellent) then (Diagnostics is Refur) (1)
16. If (S.Wdg. is Good) and (S.Core is Poor) and (Rotor is Good) then (Diagnostics is Refur) (1)
17. If (S.Wdg. is Good) and (S.Core is Poor) and (Rotor is Poor) then (Diagnostics is Ref_UP) (1)
18. If (S.Wdg. is Poor) and (S.Core is Excellent) and (Rotor is Excellent) then (Diagnostics is Refur) (1)
19. If (S.Wdg. is Poor) and (S.Core is Excellent) and (Rotor is Good) then (Diagnostics is Refur) (1)
20. If (S.Wdg. is Poor) and (S.Core is Excellent) and (Rotor is Poor) then (Diagnostics is Ref_UP) (1)
21. If (S.Wdg. is Poor) and (S.Core is Good) and (Rotor is Excellent) then (Diagnostics is Refur) (1)
22. If (S.Wdg. is Poor) and (S.Core is Good) and (Rotor is Good) then (Diagnostics is Ref_UP) (1)
23. If (S.Wdg. is Poor) and (S.Core is Good) and (Rotor is Poor) then (Diagnostics is Ref_UP) (1)
24. If (S.Wdg. is Poor) and (S.Core is Poor) and (Rotor is Excellent) then (Diagnostics is Ref_UP) (1)
25. If (S.Wdg. is Poor) and (S.Core is Poor) and (Rotor is Good) then (Diagnostics is Ref_UP) (1)

Fig. 6: Fuzzy if-then rules

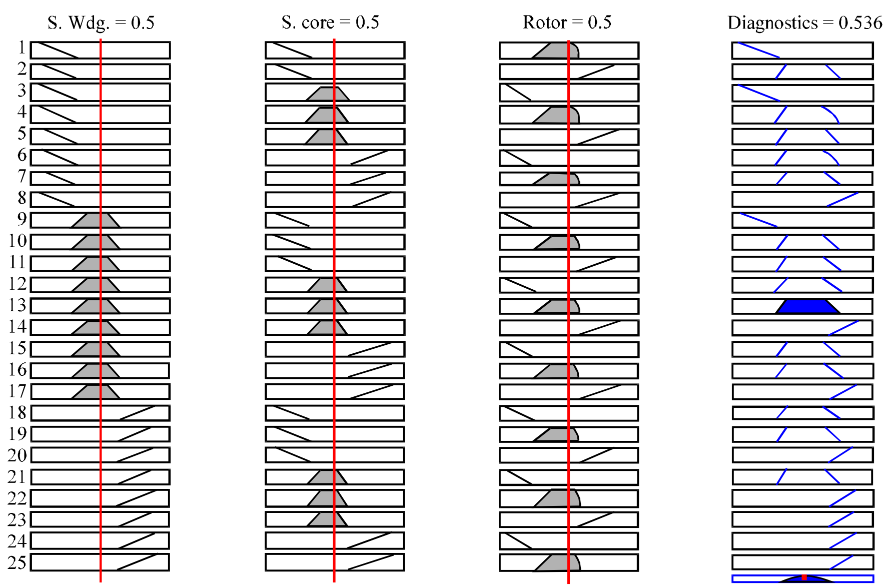

Fig. 7: Rule viewer of fuzzy logic tool box

For this, four input variables 3rd, 5th, 7th and 9th order current and voltage harmonic spectrum individually are chosen and are expressed in a range from 0-1 p.u. The research has been done using MATLAB Version 7.8.

RESULTS AND DISCUSSION

In this FIS, there is individual graphical output for each rule or combination of inputs. Also the tool gives average crisp value by using centroid method which comes out to be 0.536. Given these various values of inputs; this result i.e., 0.536 represents that the decision to be taken by the generation utility is refurbishment. If hydro generator components contain similar type of conditions then the strategy required for its rehabilitations will be same. However, since all hydro generators have different life span, different technology, a set of rule will be applied and accordingly the out put i.e., diagnostic technique applied will also vary. So the proposed method is an expert system for determining the condition monitoring of a hydro generator and can be applied to different power plant generators separately. Such an expert system which monitors condition of a hydro generator has not been developed so for.

CONCLUSION

The fuzzy logic based condition monitoring system for the condition monitoring of hydro generator has been developed. The fuzzy inference system used is of Mamdani type. It covers about 25 fuzzy If-Than rules. All of them will not be applicable at a time to a single machine. But depending upon the age and performance of the machine a set of rules will be applicable and accordingly decision can be taken for capital maintenance based on routine repair and maintenance schedule, only refurbishment or refurbishment accompanied by uprating. These decisions are based on the input representations and resultant outcome as a result of membership functions of diagnostic and its membership functions.

REFERENCES

Banshwar, A. and A.K. Chandel, 2010. Identification of harmonic sources using fuzzy logic. Proceedings of the Joint International Conference on Power Electronics, Drives and Energy Systems (PEDES) and 2010 Power India, Dec. 20-23, New Delhi, pp: 1-7.

Rahi, O.P., 2010. Application of fuzzy logic technique for power transformer diagnostics. Proceedings of National Conference on Advanced Computing and Communication Technology (ACCT-2010), June, 25-26, Rohtak.

Rahi, O.P., A. Kumar and A.K. Chandel, 2007. Condition monitoring of transformer oil using DGA technique. Proceedings of International Conference on Power System, Dec. 12-14, CPRI Bangalore, pp: 197-202.

Rahi, O.P., A.K. Chandel and M.G. Sharma, 2009. Refurbishment of aged hydro power plant-a case study. Proceedings of the International Conference, Small Hydro, April, 28-29, The Renaissance Vancouver Hotel, Vancouver (Canada) Organized By International Water Power and Dam Construction (Canada).