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Application of Fuzzy logic in Power Transformer Fault Diagnosis

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Abstract—**The increasing competition in the utility industry requires maintaining power delivery service with minimum interruption. The goal of power system fault analysis is to provide enough information to utility to be able to understand the reasons for the interruption better, and provide as quick as possible an action to restore the power delivery. The analysis should also provide enough understanding of the status of protection system components so that a preventive set of measures can be implemented to reduce the likelihood of service interruption and damages to equipment The sheer size and complexity of today's deregulated power grids require the application of more predictive techniques that are capable of discernment and decisiveness. Fuzzy logic offers this capability Fault diagnosis (FD) plays a crucial role in power system monitoring and control that ensures a stable electrical power supply to consumers.Fault diagnosis is an important component of power system asset management and congestion management as well. Transformer's performance, reliability and technical life can be increased with the implementation of better operational criteria. FD involves identifying the location and nature of faults occurring on power system due to different disturbances.FD function is the most basic fault handling function of power system supervisory control and data acquisition (SCADA) systems. Power transformers are one of the most expensive components of electrical power system and the failures of such transformers can result in serious power system issues, so fault diagnosis for power transformer is very important to insure the whole power system run normally. Due to information transmission mistakes as well as errors arising while processing data in surveying and monitoring state information of transformer, uncertain and incomplete information may be produced. Moreover, real time detection operation and control is another important characteristic so as to meet high speed diagnosis requirements. Based on these points, this paper presents an intelligent fault diagnosis method of power transformer based on fuzzy logic .By using a fuzzy logic technique, the continuous attribute values are transformed into the fuzzy values by automatically deriving membership functions from a set of data with similarity clustering The practical results show that the method is an effective method for fault diagnosis of transformer and has yielded promising results.**

Keywords- Fuzzy logic; Reliability; Power transformer, fault diagnosis.MembershipFunctions

I. Introduction

After inception of theory of the fuzzy sets by Zadeh (1965) and since the work of Mamdani (1974), manipulating data that were not precise, but rather "fuzzy" have reached a major position in systems engineering.

Fuzzy Systems are useful in any situation in which the measurements taken are imprecise or their interpretation depends strongly on the context or on human opinion.

Application areas of fuzzy systems include: the process industry,electromechanical systems, traffic and avionics control and biomedical systems etc.Evsukoff *et al* (2000) proposed a decision support system dedicated to fault detection and isolation from a human-machine co-operation point of view. Yang & Liao (1999) proposed an adaptive fuzzy system for incipient fault recognition through an evolution enhanced design approach. Complying with the practical gas records and associated fault causes as much as possible, a fuzzy reasoning algorithm is presented to establish a preliminary fuzzy diagnosis system. In this system, an evolutionary optimisation algorithm is further relied on to fine-tune the membership functions of the if then inference rules.

Lu *et al* (1998) described a fuzzy diagnostic model that contains a fast fuzzy rule generation algorithm and a priority rule based inference engine. Insfran *et al* (1999) proposed an approach for fault diagnosis, using fuzzy sets. The system allows not only the fault location, but identification of the fault type. Currents and voltages are analysed using the fault phase impedance and fuzzy sets. Dexter & Benouarets used a set of fuzzy reference models which describe faulty and fault-free operation, and a classifier based on fuzzy matching for fault diagnosis. The reference models are obtained off-line from simulation data. A fuzzy model which describes the actual machine behaviour is identified on-line from normal operating data and compared with each of the reference models. [1]

Although fuzzy systems theory is often applied to industrial process, the applications often do not work well because fuzzy logic designs are completed without rigorous mathematical exercise. The main tasks of finding appropriate membership functions and fuzzy rules are often determined simply by "trial and error". The rules can be obtained by means of optimization methods. LMI optimization has been used in order to design an optimal Takagi-Sugeno (T-S) observer based on a relaxed stability condition (Patton *et al.*, 1998). Another main approach to obtain the number, position and type of rules is to apply adaptive and learning algorithms to fuzzy systems [2]

II. *Decision-Making Using Fuzzy Approach*

The advantage of the fuzzy approach is that it supports, in a natural way, the direct integration of the human operator into the fault detection and supervision process. By avoiding an incorrect decision that can cause false alarms the aim of the Fault Diagnosis decision making is to decide whether and where the fault in the system has occurred (Kuipel & Frank (1997). Fuzzy decision making objectives are very similar to *expert systems*.Expert Systems are used to simulate the problem-solving and decision making processes of a human expert within a relatively narrow domain. This is done using special computer packages along with knowledge, information and databases (Ford, 1991; Tzafestas, 1989).[3]

A. *Formulation of decision-making*

A decision can be formulated by a set of variables (sets, relations and functions) termed a quintuple (**S, st, C, m, dc**) (Verbruggen *et al.*, 1999; Kaymak,1998). By using available information **S** is the possible actions where a selection of this set is performed. **St** are the set of uncontrolled variables by the decision maker not of the environment but they must be included in the decision making process. **C** is the set of consequences, which must be including into a multi-criteria decision-making scheme. Uncertainties resulting from the identification procedure and inherent uncertainties of the system are included, in part, in the consequences. **M** is the relation used to obtain the decision-making solutions by mapping the space **S** x **st** into the set consequences as **S** x **st** → **C.** The decision-maker has, *a priori*, aims and objectives in a preference ordering. They are taken into account in **dc** as a decision function **dc: C →F**

A number of fuzzy decision-making methods for control have been applied for more than 2 decades. For example, the formulation by Bellman and Zadeh (1970). For this approach, there is no distinction between aims and constraints; both are included in the membership functions.[4]-[9]

B. *Fuzzy Identification and Fuzzy Clusters*

To identify complex non-linear systems it is common to obtain partitions of the available data, each partition or subset is approximated by a simple model. The data can be quantitative or qualitative information or a mixture of both. Clustering algorithms are not only used for classification and pattern recognition to construct fuzzy models but also for the simplification and optimization in modeling.

III. *Transformer Monitoring And Fault Diagnosis*

The main function of a power system is to supply electrical energy to its customers with an acceptable degree of reliability and quality. Among many other things, the reliability of a power system depends on trouble-free functioning of power transformers. Consequently, their maintenance and particularly their preventive maintenance can lead to huge savings, besides achieving uninterrupted power supply.

There have been routing maintenance schedule available for electrical engineers for the maintenance of power transformers . Early detection of fault results not only in large savings in operation and maintenance costs but also prevents any premature breakdown/failure besides improving the overall system reliability, but there has been no reliable diagnostic test to assess the internal condition of the transformers except the dissolved gas analysis (DGA) test.

The DGA of transformer oils is a widely accepted technique used as a diagnostic tool for detecting the incipient faults in power transformers, but DGA analysis has certain well defined limitations which can be enlisted as follows

- The methods have been developed based on experience and judgment of human experts only.

- Due to the in-completeness of the possible ratio combinations and uncertainty of the validity of the defined ranges of key-gas ratios there is high degree of inconsistency and ambiguity.

- When these schemes are applied some times the result is "no-interpretation" then the decision is dependent only on the expert.

- Concurrently within the power transformer multiple faults occur, all these methods are unable to detect with confidence such faults.

- Owing to a lack of expert knowledge within them, these schemes are unable to detect new or unknown faults.

- The ratio methods do not cover all ranges of data.

Although there has been lot of research where AI techniques are applied for fault diagnosis through DGA But each technique has its own applicability and limitations

III. Differential Current based Fault Diagnosis Approach

Because of the high cost of the transformer, the proper type of Fault Diagnosis is supposed to detect incipient faults before they become major, and thereby prevent serious physical damage by providing sufficient time lag to SCADA and protective switchgear. The design of the FD system has to consider various nonlinear effects. where speed of fault clearing is considered important the method of FD is very convenient since the transformer terminals are all located at the same station. Discrimination between an internal fault, magnetizing inrush current and external faults with CT saturation is recognized as a challenging power transformer protection problem. It is earlier noted that the second harmonic of the current is almost ideal for determining whether a large current is due to initial inrush or due to a sudden fault. Conventional transformer FD systems may wrongly diagnose during inrush transient phenomenon by sensing the large second harmonic. However, the second harmonic component may also be generated during internal faults due to current transformer saturation or the presence of a shunt capacitor as well as the distributive capacitance in a long EHV transmission line to which the transformer may be connected. Moreover, the second harmonic components in the magnetizing inrush currents tend to be relatively small in modern large power transformers because of the improvements in the core material. Therefore, the conventional technique based on the second harmonic restrain has complexity in distinguishing between internal faults, inrush currents and external faults with CT saturation thereby intimidating transformer stability. Alternative improved techniques based on transient detection are highly desired for accurate and efficient discrimination . As an advancement to the conventional approaches, a new fuzzy logic based FD system has been developed .

A *DEVELOPMENT OF FAULT DETECTION CRITERION*

This approach is based on the principle that whatever may be the fault and whatsoever be the cause there will be disturbance in the normal current values of the transformer and by measuring the value of differential current and comparing it with restraining current a clear diagnosis of fault type is possible

The power transformer disturbances leading to fault conditions which are reflected in current based measurements and need careful diagnosis are described as follows

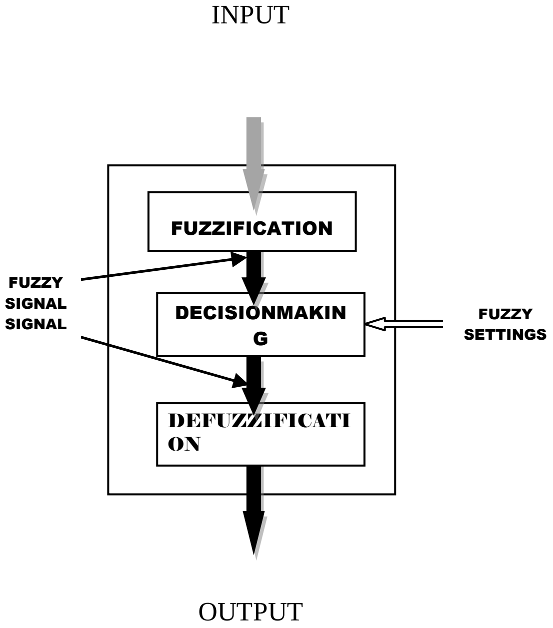

Fig. 1 Fuzzy Processor system structure

a) Inrush – accurate estimation of 2^{nd} Harmonics takes around one cycle off nominal frequencies create extra error in harmonic ratio estimation but in modern power transformers due to magnetic properties of the core the magnitude of 2^{nd} harmonic during inrush may be very low . The presence of higher harmonics does not necessarily indicate inrush as far as duration is considered , it usually takes one full cycle to reject the magnetizing inrush if an internal fault is not severe enough

b) Overexcitation – Estimation of 5^{th}Harmonics takes around one cycle off nominal frequencies create extra error in harmonic ratio estimation but in modern power transformers due to magnetic properties of the core the magnitude of 5^{th} harmonic during overexitation may be very low The 5th harmonic may be present in internal fault currents due to saturation of the CTs, and due to rotor asymmetry of generators and power electronic devices It usually takes one full cycle to reject the magnetizing inrush and stationary overexitation hypothesis if an internal fault is not severe enough

c) External faults – These faults include overloads overvoltage, external system short circuits. The measured currents display enormous rate of change and are often significantly distorted External fault current when combined with ratio mismatch may generate a false differential signal. The CTs, when saturated during external faults, may produce an extra differential signal

d) Internal faults – Theses faults include Winding Phase-Phase, Phase-Ground faults , winding interturn faults ,core insulation failure, shorted laminations, tank faults. The internal fault current may be as low as few percent of the rated value

The above facts clearly indicate that variation of current`s magnitudes during different type of disturbances is so large that direct current measurement techniques may give error full results hence the differential current based fault diagnosis system finds its utility

The algorithm for fault detection can be applied to differential currents signals for extracting several features. Fuzzy logic is used for distinguishing between the transient phenomena. The proposed algorithm is shown in figure 2. and can be explained as follows:

1. The three phase currents are measured using the appropriate current transformers.

2. The current analog signals are converted to digital signals using A/D converter and filtered using anti aliasing filter.

3. The three phase differential currents $p\ s\ I + I$ and restraining currents$p\ s\ I - I$, where *Ip* is the primary current and *Is* is the primary current are calculated.

4. Differential currents and restraining currents are compared to avoid current transformer mismatch, and errors caused by tap changer. If any of the three phase percentage differential currents exceeds a predefined threshold the fault condition is diagnosed by fuzzy system and processed information is transmitted to SCADA and protective relay mechanism

7. The ratios of the maxima of the present window to the maxima of the previous window are calculated.

8. The obtained ratios are then fed to the fuzzy logic system to carry on the discrimination between internal faults, inrush currents and external fault with current transformer saturation.

11. The decision is made by the fuzzy system whether the transient phenomena is an internal fault or not.

12. If an internal fault is detected, a tripping signal is issued; otherwise, the relay restrains and goes on to the next window.

The rules and the parameters of the fuzzy sets are determined and tuned using training data set consisting of different simulated cases. The cases are simulated under internal faults and magnetizing inrush currents as well as external faults for the system described in the next section. [9]-[16]

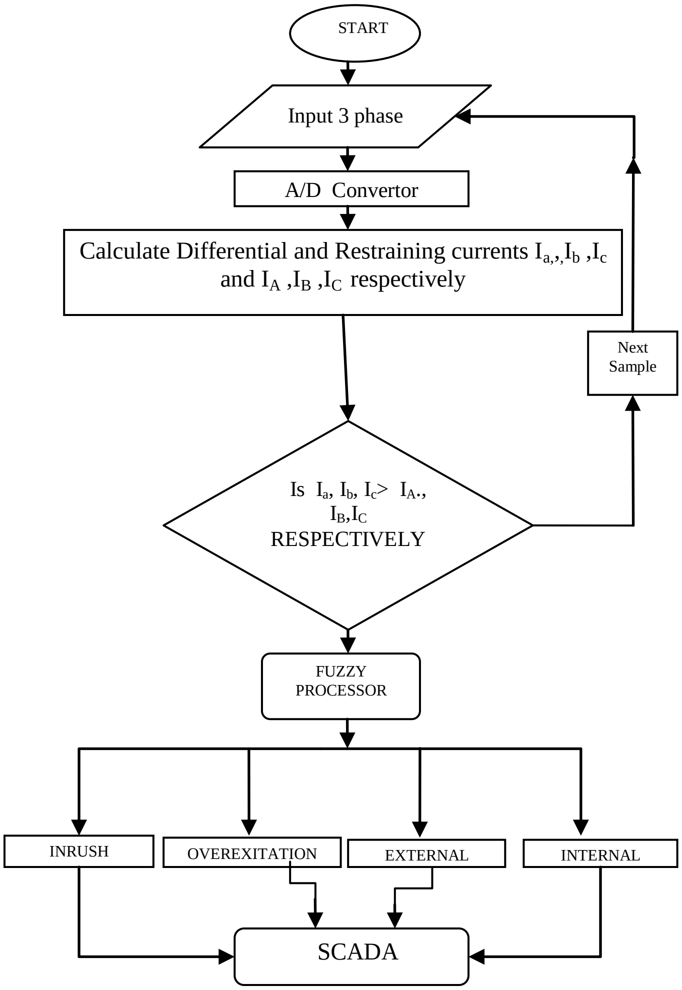

Fig 2. Simplified Flow Chart For Fuzzy Logic Based Fault Diagnosis System

The proposed algorithm is tested using different fault and no-fault cases. For internal fault cases the output is 'trip'. For cases without an internal fault the output is 'no trip'. The algorithm is tested using simulations carried out using MATLAB power system toolbox. Fig. 3 and fig. 4 show three phase differential currents For external faults with high current transformer saturation, the differential current signals are similar to that in the case of inrush. However, unlike the case of inrush current, these bursts comprise of a number of spikes clustered very close to each other. the spikes appear in the form of clusters separated in time. This is the apparent unique features that can be used to distinguish between an inrush current and external fault with CT saturation The algorithm can provide fast and precise operation in discriminating internal faults, inrush currents and external faults, even in the presence of the DC offset in the current transformers. This is an improvement in performance The technique developed is stable in the presence of magnetizing inrush current and in external faults even with current transformer saturation.

IV. CONCLUSIONS

This paper presents an effective methodology and algorithm for Fault Diagnosis and Isolation of transformer. Effective FDI plays an important role not only in protection but provides an effective tool for technical aspects of congestion management also .The proposed Current based scheme is a faster technique for implementation on today`s modern Power system There is a further research scope to in include voltages and phase angles along with currents for inclusion in the FDI System

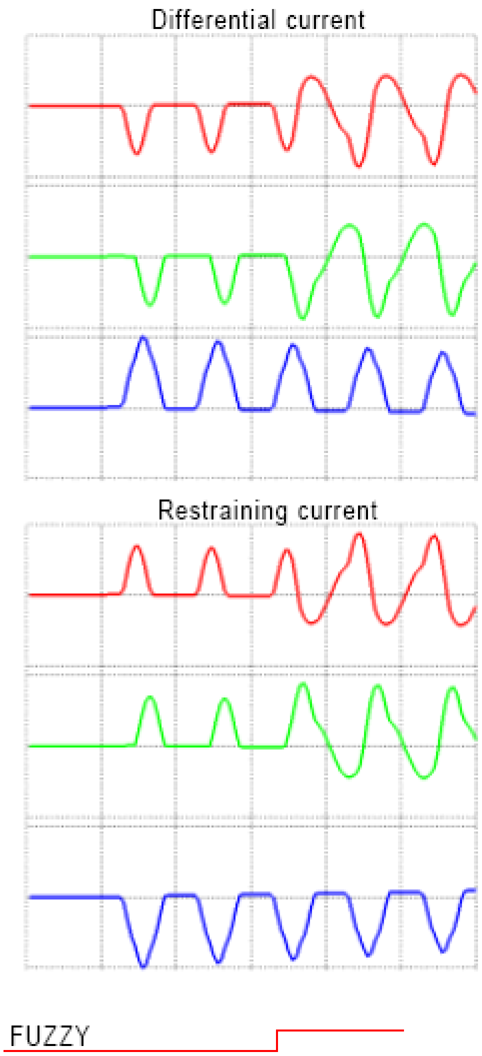

Fig. 3

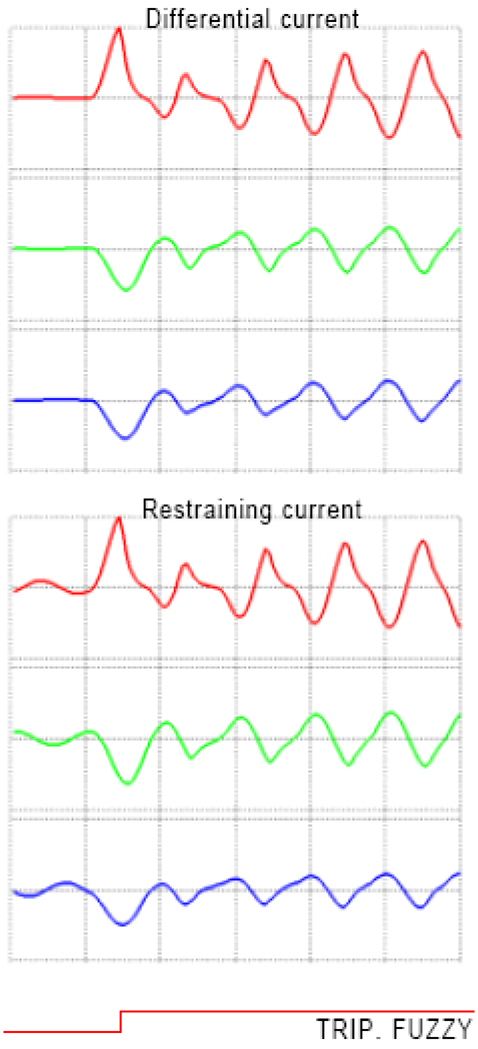

Fig 4

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