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Hologamous integrating strategies for incipient fault diagnosis of transformer

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Abstract: This paper studies an integrative fault diagnostic system on the power transformer. On-line monitor items are grounded current of iron core, internal partial discharge and oil dissolved gas. Diagnostic techniques are simple rule-based judgment, fuzzy logistic reasoning and neural network distinguishing. Considering that much faults information is interactional, intellectualized diagnosis is implemented based on integrating the neural network with the expert system. Hologamous integrating strategies are materialized by information-based integrating monitor devices, shared information database on several levels and fusion diagnosis software along thought patterns. The expert system practices logic thought by logistic reasoning. The neural network realizes image thought by model matching. Creative conclusion is educed by their integrating. The diagnosis example shows that the integrative diagnostic system is reasonable and practical.

Key words: integrating; hologamous system; fault diagnosis; power transformer

The power transformer is one of the basic pieces of electrical equipment for constructing power systems. There are various incipient and hidden faults, which come into being in the long-standing running. Inspecting, tracking and forecasting these faults are the crucial research problems in the transformer's function check.

The transformer can engender malfunctions in diverse functional parts such as the electro-circuit, magnetic-route, insulation and structure assemblies, resulting in various phenomena. To detect incipient malfunctions, many monomial diagnostic techniques have been realized practicably. According to electricity experiments, some can judge the status of electric circuits and insulation in principle. Based on oil dissolved gas analysis (DGA), some can distinguish the internal breakdown between over heating and discharge[1]. By dint of partial discharge, on-line discharge and ultrasonic inspecting can qualitatively analyze the inner lacuna and locate it generally[2]. Meanwhile, many information handling methods have been applied. By the Fourier transform algorithm, electric parameters are used to distinguish the dissymmetry breakdown. Adopting artificial intelligence such as an expert system[3] and an artificial neural network[4-6], many intelligence diagnostic systems are built. Further, there are theoretical studies to synthesize the diagnosis[7,8], such as colligating oil-gas and PD signal analysis with electricity experiment diagnosis, blending the expert system and neural network.

When running, much information is detected and monitored. To make full use of the information, we actualized hologamous information integrating the diagnostic system. Based on hologamous strategies, the diagnostic system integrates tests' data , running data, perambulatory information, and on-line monitoring information. The strategies specifically accentuate the correlativity of all diagnostic information.

In this paper, hologamous integrating strategies are materialized by integrating monitor devices, shared information base and fusion diagnosis software.

1 Faults Diagnostic Techniques

During running, there are some primary abnormal phenomena, such as keen and uneven miscellaneous noise, leaking oil or lack of oil, exceptional temperature, and lower insulation level. All these phenomena are the exterior representations of an internal failure.

By essential principles, the transformer's internal faults can be classified into failures of electro-circuit, magnetic-route and of insulation system, which have over heating or discharge symptoms.

1.1 On-line monitor items

In the study, fixed monitoring items are as follows.

1) Grounded current of iron core The current is an appearance that reflects magnetic-route status. If there is a partial short circuit in the iron core or multi-point grounded, there will be circum-currents. The

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direct influence is locally serious over heating, which causes further damage and oil accelerative decomposing.

2) Partial discharge Partial discharge (PD) may exist in crevice inside solid insulation, air bubbles inside liquid insulation, layers of different materials, or superficial lozenge side and pointed top on metals. To detect partial discharge, probe coils are installed at grounded lines of higher-voltage cannula and center cannula, iron core and its jig. The characteristic parameters are discharge quantity q, phase φ, time t and pulse number N, and derived discharge diagram such as q-φ-t chart and n-φ-t chart which can identify PD modes.

3) Oil dissolved gas If the inner contains certain breakdown, its surrounding insulation whether solid or liquid will decompose gases that dissolve into oil. The diagnostic decomposed gases are hydrogen, low molecular hydrocarbon (such as methane, hexane, ethene, and ethyne), carbon monoxide and carbon dioxide.

As a result of mutative inner failure modes and the serious degree, the blended gases have distinct components and different quantities. Some characteristic gases like H_2 and C_2H_2 are being monitored on-line, and primary gaseous components are analyzed in the laboratory.

1.2 Diagnostic techniques

1) Simple rules-based judgment Abundant running and maintenance experiences are accumulated and become reasonable criteria or judging rules. The judging rules are peeled off from the fault analysis tree (FAT). To make FAT, experts first analyze the inner breakdown mechanism, and then establish the cause-effect logic following the failure evolvement aspect and its sequence. FAT, completely reflecting the interrelation among phenomena and breakdown mode and failure reason, may be applicable especially for exporting relation rules. Therefore, FAT provides diagnostic knowledge for building the expert system, and is used as reasoning path.

2) Fuzzy logistic expert system reasoning In expert systems, the knowledge includes apriority knowledge and heuristic knowledge. The heuristic is the spirit knowledge got from experts' practice and experience. Complexity and indetermination indwell in a diagnostic system. The complexity is that the system must handle very abundant data and information. Due to the indeterminacy of the diagnostic object, lack of information and limitation of experience knowledge, the indetermination is dependent on the following situations: ① Randomicity of failure scope or size; ② Ambiguity of qualitative language expressions; ③ Affinity of causality between phenomenon and failure reason; ④ Neutrality of mathematics. The indetermination is described by fuzzy set theory and fuzzy reasoning rules.

3) Neural network distinguishing A neural network (NN), which shows advantages of auto-organize, auto-study and higher efficiency, is utilized to diagnose some detecting items like PD and DGA. First, experts organize standard training stylebooks, which figure the relation between various characteristics afforded by monitors and corresponding failure modes. Then by calculating, study strategies adjust internal network construction and mutual contacts, to reflect the innate character meaning of the samples. In application, the monitor information will be inputted to an NN, and NN's exportation will respond to the failure mode.

2 Hologamous Diagnosis in Levels

Transformer's various parts are interrelated and interactional, so the inner failure is a coactive result affected by inner electricity, magnetism, physics and chemistry factors. The hologamous information integrating diagnostic system abstracts and syncretizes levels of spatiotemporal information about the object.

2.1 Necessity of hologamous diagnosis

Numerous inner failures usually reflect extensive detectable information.

Take for example the failure in windings. The short circuit is usually caused by a partial breakdown of surface solid insulation, which may make the solid insulation further weaken. The fault can be detected by DGA and PD and even electrical examination in serious one.

As for partial discharge, the discharges inside the surrounding screen or between the conductor and ground come down to solid insulation, whereas other discharges such as suspended electrostatic discharge and gas discharge in oil do not involve solid insulation. In these two PD patterns, DGA characteristics differ markedly.

A long period of movement records can reflect the status more valuably. Historical data have particular value to failure forecast. With some measurement such as the tgδ test, because of interference, the accuracy is not enough. Only by comparing the data with the history, can such a test result be used as an estimable judgment.

From a systemic view, the more information sources are, the more the conflict probabilities among information if a united judge mechanism is lacking. Knowledge "explosion" during logical reasoning due to using more multifarious data, will ill affect the diagnosis results.

The significant point of syncretic diagnosis is fusion of the information.

2.2 Gathering on the hardware

This target is to aggregate sensors and detect devices. The sticking point is to digitalize or intellectualize the devices. All devices are fastened on an information-integrating confederative system.

In particular, the gathering emphasizes uniform hardware at the information level, not projecting a full-functional fixture.

In our work, there are on-line monitor items in section 1.1 and general electrical parameters detecting, and all these are gathered by a center controller.

2.3 Share the database

Shared database is the basis for integrating information. For further diagnosis, presumable design and manufacturing data, historical test data and maintenance information are gathered. The information may be integrated at several levels of consentaneous structure as shown in Fig.1.

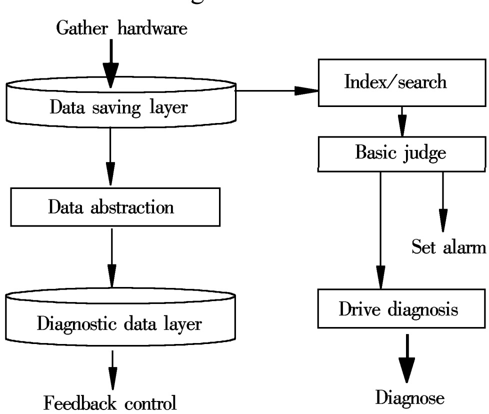

Fig.1 Structure of shared database

In the data saving layer, the database integrates various original data, on which the fleet search is realized. According to the original data and the FAT, the system makes a primary judgment, and then gives an alarm or recommends further diagnosis, which is called data-spy.

In the diagnostic data layer, the database manages all kinds of characteristic data whether they are qualitative or quantitative, determinate or fuzzy. Database also endows them with corresponding reasoning factors such as popedom, reliability and applied maneuver.

2.4 Focuse on the software

For syncretic diagnosis, image thought, logical thought and creativity thought patterns are inducted.

Using a neural network, image thought can be realized. NN first gradually saves some problem solving methods as right modes. When faced with a concrete scene, NN compares the particular information on characteristic with memorial modes, and then handles the actual problem according to a matching mode. But, NN lacks the ability to explain and hard to realize the holistic analysis.

In an expert system, logical thought transacts logical problem by logical reasoning. By logical reasoning, ES can educe a logical estimate about a problem. However, it is difficult to perfect the logical rules on which logical thought is grounded. As a result, if the prior condition is unreliable, a mistaken conclusion will be obtained. This is exactly the limitation inside ES.

For mutual reinforcement, a composite intelligence diagnostic system named ES-NN is organized. First, it makes a normal analysis according to either image thought or logical thought. When contradictory information is revealed, synthesizing all known information, it puts forward a new assumption to explain the contradictory phenomenon. Breaking through the formularic type of thought, this process can be called creative thought. As shown in Fig.2, ES-NN fusion system uses ES as the main framework, assisted by NN.

In ES-NN system, the ES carries out all functions that the generic diagnostic expert system possesses. The fuzzy pretreatment module handles various data. All the information passing the shared "dynamic database" reaches the inference module.

NN includes several molded pieces, which carry out DGA and PD data analysis and failure mode estimation. Stirred up by ES, NN gets study samples from the knowledge database for training and cur-sample from dynamic database for application. The study results are saved in the network model base, but judgment results are stored in dynamic database for ES to make further synthesis.

The ES-NN analysis includes a series of steps and some intramural feedback. The ES analyzes the diagnostic object from the systemic angle, and identifies the total appearance. Unified by ES, the data handling faculty and pattern distinguishing talent of NN are developed, as well as the heuristic reasoning ability and collective harmony of the ES. With the positive participation of the customer, ES-NN realizes the creation of knowledge or samples, thus enhancing the plasticity.

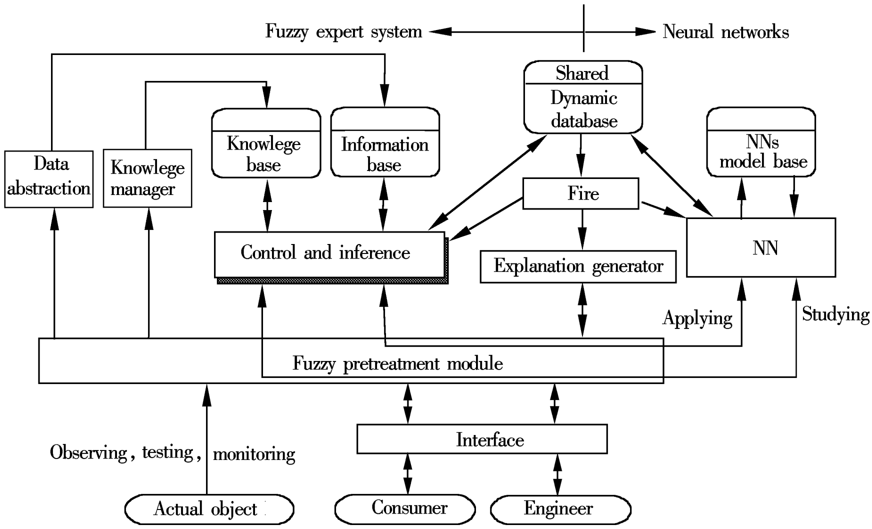

Fig.2 ES-NN synthesized diagnosis flow

3 Examples

Test data of an SF-31500/110 bi-winding transformer are listed in Tab. 1, where, I_{FeO} is a grounded current of iron core, PD describes the online discharge character, and DGA is the contents of gases dissolved in the oil.

Tab.1 Three tests' data for a transformer

Items	Test data
I_{FeO}/A	1.05
PD	Unbiased discharging wave
DGA/10^{-6}	$\varphi(H_2)=14$; $\varphi(CH_4)=29$; $\varphi(C_2H_2)$ is trace; $\varphi(C_2H_4)=178$; $\varphi(C_2H_6)=18$

In detecting that I_{FeO} exceeds the allowable value (routine: 0.1A) extremely, the data-spy raises an alarm. The alarm reveals that there is some trouble in the iron core.

In PD test, there is no notable discharge wave mutant. It indicates there is no gusty discharge or vertiginous interim failure. So unstable grounding is obviated.

In DGA test, wakening NN module, the inputs are $\{C_2H_2/(C_1+C_2), H_2/(C_1+C_2+H_2), C_2H_4/(C_1+C_2), CH_4/(C_1+C_2)\} = \{0, 0.059, 0.791, 0.129\}$, and the outputs are "overheated: 0.979" and other less than 0.1 in reliability. Characteristic gas method also judges that trace C_2H_2 hints no discharge within the transformer.

The above are three monomial diagnostic conclusions, without an assured verdict regarding the local failure.

Then the hologamous system integrates the three tests through reasoning inference and gains consensus: "stable multi-point grounded leads overheat in iron core".

And, the later overhauling discovered that the dielectric for the core underlay was breached, which led to stable overheat. These show that the hologamous diagnostic is more reasonable, detailed and unambiguous.

4 Conclusion

By applying all these techniques and strategies in the real-time diagnostic and administrant system of power transformer (namely RDAS), the diagnosis practicability has improved. The social and economic benefits are increased.

Due to the validity of hologamous integration, integrative multiform diagnostic mechanisms in uniform systems will be a promising evolving direction for future diagnostic technique.

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变压器内部故障诊断的融合集成策略研究

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摘要: 研究了变压器故障的集成融合诊断系统. 该系统中在线监测项目主要有铁心接地电流、局部放电和油中溶解气体; 分析手段包括简单规则判断、模糊逻辑推理和神经网络判别. 考虑到众多故障信息的相互影响, 基于神经网络和专家系统的集成实现智能化诊断. 其融合集成策略主要包括基于信息集成监测装置、多层次地共享信息库和遵循思维规律融合诊断等, 该专家系统实现了推理式的逻辑思维, 神经网络实现了模式化的形象思维, 它们相互结合可得出创造性的结论. 给出了本文系统的一个实例, 表明融合诊断更合理可行.

关键词: 集成; 融合系统; 故障诊断; 电力变压器

中图分类号: TM41