Chapter 9 Conclusions

9.1 Conclusions

Artificial intelligence (AI) based power transformer incipient fault diagnosis were systematically studied in the work of this dissertation. The following conclusions highlight the results.

- Literature study shows that the limitation of conventional methods (the ratio methods and key gas method) is that they rely too much on human experts, and AI based techniques could be a solution.
- International standards (IEC 599 and IEEE C57.104) are the basis of knowledge based power transformer fault diagnosis. The original version of IEC 599 was identified as the framework of the fault diagnosis rule database. After modification of these guideline rules and addition of special empirical rules, the inference engine of rule-based diagnosis was setup.
- Elaborate selection of the training data set is an effective practice in neural network applications. It could yield faster training, better training performance, and help solving the over training problem.
- For neural network based "normal", "overheating" and "discharge" diagnosis, five gas-in-oil concentrations including H_2, CH_4, C_2H_2, C_2H_4 and C_2H_6 are the best choice. For "cellulose degradation" diagnosis, however, seven gas-in-oil concentrations including H_2, CH_4, C_2H_2, C_2H_4, C_2H_6, CO and CO_2 are the best choice.
- After comparison study of multi-layer perceptron (MLP) networks, multivariate Gaussian (MVG) classifiers, and learning vector quantization (LVQ) networks, three-layer single-output MLP based modular network was identified as the best choice for power transformer incipient fault diagnosis.
- A hybrid diagnosis concept was proposed and implemented to manage the combination of rule based and neural network based diagnosis. The outcome is a hybrid diagnosis system, the ANNEPS. Testing results proved that the performance of the hybrid diagnosis

is better than that of the rule or neural network based diagnosis works alone. Testing results also shows that the ANNEPS is much better than conventional ratio methods

- In the ANNEPS, an abnormal condition screening process exists before the rule-based detector, which ensures that very minor fault conditions be identified for detailed investigation. A knowledge based fuzzy combination mechanism was used in the output combination. The competition and compromise of this combination mechanism ensures that the hybrid diagnosis has better performance than the building components.
- Based on literature study and industrial experience consulting, fuzzy systems were developed for assessment of transformer oil/paper insulation conditions, and estimation of oil sampling interval and maintenance recommendations. The insulation condition assessment takes into the results of conventional oil/paper tests, manipulates them according to elaborately defined fuzzy membership functions, and concludes based on fuzzy calculation. The estimation of oil sampling interval is based on gas-in-oil concentrations. It involves a series of crisp and fuzzy calculations. Maintenance recommendations are solely dependent on oil sampling intervals.
- A 7×21×5 MLP network was identified as the best choice for power transformer incipient fault location. Logistic regression and fuzzy logic based fault location techniques were studied but failed to yield comparable performance as the 7×21×5 MLP. However, it was realized from the study that logistic regression has the potential of auditing the feature selection process of neural network applications. Study of logistic regression and neural network based techniques suggests that it will be hard to set up a rule based fault location expert system.
- For OLTC "coking" diagnosis, logistic regression analysis and neural networks were found to be comparable. Logistic regression analysis can provide the guidance of selecting neural network inputs. Modular neural networks can improve the diagnostic performance. A linear/sigmoid activation function is preferred for the MLP neural network middle/output layer.

9.2 Contributions

The following summarize the major contributions:

- The literature of power transformer incipient fault developing mechanism and diagnosis were reviewed, which can be the start point of the future researchers.
- A knowledge based fault detection inference engine was developed via modification of international standards and addition of special rules.
- A multi-layer perceptron (MLP) based modular neural network for fault diagnosis was identified as the best choice for neural network based power transformer incipient fault diagnosis.
- The concept of a hybrid diagnosis was proposed and implemented, the result is a neural network and expert system based power transformer incipient diagnosis tool, the ANNEPS system.
- The abnormal condition screening process, as well as the principle and algorithms of combining the outputs of knowledge based and neural network based diagnosis, were proposed and implemented in the ANNEPS.
- Methods of fuzzy logic based transformer oil/paper insulation condition assessment, and estimation of oil sampling interval and maintenance recommendations, were proposed and implemented.
- Methods of power transformer incipient fault location were studied and a 7×21×5 MLP network was identified as the best choice.
- Methods of on-load tap changer (OLTC) coking diagnosis were studied. A MLP based modular network was identified as the best choice.
- Logistic regression analysis was identified as a good auditor in neural network input pattern selection processes.

9.3 Future work

The work in this dissertation is quite complete from a research point of view. The following are some suggestions for the future work that could help promote its practical application.

- Develop a rule based fault location system and combine it with the neural network based one of this study. The framework could be drawn from IEC 599-1978. Major modification and many special rules may be necessary.
- Collect more data for OLTC coking diagnosis, rerun the neural network training and logistic analysis, combine the outputs using the same methods as those in the ANNEPS, and integrate the OLTC coking diagnosis function into the ANNEPS system.
- Test the ANNEPS extensively using the Internet based ANNEPS. Re-train the neural network if necessary.

Related Publications

[1] Zhenyuan Wang, Yuwen Zhang, Chun Li, Yilu Liu, “ANN based transformer fault diagnosis”, Proceedings of the American Power Conference, Vol.1, Illinois Inst. Technol., Chicago, IL, USA, 1997, pp.428-432

[2] Zhenyuan Wang, Yilu Liu, P.J. Griffin, “A combined ANN and expert system tool for transformer fault diagnosis”, PE-411-PWRD-0-12-1997, IEEE Transactions on Power Delivery, Vol.13, No.4, Oct 1998, pp.1224-1229

[3] Zhenyuan Wang, Yilu Liu, Paul J. Griffin, “Neural Net and Expert System Diagnose Transformer Faults”, IEEE Computer Applications in Power, Jan 2000, pp.50-55

[4] Zhenyuan Wang, Yilu Liu, Nien-Chung Wang, Tzong Yih Guo, Frank T.C. Huang, P.J. Griffin, “Artificial Intelligence in Power Equipment Fault Diagnosis”, IEEE PES 2000 Winter Meeting, Singapore, Singapore, Jan 2000

[5] Zhenyuan Wang, Yilu Liu, Paul J. Griffin, “Artificial Intelligence in OLTC Fault Diagnosis Using Dissolved Gas-In-Oil Information”, IEEE PES 2000 Summer Meeting, Seattle, USA, July 2000

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Resume

Dr. Zhenyuan Wang was born in Fangcheng, Henan Province, China. He grew up in the countryside, and went to schools of all levels. He entered Tsinghua University at Beijing, China in 1985, spent ten half years there, and obtained his B.S., M.S., and Ph.D. degrees there in 1990, 1992 and 1996, respectively, all in High Voltage Engineering and Techniques major. He came to the United States in May 1996, first served as a research scientist, and then entered the Ph.D. program at the Department of Electrical Engineering, Virginia Tech, pursuing another doctoral degree.

Dr. Wang's research interests are electric power equipment condition monitoring and fault diagnosis, applications of artificial intelligence and information technologies, power system transient/harmonic analysis, power quality issues, power system studies, and power system market strategies. He has authored or co-authored over 25 technical papers. He is a member of IEEE.