REVIEW ON TRANSFORMER FAULT ANALYSIS TECHNIQUES

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ABSTRACT

A transformer is one of the most important units in power networks; thus, fault diagnosis of transformers is quite significant. In this proposed approach, the frequency-response analysis, deemed as a suitable diagnostic method for electrical and/or mechanical faults of a transformer, is employed to make a decision over a defective phase. To deal with wideband frequency responses of each phase, a synthetic spectral analysis is proposed, which augments low- and medium-frequency components, and equalizes the frequency intervals of a resulting combined curve by a log-frequency interpolation. Furthermore, for discriminating a defective phase through computing overall amounts of deviation with other phases, the two well-known criteria and three proposed criteria are examined with experiment data. Also the wavelet transform is a powerful tool in the analysis of the power transformer transient phenomena because of its ability to extract information from the transient signals simultaneously in both the time and frequency domain.
This paper present review of different technologies for transformer fault analysis. This paper will be helpful for future researcher and students who are study in the field of three phase transformer fault analysis.

Keyword: *- Fault analysis, three phase transformer.*

1. INTRODUCTION

Power transformer is essential devices in a transmission and distribution system. Failure of a power transformer may cause a break in power supply and loss of profits. Therefore, it is of great importance to detect incipient failures in power transformers as early as possible, so that we can switch them safely and improve the reliability of power systems. A long in-service transformer is subject to electrical and thermal stresses, which may form byproduct gases to indicate the type of incipient failure. Dissolved gas analysis (DGA) is a common practice in the incipient fault diagnosis of power transformers [1], [2]. It tests and periodically samples the insulation oil of transformers to obtain the constituent gases in the oil, which are formed due to breakdown of the insulating materials inside. As study results indicate, corona, overheating, and arcing are the three main causes for insulation degradation in a transformer [2]–[4]. The energy dissipation is the least in corona, medium in overheating, and highest in arcing. The fault-related gases include hydrogen (H_2), methane (CH_4), acetylene (C_2H_2), ethane (C_2H_6), carbon monoxide (CO), and carbon dioxide (CO_2). In the past, various fault diagnosis techniques have been proposed, including the conventional key gas method, ratio method [2], [5], and recently, the expert systems [6], [7], neural-network (NN) [8], and fuzzy logic approaches [9]–[11]. The conventional key gas or ratio method is based on experience in fault diagnosis using DGA data, which may vary from utility to utility due to the heuristic nature of the method and no general mathematical formulation can be used. The expert system and fuzzy logic approaches can take human expertise, and have been successfully applied in this field. However, there are some intrinsic shortcomings, such as the difficulty of acquiring knowledge and maintaining a database. The NNs can directly acquire experience from the training data, and exhibit highly nonlinear input–output relationships. This can overcome some of the shortcomings of the expert system. However, the training data must be sufficient and compatible to ensure proper training. A further limitation of the NN approach is the inability to produce linguistic output. Recently, the combinations of fuzzy logic and AI approach have yielded promising results in the field [6].

2. DIFFERENT TECHNIQUES FOR TRANSFOMRMER FAULT ANALYSIS

One of the tests carried out on a transformer after assembly is the lightning impulse test, for assessment of the integrity of its winding insulation. In the case of a fault, it has been well established that the pattern of the fault currents contains a typical signature of the nature and location of the insulation failure involved. One of method describes a new approach using the 'wavelet transforms' to classify the patterns inherent in different fault currents [1]. Whereas conventional frequency response analysis based techniques fail to identify the time-localization of a particular frequency component in a time-dependent signal, the wavelets are not only **lo**calized in frequency, hut also in time. The 'time-frequency localization' feature of wavelet transform is employed for pattern classification of impulse fault currents of transformers. Results for simulated models of 3,5 and **7** MVA transformers are presented to illustrate the' ability of this approach to classify insulation failures.

The nature of winding currents in transformers corresponds to the type and location of impulse faults. Wavelet analyses of such complex current waveforms have been for classification of shunt **as** well as series type of impulse faults in transformers. Studies have been carried out using results obtained from EMTP model of three transformers. 3-D **as** well **as** 2-D scatter plots using appropriate classification parameters show that different types of fault in a transformer form clearly delimited separate clusters. Hence, it may be stated that pattern classification of impulse faults in transformers **can** be done successfully using wavelet analysis.

The frequency-response analysis, deemed as a suitable diagnostic method for electrical and/or mechanical faults of a transformer, is employed to make a decision over a defective phase [2]. To deal with wideband frequency responses of each phase, a synthetic spectral analysis is proposed, which augments low- and medium-frequency components, and equalizes the frequency intervals of a resulting combined curve by a log-frequency interpolation. Furthermore, for discriminating a defective phase through computing overall amounts of deviation with other phases, the two well-known criteria and three proposed criteria are examined with experiment data. The overall diagnosis results show that the proposed criterion discriminates a defective phase with the highest average hit ratio among all of the provided criteria for selected faults.

In determining which phase has a fault in a power transformer, FRA is adopted as a basic diagnostic tool. The frequency responses estimated by spectral analysis using the conventional discrete Fourier transform (DFT) have insufficient low- and medium-frequency components. To overcome the problem, SSA is proposed, which is based on CCM for high-quality frequency responses and the log-frequency interpolation for a balanced comparison over a whole frequency range. For discriminating a defective phase, two conventional and three proposed criteria are analyzed, and benchmarks are undertaken through various experimental data. Among them, ASLE is proved to be the most pertinent criterion for selected faults via overall hit ratios. To deal with the situation of no-reference magnitude responses, three phases are compared in pairs alternatively as the interphase comparison, and even in this unfortunate case, ASLE produces satisfying results with a final hit ratio over 90%. In order to verify the effectiveness and scalability of the proposed method including SSA and ASLE, large power transformers up into the hundreds of megavolt-amperes, besides the kilo- and megavolt-ampere transformers, have to be tested by the proposed method for the detection of damages on large power banks and winding displacements without shorted turns.

The fault detection and analysis for power transformer are the key measures to improve the security of power systems and the reliability of power supply. Due to the complicity of the power transformer structure and the variations in operating conditions, the occurrence of a fault inside power transformer is uncertain and random. Until now, the fault statistics of power transformer is very limited due to the low fault rate. A novel fault tree analysis method based on fuzzy set theory is proposed for power transformer. Using this method, the index of fault rate can be converted into fuzzy number of fault rate [3]. The method of expert grading can be used to perform the probability of fault estimation without the requirement for corresponding statistics information. The details of fuzzy number design are described in the paper and an application example of the method is also provided. The results show that the proposed fuzzy fault tree analysis method is flexible and adaptive for fault diagnose of power transformer. Therefore, it is a useful engineering tool for the fault analysis and prevention of power transformer.

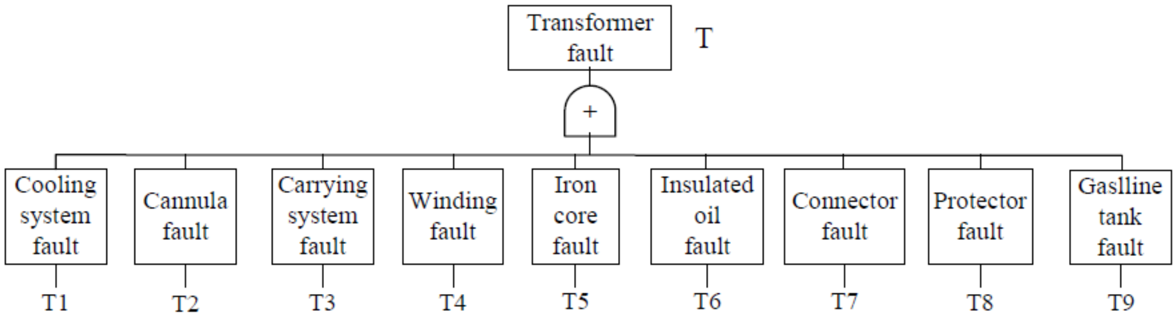

Fig 1:- Fault tree for transformer fault analysis using fuzzy logic controller technique [3].

Fuzzy-sets theory is useful for studying the reliability of power transformers. Combined with the fault tree analysis, it is able to analyze the fault efficiently, without the disadvantages of conventional fault tree analysis method. The engineering analysis of a practical application verified the effectiveness of the proposed method. The fuzzy fault tree method can be easily designed with an aim of prevention of the fault.

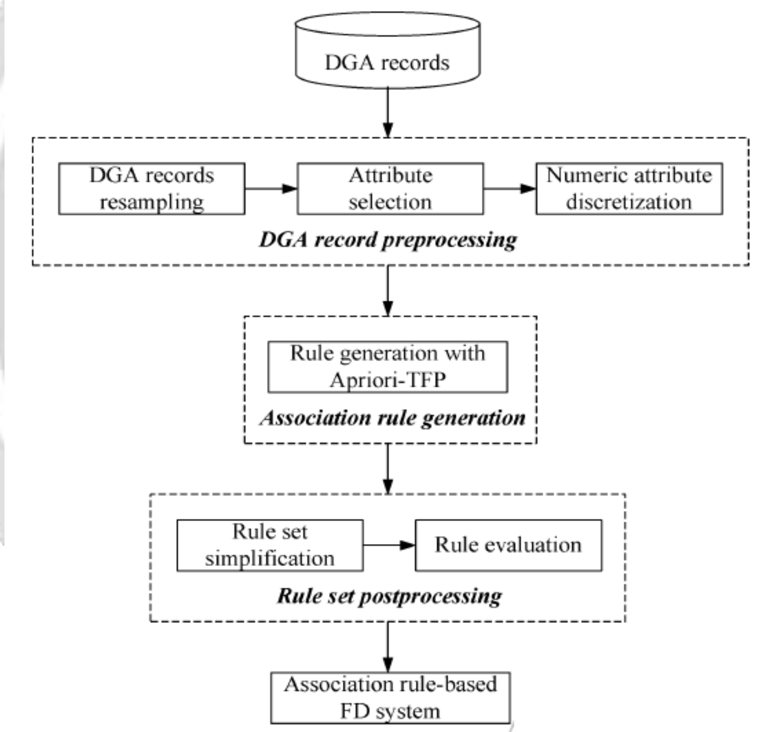

Fig 2:- Development process of an association rule-based FD classifier used for FD of power transformers [4].

One of the techniques presents a novel association rule mining (ARM)-based dissolved gas analysis (DGA) approach to fault diagnosis (FD) of power transformers [4]. In the development of the ARM-based DGA approach, an attribute selection method and a continuous datum attribute discretization method are used for choosing user-interested ARM attributes from a DGA data set, i.e. the items that are employed to extract association rules. The given DGA data set is composed of two parts, i.e. training and test DGA data sets. An ARM algorithm namely A priori-Total From Partial is proposed for generating an association rule set (ARS) from the training DGA data set. Afterwards, an ARS simplification method and a rule fitness evaluation method are utilized to select useful rules from the ARS and assign a fitness value to each of the useful rules, respectively. Based upon the useful association rules, a transformer FD classifier is developed, in which an optimal rule selection method is employed for selecting the most accurate rule from the classifier for diagnosing a test DGA record. For comparison purposes, five widely used FD methods are also tested with the same training and test data sets in experiments. Results show that the proposed ARM-based DGA approach is capable of generating a number of meaningful association rules, which can also cover the empirical rules defined in industry standards. Moreover, a higher FD accuracy can be achieved with the association rule-based FD classifier, compared with that derived by the other methods.

The main procedures of an ARM process are developed, including data preprocessing, rule discovery with Apriori-TFP, and ARS post processing. Then, with the useful rules extracted from a generated ARS, an FD classifier is constructed and utilized for FD of power transformers with the proposed implementation method. For comparison purposes, six DGA FD methods of power transformers are implemented respectively, including the presented ARM-based DGA method, the standard Dornenburg and Rogers ratio methods, the ANN, SVM, and KNN classifiers. The final results demonstrate that the novel ARM-based DGA approach has achieved the highest FD accuracies. In addition, the capability of the proposed AR Mbased DGA approach in discovering the empirical rules of the Dornenburg and Rogers ratio methods is demonstrated, which can verify the meaningful connections between the association rules generated by the approach and the empirical rules defined in a conventional DGA method.

One of the paper proposes a method for incipient fault diagnosis in oil-immersed transformers using grey clustering analysis (GCA) [5]. Incipient faults can produce hydrocarbon molecules and carbon oxides due to the thermal decomposition of oil, cellulose, and other solid insulation. The power transformers can be detected and monitor abnormal conditions with dissolved gas analysis (DGA). Various artificial intelligent (AI) techniques have been proposed for transformer fault diagnosis; however they have some limitations such as accuracy of diagnosis, requirement of inference rules, and determination of the detection architecture. IEC/Cigre standard and GCA are applied to diagnose internal faults including thermal faults, electrical faults, and faults with cellulosic insulation degrading. Compared with other diagnostic techniques, numerical tests with practical gas records were conducted to show the effectiveness of the proposed model, and are easy to implement with the portable device and hardware device.

The proposed method could avoid the determination of the linguistic variables, membership functions, inference rules, network architecture, and parameters assignment, and is easy to implement. GCA is a useful method to deal with the problems of limited, deficient, and no rules available for data processing. Its analysis makes use of minor data and does not demand strict statistical procedures and inference rules. Compared with other AI approaches, the proposed method shows good performance for fault diagnosis. To develop an assistance tool, the proposed method can be further constructed in the on-line model, and be integrated into the monitoring instrument.

A new hybrid self-adaptive training approach-based radial basis function (RBF) neural network for power transformer fault diagnosis is presented [6]. The proposed method is able to generate RBF neural network models based on fuzzy c-means (FCM) and quantum-inspired particle swarm optimization (QPSO), which can automatically configure network structure and obtain model parameters. With these methods, the number of neuron, centers and radii of hidden layer activated functions, as well as output connection weights can be automatically calculated. This learning method is proved to be effective by applying the RBF neural network in the classification of five benchmark testing data sets, and power transformer fault data set. The results clearly demonstrated the improved classification accuracy compared with other alternatives and showed that it can be used as a reliable tool for power transformer fault analysis.

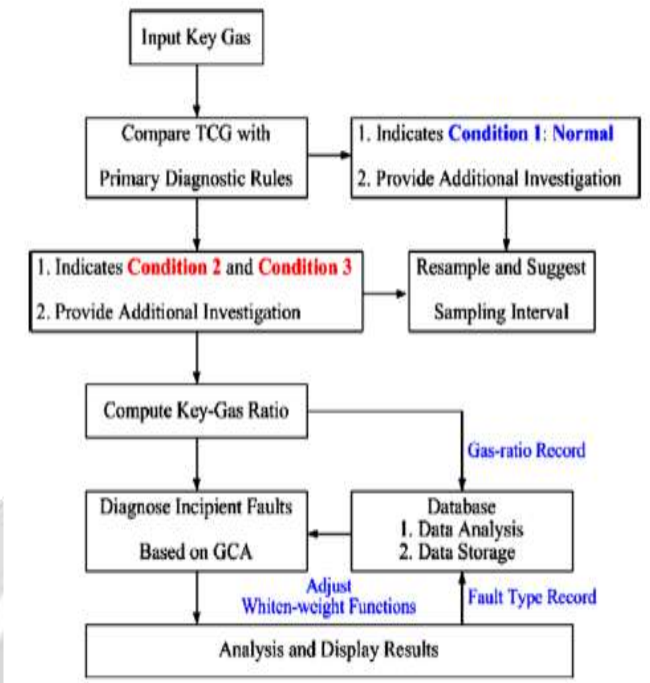

Fig 3:- Flow chart of the fault diagnostic procedure [5].

The proposed learning approach is able to generate RBF neural network models based on specially designed FCM and QPSO, which can auto-configure the structure of networks and obtain the model parameters. The availability of this method is proved by applying RBF neural network in classification of five famous benchmark data sets, and power transformer history faults dataset. The result suggests that the proposed training algorithms have good performance on data clustering, improving stability and generalization ability of RBF neural networks. The promising neural network performance on the validation data sets illustrates the improved accuracy of the proposed method when compared to the other alternatives and showed that it could be used as a reliable tool for transformer fault analysis.

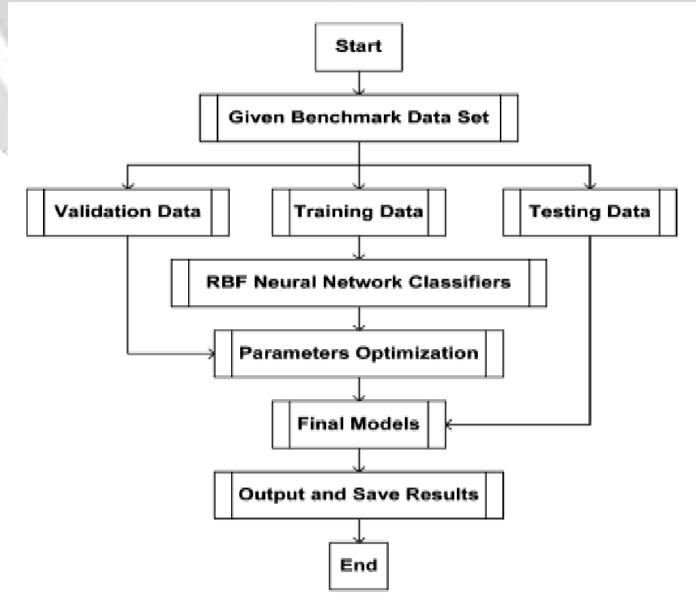

Fig 4:- Flowchart for the proposed RBF Neural network approach [6].

One of the study presents an intelligent fault classification method for identification of transformer winding fault through transfer function (TF) analysis [7]. For this analysis support vector machine (SVM) is used. The required data for training and testing of SVM are obtained by measurement on two groups of transformers (one is a classic 20 kV transformer and the other is a model transformer) under intact condition and under different fault conditions (axial displacement, radial deformation, disc space variation and short circuit of winding). Two different features extracted from the measured TFs are then used as the inputs to SVM classifier for fault classification. The accuracy of proposed method is compared with the accuracy of past well-known works. This comparison indicates that the proposed method can be used as a reliable method for transformer winding fault recognition.

The proposed method is able to accurately distinguish different fault types of AD, RD, DSV and SC. For training and testing purposes of the SVM algorithm, the measured data related to two groups of transformers is employed. After extracting the features of the measured TFs by mathematical indices (feature 1) and VF method (feature 2), they are applied to SVM algorithm, for its training. Similar measured parameters from group 2 transformers are used for testing of the method. The verification process reveals that the proposed method, based on SVM using feature 1, has a high accuracy. Comparing with the available methods in the literature and ANN, this can be recognised as a reliable method for detection of transformers winding fault type.

Any failures in transformer directly reduce network reliability and increase maintenance costs. Consequently, the preventive maintenance techniques are increasingly developed. In this regard, frequency response analysis is an appropriate method in order to diagnose any change which occurs in transformer physical construction.

This contribution has been concentrated on fault diagnosis by use of Frequency Response Analysis (FRA) [8]. A number of measurements on faulty transformers which are led to fault diagnosis has represented and discussed. These practical studies are performed during maintenance processes or on site periodic inspections. The results are very worthwhile to better understand how behave transformer frequency responses due to various faults. These obtained results can be very interesting and usable for maintenance engineers to find the occurred fault.

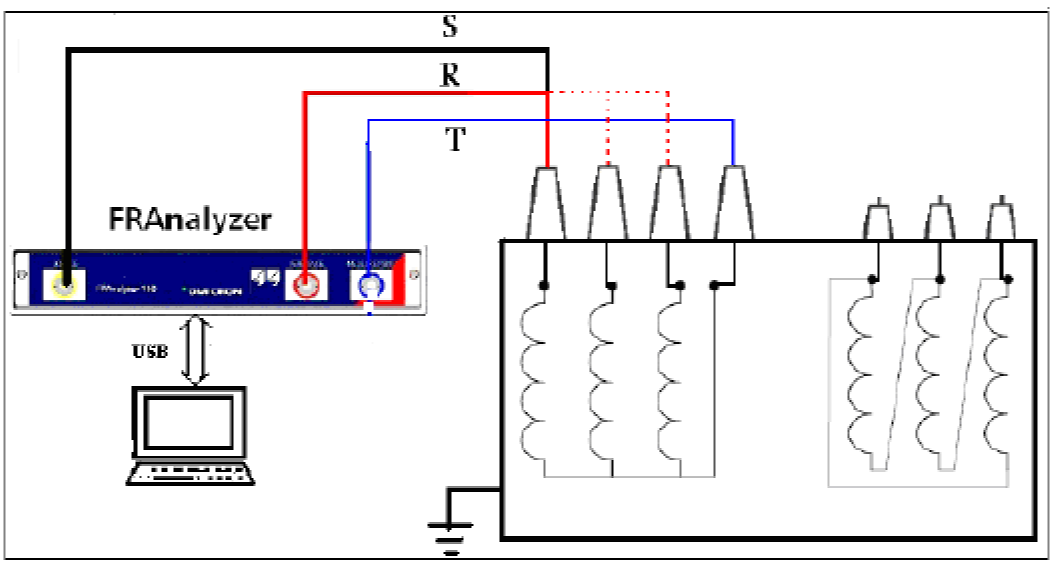

Fig 5:- a schematic diagram of the experimental set-up using FR Analyzer [8].

With respect to the weakness of modeling methods related to FRA, practical measurements and classification of the obtained results are very worthwhile. In this methodology, some measurements of frequency response were carried out on a number of faulty transformers. The effects of short-circuit and winding deformation on FRA curves are investigated. These measurements are very useful to better assessment the characteristics of transformer frequency behaviors which are applicable to interpret FRA plots.

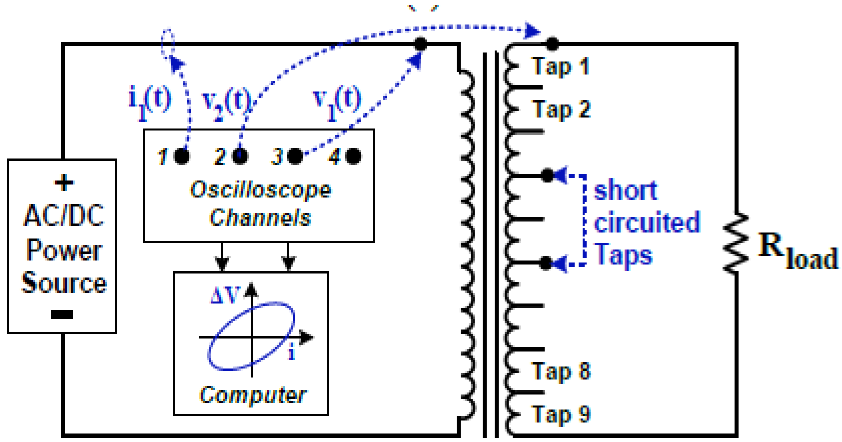

Fig 6:- Detailed technical setup [9].

Online technique is based on considering the correlation between the instantaneous input and output voltage difference (ΔV) and the input current of a particular phase as a finger print of the transformer that could be measured every cycle to identify any incipient mechanical deformation within power transformers [9]. To precisely emulate real transformer operation under various winding mechanical deformations, a detailed three-dimensional finite-element model is developed. Detailed simulations with (non) sinusoidal excitation are performed and analyzed to demonstrate the unique impact of each fault on the ΔV-I locus. Impact of harmonic order, magnitude and phase angle is also investigated. Furthermore, practical measurements have been performed to validate the effect of winding short circuit fault on the proposed ΔV-I locus without and with the impact of system harmonics**.**
Under sinusoidal operating conditions, the ΔV-I locus of the healthy/faulty transformer is an ellipse. Harmonics distort the shape of locus by introducing minor loops. The shape, magnitude and number of minor loops depend on the order, percentage and phase angle of harmonics. For sinusoidal and non-sinusoidal operating conditions, the ΔV-I locus of healthy transformer can be used as the fingerprint and can be continuously compared with the online measured locus to detect internal faults. Each fault impacts the ΔV-I locus shape, area and major axis rotation in a unique way with a certain degree of change that depends on the fault type and level, as well as harmonic order, magnitude and phase angle. In contrast to conventional off-line sweep frequency response techniques, the ΔV-I locus is conducted at the power frequency, does not require taking the transformer out of service and hence continuous online evaluations of transformer winding mechanical integrity can be realized. The online ΔV-I locus can identify and qualify transformer internal faults under (non)sinusoidal operating conditions. However, its application to practical three-phase power transformers has not been explored and requires more research.
Three-phase bus impedance matrix reveals some good potential in fault analysis in phase coordinates. In one of the paper, a comprehensive methodology is proposed to analyze a large variety of faults including short circuits in buses and lines, open circuits, open circuits with falling conductors and internal faults of transformer, separately or simultaneously, in unbalanced networks. Load effect is also considered [10]. The methodology is based on the compensation theorem and Thevenin equivalent circuit which derives a fault side equation for each fault case. By combining the fault side and the network side equations, it replaces the fault side with equivalent injected current sources and calculates the voltage mismatch in every bus by using three-phase bus impedance matrix. A modified transformer model is also proposed to account for internal faults of transformer windings. The formulation is derived based on the initial three-phase bus impedance matrix and except for internal faults, there is no need to modify the impedance matrix during fault analysis which eliminates the demand for new factorization or inversion of a huge matrix. Moreover, a correction factor matrix is proposed which improves the results of a previous sequence component method in literature. The methodology is tested on IEEE 13-node and IEEE 34-node test 22feeders which are inherently unbalanced networks and it is implemented in MATLAB software.
For all fault types, a fault side equation is proposed which presents a relation between the output fault currents and the fault terminal voltages. Also a modified transformer model and a new treatment for SCL faults are proposed to deal with the internal faults of transformer windings and line short circuit faults, respectively. The evaluation shows that the method is useful and leads to precise results in SCB and SCL faults analysis and can deal with OCs, OCFs and IFTs as well. Also the modification factor matrix improves the results of [1] for short circuit faults in phases other than *a* and phase pairs other than *bc*. The proposed transformer model is capable of analyzing different IFTs including interdisk, turn to ground, axial displacement and cross-country faults, though in order to have more precise

results, it might require improvement to account for mutual inductances between windings and the capacitances presented in distributed model of transformers.
The privilege of this method is that it avoids any excessive inversion or factorization of system matrix. The during-fault currents and voltages could be calculated straight and by simple equations and the number of required operations for each fault case is relatively low. Moreover, the method of this paper is comprehensive which covers a large variety of faults and is capable of considering load effect. Any number of arbitrary faults could be analyzed simultaneously.

4. CONCLUSION

A transformer is one of the most important units in power networks; thus, fault diagnosis of transformers is quite significant. In this proposed approach, the frequency-response analysis, deemed as a suitable diagnostic method for electrical and/or mechanical faults of a transformer, is employed to make a decision over a defective phase. To deal with wideband frequency responses of each phase, a synthetic spectral analysis is proposed, which augments low- and medium-frequency components, and equalizes the frequency intervals of a resulting combined curve by a log-frequency interpolation. Furthermore, for discriminating a defective phase through computing overall amounts of deviation with other phases, the two well-known criteria and three proposed criteria are examined with experiment data. This paper present review of different technologies for transformer fault analysis. This paper will be helpful for future researcher and students who are study in the field of three phase transformer fault analysis.

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