Study Committee B3

Substations and Electrical Installations

Paper B3-10366_2022

Integrated Intellectual Automated System of Monitoring, Diagnosis and Control of Power Transformer Stock Technical Condition

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Rationale

- lesser number of parameters is controlled online as compared to offline
- transformer diagnostic systems based on offline measurements can miss rapidly developing defects
- the purpose of development is to minimize the disadvantages and to strengthen the advantages of online and offline monitoring approaches in one complex software solution

Method/Approach

- The automated system for monitoring, diagnosis and management of the technical condition of power transformer fleet was developed. The system integrates the online and offline diagnosis approaches, thus enabling the synergetic effect of both.
- The online data in the offline analysis subsystem are required for the on-the-fly technical condition index calculation and assessment of the transformer fleet condition as a whole. Based on this data, the plan for maintenance and repairs of a power utility's transformer fleet may be adjusted promptly.
- When making a decision on the technical condition, the offline subsystem considers jointly online operational data and latest offline data of several types of measurements. This enables to utilize all available information regarding the asset being diagnosed at a specific point in time, which increases the efficiency and quality of the condition assessment and provided recommendations for the personnel on the adjustments in operation mode.

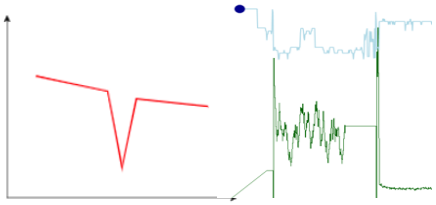
Usefulness and applicability for personnel

Integration of online and offline measurement data in a single system with their subsequent processing by artificial intelligence enables:

- increasing the practical value of online monitoring data for assessment of the technical condition of the transformer and its components;
- increasing the efficiency of application and trustworthiness level for the online monitoring systems among personnel;
- further improving the quality of transformer operation management, among other things by improving the accuracy of the transformer remaining useful life assessment due to the concurrent analysis of the online and offline data.

Experimental setup & test results

- ASMD with the forecasting function was tested in pilot operation at a 500 kV electrical substation, where two auto transformers, subject to special monitoring, were equipped with these systems
- the list of data sources comprised dissolved gases and oil moisture monitor, high voltage bushing monitors, top oil and temperature sensors
- during the operation, changes in the technical condition index were dete[illegible]



Graphs of changes in the technical condition index

Objects of investigation

- the offline software, solves the tasks of 6-750 kV power transformers operation, and also most of the strategic tasks of equipment. It has a long (more than 25 years) history of operation, covers a large number of utilities, is well known to personnel (420 workplaces)
- the online part of the software named ASMD is an open-architecture, created for monitoring, diagnosis and control of the technical condition of oil-filled transformers, auto transformers and reactors
- the information involved in the operation of the online subsystem: - parameters characterizing the transformer condition (operating parameters from local control systems, data from sensors and monitoring devices); - offline data

Discussion

- combining online and offline diagnostic is an enabler for more accurate diagnostic techniques, tailored for each particular instance of an electrical asset
- at the same time, there is not a common practice of calculating and using the assessment of a PT condition, in general, in online mode
- a good example is Oomen's equilibrium curves where the moisture content of the paper is determined by the moisture content of oil and the oil temperature. Having been developed as a general tool for a big range of power transformers, it can be taken as a prior hypothesis and updated each time with offline measurements of temperature and both moisture contents, thus creating a posterior hypothesis in the form of transformer-specific curves. Such curves will be more accurate than general equilibrium curves for establishing oil-paper moisture dependency

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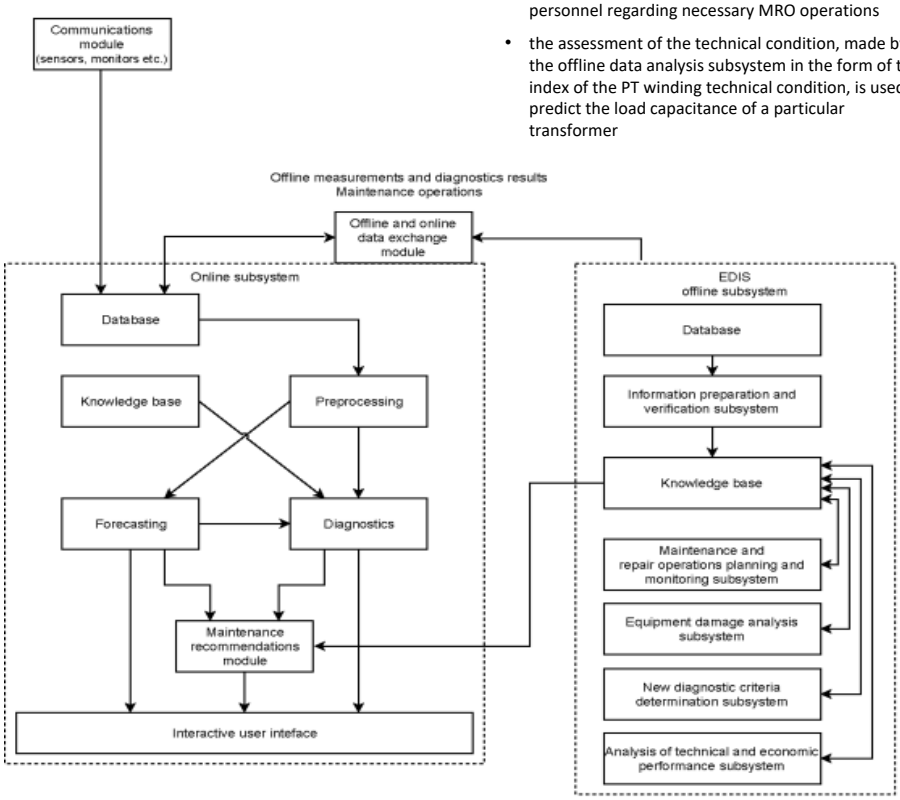
Integration of both offline and online approaches

- offline subsystem: information about operating mode changes and online monitoring readings to complement the offline database with actual values and potential adjustments in diagnostic conclusions and calculation of the current health index
- online subsystem: information on operational impacts, assessment of technical condition by the offline subsystem and the offline measurement data necessary for the online analysis, which are used to verify the online data, taken into consideration in the algorithms for assessment of the technical condition, in calculation of the remaining useful life, in recommendations to personnel on changing the operating mode and on necessary maintenance and repair operations

Offline information is typically not used in online diagnosis

The offline information in the online data analysis subsystem is required for:

- the information about performed repair operations (degassing, oil regeneration, oil replacement, drying of solid insulation, etc.) and has an effect on: changes in parameters of models for prediction of DGA values, insulation moisture, remaining useful life, etc.
- some of the data from offline tests and measurements are used to revise the results of calculations, made using online data: for example, consideration of the influence of the oil oxidation degree when calculating the solid insulation ageing
- assessment of the transformers technical condition, made by the offline data analysis subsystem in the form of the nature and type of defect, the degree of its development (localization), is used in the unit for generation of operational recommendations ~~to~~ for personnel regarding necessary MRO operations
- the assessment of the technical condition, made by the offline data analysis subsystem in the form of the index of the PT winding technical condition, is used to predict the load capacitance of a particular transformer



Scheme of subsystems for online and offline data collection and analysis, data exchange unit, as well as information flows of their interaction

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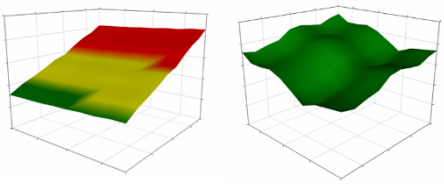
Distinct online subsystem features Data verification

The verification is achieved by the following means:

- natural range of values, when an outlier parameter is indicative of a measurement error
- a check of synchronous changes in correlated parameters
- a check of change in trends in similar parameters of the online and offline monitoring as well as in correlated parameters of online and offline monitoring

As a result of the verification procedure, verified and updated data series with no errors are formed in databases of online and offline



Example of projection of critical and nominal ranges of gas concentration values

- The software implements a 3D forecast representation. Each point of the predicted surface of values corresponds to the concentration value (vertical axis) that will be reached in the future at each load and temperature value (horizontal axes)

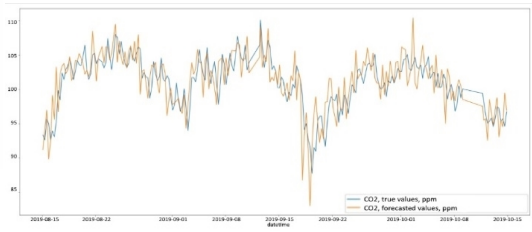
Distinct offline subsystem features

The most valuable and fast-developing component is the knowledge base. The knowledge base of the system comprises:

- libraries of criteria for assessment of monitored offline parameters and their trends
- algorithms for determination of a type, nature of a defect, a degree of its development, danger and, if possible, localization
- an algorithm for determination of an assembly (subsystem) of a power transformer, in which a defect develops, based on the basis of machine learning using data of transformer damages
- an algorithm for search for a case, similar to the one under consideration, in the transformer damages database
- algorithms for scheduling maintenance and repair operations (their scopes and dates), taking into consideration the type, degree of development and danger of a defect and its localization

Short run forecasting

- ASMD's prediction unit uses a model of gas concentrations change. The model is generated by the system automatically, using machine learning methods, based on the history of measurements of gas concentrations, operating mode and ambient temperature for a particular power transformer. The predictive model is a combination of autoregression and regression models. It connects dissolved data concentration values with historical concentration values and ambient temperature, oil temperature and load values
- the developed approach of constructing a predictive model DGA results has a good accuracy. According to the results of comparing the predicted values and the actual measured ones, their difference ranges from 3.2 to 5.4% as per the point-to-point comparison



Actual and predicted development of carbon dioxide concentration

Conclusion

Integration of online and offline measurement data into a single system with their subsequent processing by artificial intelligence enables:

- reducing the number of false alarms provided by the online monitoring system
- mutually verifying and supplementing the data received from the offline and online monitoring;
- taking into consideration the results of the offline measurement data analysis and the data itself when forming the online subsystem results, including in order to control the PT load capacity
- improving the quality of transformer operation management by improving the accuracy of the transformer remaining useful life assessment due to the mutual consideration of the online and offline data.
- recording data of the online measurements in diagnosis and calculation of the current technical condition index both for a piece of equipment and in the course of analysis of the transformer fleet technical condition, as a whole, in the offline part of II ASMDM
- increasing the response time to fast-developing defects, in particular, giving more prompt and balanced recommendations to personnel regarding necessary changes in the transformer operating mode, maintenance and repair