Harmonic Analysis Study for High-voltage Distribution Equipment on Power Factor

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Abstract. Dielectric loss factor measurement is an important index in accessing the insulation performance of power equipment. With the development of the condition-based maintenance and smart grid, more attention has been paid to online diagnostic technologies for the dielectric loss factor measurement. Various methods have been developed in this field in which harmonic analysis (HA) is prevalent due to its performance of resisting disturbance and stability superior to others. When performing the HA method on the sampled data, the non-simultaneous sampling and the lack of synchronization between sampling rate and the signal period are believed to be the main source of error in the measurement of the magnitude and the phase of the signals. To improve the effectiveness of the HA method, measures were taken by means of the designing online monitoring system. The basic principle of the HA method is presented in this paper and an online monitoring system based on DSP technology is developed accordingly. At last, this paper analyses the on-line monitoring results resulted from the online monitoring system on a substation.

Keywords: Dielectric loss factor, Harmonic analysis method, online monitoring system.

1   Introduction

To ensure the safe and reliable operation of a power system it is necessary to monitor periodically the insulation condition of HV apparatus. This may be accomplished through measuring partial discharge levels, dielectric loss factor and capacitance using conventional well-established time based maintenance method. To implement these routine tests require removal of equipment from service, however, the measure and continuous monitor may be carried out directly if on-line monitoring method is adopted. These on-line dielectric loss factor measuring methods detect the current flowing through the test object and the voltage signal applied to it. The various techniques reported in the literature differ from each other in the manner how the signals are acquired and how the gathered data are handled. In the work reported in this paper a distributed on-line monitoring system has been developed based on

digital signal processing (DSP) technology. A method based on harmonic analysis using Discrete Fourier transform (DFT) has been used. To improve the effectiveness of the DFT algorithm, a few difficulties were overcome when the most fundamental method is utilized in digital spectrum analysis [1-5].

The on-line monitoring system detect the following parameters: running voltage, frequency, insulation current (current pass through capacitance of equipment), capacitance, dielectric loss factor tanδ, the current and voltage harmonic components of the 3rd, 5th and 7th, environment temperature and humidity etc.

2   Design of The online Monitoring system

The distributed on-line monitoring system reported in this paper is based on the half duplex RS-485 bus and fiber optical communication technology. The monitoring system consists of three parts: a) local control unit, b) substation control unit, c) remote expert and diagnosis platform. This paper only focuses on the introduction of the local control unit and substation control unit. As the remote expert and diagnosis platform is still under construction, this paper will not present more information about it.

2.1   Local Control Unit

Local control unit (LCU) is the key component of the substation online monitoring system. To reduce the signal and power supply cables, the LCU is installed in field of one or two group of three-phase HV apparatus. The current and voltage signals picked up through transducers are led into LCU and then coupled, conditioned, analog/ digital converted and processed. Measuring parameters are treated within the LCU. The distributed online monitoring system at present includes six kinds of LCU, for bushing, potential transformer (capacitor voltage transformer), metal oxide arrester, instrument transformer, transformer, ambient temperature and humidity. It is easy to integrate other online monitoring function such as DGA, partial Charge, moisture and pressure of SF6 gas chamber etc into the system.

First, the analog signals are passed through a signal conditioning circuit which provides the transient protection and isolation of the input analog signals. A 16-bit resolution ADC is used to implement simultaneous sampling of the current and voltage signals. Finally, the algorithm of the DFT is performed inside the DSP chip and the digital computation of the dielectric loss factor, capacitance and other parameters are ready for uploading to the substation control unit (SCU). In addition to the values of the dielectric loss factor and capacitance, the waveforms of the voltage, current, temperature, humidity and frequency signals and the harmonic components of the voltage and current can be displayed at SCU.

2.2   Substation Control Unit

A substation control unit (SCU), installed in the control cabinet, is the control center of the online monitoring system at the substation. The SCU can send out commands based on the communication protocol, such as start sampling, stop sampling, upload data, reset DSP etc, to control the operation of the LCU. And also, the SCU can process the LCU data to display all the monitoring results to engineers who may concern about the operation condition of the HV equipment.

A field RS485 bus is applied in the monitoring system for communication. It is in digital, multi spots and bi-directional communication mode. Relying on the flexible communication network a SCU can link with extendible LCU without exact number limit. The onsite twisted pair daisy chain RS485 network is connected through fiber-optic cable to the SCU. Compared with systems based on electrical cables, the approach of optical fiber communications has advantages, the most important of which are: fiber-optic cables are immune to problems of electrical cables such as ground loops or electromagnetic interference (EMI). High voltage signals are completely isolated between the onsite electrical cables and the control computer in the control room.

In addition, the SCU monitors and manages the operation of the LCU. If some failures occurs with one or more LCU, the SCU will reset the LCU a couple of times to fix the problem even the malfunction of one or more LCUs will not affect the operation of the remaining LCUs in the online monitoring system.

2.3   Integrate to the Online monitoring System

The objective of the online monitoring system is to meet development of the smart grid and adapt to the newly adopted power production management policy. The state grid corporation of china plans to build a fully covered system, two level of deployment and three level of application, through the construction of the system to standardize the system structure, sensor or device calibration, certification, installation, communication protocol etc at the same time, so that to show all the information such as the data display, warning results, analysis, diagnosis, evaluation, forecast etc at different level of application.

2.3.1   Terms and Definitions

Before to state the detail part or element of the overall online monitoring system, there are a few terms and definitions must to make it clear so that to help understand the system. CAC is short for the Condition Information Acquisition Controller, installed in the substation, which can connect all the monitoring device or sensors though industrial communication bus such as RS485 or Ethernet or serial port to from an online monitoring system in a substation. The CAC can receive all the information from the monitoring devices and send commands to control the process of the monitoring devices; CMU is short for the Comprehensive Monitoring Unit, installed in substation, which can receive the information from the monitoring devices or

sensors, after process the raw data, it can communication with substation monitoring unit through standardized communication bus or interfaces; SMU is short for the Substation Monitoring Unit, installed in substation, which is responsible for the data analysis, administration of the CMU and monitoring devices, parameter setting, data summon, time synchronization, device reset etc, and also to communication with the CAG; CAG is short for the Condition Acquisition Gateway, arranged at the provincial utilities, which can communication with the CAC.

2.3.2   System Structure

The overall system structure, two level of deployment and three level of application. The two level of deployment is to arrange the online monitoring system at the each province based utility and headquarter of the state grid corporation. The municipal utilities (substations) plan to arrange CACs (Condition Information Acquisition Controller) to connect all the online monitoring sensors or devices so that the municipal information can be transferred to the province and headquarter system. The three level of application is that the monitoring system can be used by municipal utilities and provincial utilities and headquarter of the state grid corporation.

2.3.3   System Interface Classification

The substation online monitoring system has four levels, which are process level, bay/unit level, station level, and CAG level. To make the online monitoring system work smoothly, the information obtained from the monitoring transducers or devices transfers three communication protocols to the CAG. The three communication protocols are interfaces I0, I1, I2. Interface I0 is between the monitoring devices (or transducers) and CMU, one way is to transfer the conditioned, A/D conversion, preconditioned signal to the CMU, the other is send setting parameters, time synchronization command, data summon command, device reset etc to the monitoring devices; Interface I1 is between the CMU and SMU. The CMU calculates the monitoring data through the calculation model, after that the CMU send the normalized data, analysis results, warning results to the SMU. The SMU can update the calculation models, summon data, time synchronization, reset etc to the CMU; Interface I2 is between the SMU and CAG. The SMU send the monitoring data, analysis results, warning information etc to the provincial based CAG. The SMU can also receive the analysis models, parameter configurations, data summon, time synchronization, device reset etc from the CAG;

2.3.4   Substation System Structure

The substation online monitoring system is a distributed and hierarchy structure, which is composed of process level, unit/bay level, station level, remote monitoring center.

The process level consists of all the monitoring devices or sensors of the transformers, reactors, circuit breakers, GISs (Gas Insulated Switchgear), MOAs

(Metal Oxide Arrester), bushings etc. The monitoring devices including DGA (Dissolved Gas Analysis), PD (Partial Discharge), transformer oil and winding temperature, transformer core ground current, dielectric loss factor, temperature, moisture, pressure and density of the GIS cabinet etc.

The IEC61850 standard is the communication standard for the smart substation, which has been successfully used in the substation automation system. At the pilot stage of the smart substation project, not all of the online monitoring devices can comply with the IEC61850 standard, the CMU is adopted so that the online monitoring system can comply with the IEC61850, as the development of new monitoring devices which embedded with IEC61850 module, the CMU and unit/bay level can be omitted in future application.

The station level is the SMU, which controls the operation of the whole online monitoring system, and also collect all the monitoring results to analysis, diagnosis, warning, data display, data storage and forward.

The remote monitoring center is also called provincial utility monitoring unit. In this paper, it is only focus on the transportation equipment and the system structure. The transportation online monitoring system as a sub system of the CAG, it can use the analysis models and methods to evaluate the condition of the high voltage equipment based on the online monitoring data or live measuring data. The data or analysis results based on the CAG platform can be published through web in the exclusive networks, and also it can offer the information to other system as foundation data of the asset condition evaluation and maintenance.

3   Summary

The developed measuring unit of the on-line monitoring system can effectively improve the simultaneous sample between multi-channel voltage and current signals. And the dynamic sampling rate setting method can trace the frequency fluctuation and improve the synchronization between the sampling rate and signal period. The methods described in this paper not only can improve the effectiveness of the DFT algorithm, but also can withstand frequency fluctuation.

Furthermore, the direct reference voltage and sampling transducer designed by the author can further reduce the phase shift of the voltage and current signals. The protection and safety measures are proved reliable and safe in field operation. The distributed on-line monitoring system has high precision of measurement, strong ability of anti-interferences, easy to integrate other functions, flexible communication networks, steady and reliable running performance. The suitability of the developed system for on-line application has been demonstrated.

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