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Recent Trends InDigital Differential Protection of Power Transformer

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Abstract: Digital protection has several advantages over conventional protection scheme. For protecting costliest and vital equipment such as transformer, digital schemes have been proposed by several authors in recent past. This paper throws light on all such efforts and it will help researchers to focus on integrated efforts to protect transformer in a better and efficient way. Artificial intelligence along with signature and pattern recognition techniques give much more useful information about happenings in and outside of transformer. Efforts are put by all concerned with fast, accurate, flexible, reliable and easy to understand scheme of protection. With the advent of soft computing methods condition monitoring with protection has become on line objective. Keeping all these state of art techniques of protection, this paper will be a useful resource. Discrimination of several faults external and internal needs digital signal processing and feature extraction as well. Many algorithms are proposed as summarized in paper.
Keywords :-Alternative Transients Program (ATP), current transformer (CT).

Introduction

For the last 15 years, there has been considerable interest in the area of digital protection of power apparatus [l]. In the early 1970sdedicated digital relays using minicomputers were proposed. Some utilities also tested minicomputer based experimental on-line systems for digital protection of transmission lines in their sub stations[2,3]. The main features which have encouraged many researchers to investigate the feasibility of designing digital relays for power system protection are its economy, reliability, flexibility, improved performance over conventional relays and the possibility of integrating a digital relay into the hierarchical computer system within the substation.
The introduction of microprocessors has brought about novel and low-cost possibilities for the development of protection devices for power systems and power apparatus. The capability of the currently available microprocessors is such that all the digital relaying functions performed by the minicomputers of the 1970scan now be done by microprocessor systems. As a result, many investigators published results of work on specific hardware and software techniques for microprocessor based transmission line relays. A few prototype distance relays using multiple microprocessors have also been tested on-line [4 , 5] .As the utilities gain experience with the use of these prototype digital relays, one can foresee that low cost, dedicated microprocessor based relays will appear in commercial service during the next few years. Considerable attention has not been given to the on-line implementation of digital power transformer protection. Only during the last few years, researchers have been investigating microprocessor based three phase transformer relays [6, 7]. The technical literature available on this subject is mainly on the algorithms for power transformer protection. Various claims have been made on the speed, accuracy, computational burden, etc. of these algorithms. It seems quite difficult to grasp the real significance of these algorithms since they are evaluated using different models.
Power system development is reflected in the development of all the power system devices generators, transformers with different sizes, transmission lines and the protection equipment. Modern power transformer is one of the most vital devices of the electric power system and its protection is critical. For this reason, the protection of power transformers has taken an important consideration by the researchers [8-10]. One of the most

effective transformer protection methods is the differential protection algorithm. Typically, transformer protection is focused on discriminating the internal faults from the magnetizing inrush currents in the power transformers and overcoming the Current Transformers (CT) related issues.

Following are some recent methodologies proposed and practiced by eminent researchers around the world in the field of digital protection of transformer.

Application of zero-sequence filter on transformer differential protection

Delta-Wye transformer connections create discontinuities in the zero-sequence network as the zero-sequence current can flow at one side of the transformer without flowing at the other side[11]. This effect generates a zero-sequence differential current that can make the differential unit trip. Traditional solutions applied to remove the zero sequence differential current where based on delta connected CTs. Zero-sequence filters in digital relays are software implemented. In many digital relays the zero sequence filter can be enabled or disabled. On the other hand, some relays can remove the zero-sequence current calculated from the phase currents or from the ground currents (currents measured in the neutral grounding). This paper reviews the transformer configurations that require the enabling of the zero-sequence filter by taking into account not only the connection group but also the construction of the magnetic core (this aspect is not always considered), explaining in detail the phantom or virtual tertiary effect of three-legged wye-wye transformers. Real false trips due to this effect are included. The paper also explains the differences between both methods used for the zero-sequence current calculation (the one based on the phase currents and the one based on the ground current). The influence on the differential unit, harmonic restraint and common external fault detectors is analyzed. The first method can lead to a reduction of the differential current and to an erroneous phase selection during an internal fault. However, "2 out of 3" logics both for harmonic blocking and for a phase directional comparison unit can be implemented increasing the stability The second method provides very good sensibility and phase selection but does not allow the implementation of the "2 out of 3" logics reducing the stability. Cases based on real events and RTDS simulations are reviewed.

A digital current transformer model for relay studies

The errors introduced by the current transformer (CT) during fault conditions, especially when the CT goes into saturation, affect the accuracy of the protection system. In order to study the transient performance of a CT thoroughly, it is necessary to develop an appropriate numerical CT model[12]. In this paper, a digital model of current transformer suitable for relay studies based on the classical Preisach model is presented

Applications of digital power simulators advantages

This paper emphasizes the advantages of using a digital power simulator, including the CVT (capacitive voltage transformer), for testing the high voltage numerical distance protections [13]. The different faults which may occur in a power system are generated by the simulator MORGAT. The TMS simulator is first used to deal with the investigations on the applied methodologies as well as the asymptotic behavior of the system under study. MORGAT is used once again for the last stage to test the protection performances. That is the common and one of the best ways for obtaining time response improvements

Modeling and simulation of the power transformer faults and related protective relay behavior

The modeling of power transformer faults and its application to performance evaluation of a commercial digital power transformer relay are the objectives of this study [14]. A new method to build an EMTP/ATP power transformer model is proposed in this paper. Detailed modeling of the transformer relay is also discussed. The transient waveforms generated by ATP under different operating conditions are utilized to evaluate the performance of the transformer relay. The computer simulation results presented in this paper are consistent with the laboratory test results obtained using an analog power system model

A software design technique for differential protection of power transformers

This paper presents design software for Fourier Transform based logic technique for protection of transformer [15]. This software is designed to simulate the operation of the digital differential relay for electrical power transformers. It improves and enhances the sensitivity of operation of the digital differential relay that protects power transformers by discriminating between inrush current and fault current without blocking the relay during the energization of power transformers, as well as avoiding tripping during the normal operation of tap changer. The digital differential relay is designed using a simulation technique in MATLAB Simulink environment. The different tests are selected to simulate different cases of operation and faults.

Visualization and animation of protective relay operation

The evolution of software engineering, multitasking environment, object oriented programming and symbolically assisted simulation methods have enable the creation of interactive simulation environments that come close to providing a virtual experience of the actual system [16]. These systems are useful for a variety of engineering and educational purposes. An important issue in power engineering is the understanding of protective relay operation and response to system disturbances. This paper focuses on protective relaying applications and the use of a virtual environment for the animation and visualization of protective relaying applications. The paper describes the virtual environment and the interaction of animation and visualization of protective relaying modules. The animation and visualization can be performed in the virtual environment or in an offline environment where the system disturbance is captured into a COMTRADE file and "played back" into the animator/visualizer. Two examples of protective relay types are presented: (a) a modified mho relay; and (b) a transformer differential relay. This tool is extremely valuable for educational purposes. Another potential application is digital relay testing.

New digital distance relaying scheme for phase faults on doubly fed transmission lines

Performance of conventional non-pilot phase distance relay is affected by series capacitor (SC), remote in feed/out feed, prefault system conditions and arc resistance [17]. The work presented in this study addresses the problems encountered by conventional non-pilot phase distance relay when protecting doubly fed series compensated transmission lines. One of the key points of this study is the detailed analysis of the apparent impedance as seen from the relaying point taking into account the effects of transmission line parameter uncertainties, behavior of SC, arc resistance and variations in the system parameters external to the protected line. Based on extensive computer simulations of the infeed/outfeed, arc resistance and effects of SC on the relay characteristics, a new digital distance relaying scheme is proposed. It is based on digital computation of impedance of faulted portion of transmission line using symmetrical components of currents and voltages measured at local end only. To validate the proposed scheme, numerous computer simulations have been carried out on an existing Indian 400 kV, 300 km long series compensated transmission line using MATLAB/SIMULINK software. Simulation results demonstrate the effectiveness of the proposed scheme as the percentage error is within 5 .

A Novel Algorithm to Avoid the Mal operation of UHV Voltage regulating Transformers

A typical mal-operation case of the differential protection utilized in the ultra-high voltage (UHV) voltage-regulating transformer (VRT) under inrush conditions is investigated in this paper[18]. It indicates that the second harmonic restraint principle cannot identify the inrush current reliably under such conditions. This paper proposes a normalized equivalent instantaneous inductance (NEII)-based inrush blocking method, which improves the equivalent instantaneous inductance (EII)-based method in the UHV VRT protection. Although the EII-based method is capable of discriminating inrush currents and internal faults, some factors constrain its application, such as the field limitation of measuring the terminal voltage of the transformer and the difficulty of determining a reasonable threshold due to the diversity of transformer magnetizing characteristics. The proposed NEII-based method overcomes limitations of the EII-based method and can be adopted in UHVVRT protection. A number of simulation tests have verified the effectiveness of the proposed method.

Time-time-transform application to fault diagnosis of power transformers

Application of time-time (TT)-transform for differential protection of power transformers has been suggested [19]. At first, external and internal disturbances are discriminated. If the disturbance is external, relay scheme restrains more analysis and tripping. Otherwise, the differential current signal is analysed by TT-transform and TT-matrix is computed. Next, a suggested index is computed, accordingly. Discrimination between inrush current and internal fault is performed by the proposed index. To investigate the effectiveness of the method, a typical power system has been modelled in EMTP software. Also, the relay scheme has been developed in MATLAB environment. Then, differential currents extracted from the system modelled in EMTP have been fed to MATLAB for analysis. Also, the performance of the method in noisy environments has been assessed. To make an analogy between the TT-transform-based method and wavelet transform-based methods, a wavelet transform-based scheme has been developed in MATLAB environment and results have been compared to the results of the TT-transform-based method. In addition, an *S*-transform-based method has been implemented in MATLAB and has been compared with the suggested method. The results show that the method is superior to both wavelet transform and *S*-transform-based methods.

Innovative Differential Protection of Power Transformers Using Low-Energy Current Sensors

Traditional differential protection systems are applied on large power transformers using current transformers (CTs) [20]. However, because of high secondary currents (often exceeding 100 kARMS), differential protection systems for electric arc furnace transformers have not been applied in the past due to the lack of commercially available CTs. This paper will present differential protection systems that have been in use for many years using Rogowski coil current sensors. These protection systems use high-precision printed circuit board Rogowski coil current sensors. This paper reviews the characteristics, designs, and application of these Rogowski coil sensors for advanced protection, control, and metering systems with new multifunction relays. This paper compares performance characteristics of new solutions based on Rogowski coil sensors with the conventional differential protection systems based on CTs, demonstrating that the new systems do not have the limitations of conventional technology. Operating experience from several site applications is included

Time-Domain Analysis of Differential Power Signal to Detect Magnetizing Inrush in Power Transformers

In this paper, a novel power-based algorithm to discriminate between switching and internal fault conditions in power transformers is proposed and evaluated [21]. First, the differential power signal is scrutinized and its intrinsic features during inrush conditions are introduced. Afterwards, a combined time-domain-based wave shape classification technique is proposed. This technique exploits the suggested features and provides two discriminative indices. Based on the values of these indices, inrush power signals are identified after only half a cycle. This method is founded upon some inherent low-frequency features of power waveforms and is independent of the magnitude of differential power. The approach is also unaffected by power system parameters, operating conditions, noise and transformer magnetizing curves. Simplicity of the suggested features and equations describe how the proposed method can help make it a practical solution for the inrush problem. Extensive simulations carried out in PSCAD/EMTDC software validate the merit of this technique for various conditions, such as current-transformer saturation. Furthermore, real-time testing of the proposed method using real fault and inrush signals confirms the possibility of implementing this algorithm for industrial applications.

New approach for power transformer protection based on intelligent hybrid systems

A power transformer needs continuous monitoring and fast protection as it is a very expensive piece of equipment and an essential element in an electrical power system [22]. The most common protection technique used is the percentage differential logic, which provides discrimination between an internal fault and different operating conditions. Unfortunately, there are some operating conditions of power transformers that can mislead the conventional protection affecting the power system stability negatively. This study proposes the development of a new algorithm to improve the protection performance by using fuzzy logic, artificial neural networks and genetic algorithms. An electrical power system was modeled using Alternative Transients Program software to obtain the operational conditions and fault situations needed to test the algorithm developed, as well as a commercial differential relay. Results show improved reliability, as well as a fast response of the proposed technique when compared with conventional ones.

Power Transformer Differential Protection Based on Clarke's Transform and Fuzzy Systems

The power transformer is a piece of electrical equipment that needs continuous monitoring and fast protection since it is very expensive and an essential element for a power system to perform effectively [23]. The most common protection technique used is the percentage differential logic, which provides discrimination between an internal fault and different operating conditions. Unfortunately, there are some operating conditions of power transformers that can affect the protection behavior and the power system stability. This paper proposes the development of a new algorithm to improve the differential protection performance by using fuzzy logic and Clarke's transform. An electrical power system was modeled using Alternative Transients Program (ATP) software to obtain the operational conditions and fault situations needed to test the algorithm developed. The results were compared to a commercial relay for validation, showing the advantages of the new method.

Transformer Differential Protection Using Principal Component Analysis

This paper describes a new algorithm for transformer differential protection, based on pattern recognition of the differential current obtained as the phasor sum of the current-transformer secondary currents [24]. The algorithm uses principal component analysis to preprocess data from the power system in order to eliminate redundant information and enhance hidden pattern in differential current to discriminate between internal faults (transformer differential protection zone) from inrush and over excitation conditions. The algorithm was proven using PSCAD/EMTDC simulations in a three-phase power system considering critical fault cases. The results show the feasibility to implement this algorithm for transformer differential protection.

Transformer Inrush Current and Comparison of Harmonic Restraint Methods in Transformer Protection

It is well known that differential protection is most suitable for transformer protection [25]. However, inrush current due to transformer energization can appear as fault to the protective relay. To improve the security while maintaining the required levels of sensitivity, many restraint methods have been proposed to inhibit operation of the differential element. This paper first will analyze the magnetizing inrush current during transformer energization with a simplified excitation curve. It derives mathematical equations to compute the inrush current based on the residual flux and saturation flux for the worst case energization event. This paper reviews several popular restraint methods used today. A conceptual logic diagram is provided for each method. Advantages and disadvantages of different methods are analyzed for various systems. Finally, using data recorded from real life events and data generated by digital simulations, a performance comparison of different methods is provided.

Universal Adaptive Differential Protection for Regulating Transformers

Since regulating transformers have proved to be efficient in controlling the power flow and regulating the voltage, they are more and more widely used in today's environment of energy production, transmission and distribution [26]. This changing environment challenges protection engineers as well to improve the sensitivity of protection, so that low-current faults could be detected (like turn-to-turn short circuits in transformer windings) and a warning message could be given. Moreover, the idea of an adaptive protection that adjusts the operating characteristics of the relay system in response to changing system conditions has become much more promising. It improves the protection sensitivity and simplifies its conception. This paper presents an adaptive adjustment concept in relation to the position change of the on load tap changer for universal differential protection of regulating transformers; such a concept provides a sensitive and cost-efficient protection for regulating transformers. Various simulations are carried out with the Electro-Magnetic Transients Program/Alternative Transients Program. The simulation results indicate the functional efficiency of the proposed concept under different fault conditions; the protection is sensitive to low level intern faults. The paper concludes by describing the software implementation of the algorithm on a test system based on a digital signal processor.

Simulation of a differential current protection scheme involving multiple current transformers

Differential protection schemes for bus bars, generators or transformers connect multiple current transformers in parallel across a common burden [27]. This paper describes the techniques used to simulate such an arrangement and concentrates particularly on the three current transformer case

Fast algorithm for digital protection of power transformers

A simple algorithm for fast computation is an important requirement for the efficient application of microprocessors in power-system relaying [28]. Using the rectangular transform technique, a fast and accurate algorithm has been developed for transformer protection. The algorithm generates the Fourier coefficients by addition and subtraction routines only. The method provides good discrimination between the nonzero differential current produced by the transformer energization and that produced by internal faults. The algorithm provides fast fault detection and yields a large blocking signal, using second or higher harmonic components. The digital simulation and test results on a variety of fault and inrush conditions, including the periodic inrush ones, clearly demonstrate the efficacy of this algorithm for the protection of the power transformer. Furthermore, owing to the relative simplicity and absence of time consuming multiplication and division calculations, the algorithm is quite suitable for microprocessor-based protection of power systems.

Conclusion

This paper concludes with unification of different algorithms and technologies for digital protection of transformers. Over the years modern state of art techniques need to be convincing to utilities else they will lose the charm of their several advantages. In countries where classical practices are heavily relied upon, there is a need to augment protection using digital means. Once checked over specific period of time then classical protection schemes should be slowly removed from the system. There is lot of promising scope when we see the contribution of eminent researchers in the field of signal processing and advanced interpretation of complex issues of protection.

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