THE MULTIFUNCTIONAL NUMERICAL TRANSFORMER PROTECTION AND CONTROL SYSTEM WITH ADAPTIVE AND FLEXIBLE FEATURES

J Wang, Z Gajic, S Holst

ABB Automation Products AB, Sweden

INTRODUCTION

For several decades, the power system protection relay has experienced many important changes, from purely electromechanical type to the mixture of electronic and electromechanical type, then to fully static, and now fully numerical relays based on microprocessors. In the transformer protection area, similar changes can be seen. It is a dream for protection engineers to have a system that not only has many different functions for customers' option, but also can be easily configured for different applications. On the other hand, it is expected to have control functions such as on load tap changer control function in combination with protection system so that a protection and control system can be formed within one hardware and software system. With the fast development in the area of digital technology, the hardware and software must be possible to provide economic solutions regarding the cost of functions and hardware cards for a dedicated application. It is the motivation to build a powerful transformer protection and control system in order to fulfil the requirement from different applications. In this paper, distinct futures in the newly developed transformer protection and control system will be presented.

A modern transformer protection and control system has many functions reflecting the technical trends of function integration, such as transformer differential protection, restricted earth fault protection, thermal overload protection, overexcitation protection, earth fault protection, directional or non-directional overcurrent protection, overvoltage and undervoltage protection, voltage control function for single transformer and parallel transformers as well as frequency measurement function. The integrated transformer protection and control system also includes adaptive functions such as the adaptive measurement with analogue inputs during the frequency change in power systems, and on load tap changer position compensation for increased sensitivity of the differential protection. The modern transformer differential protection demonstrates more adaptive features that give the possibility to combine high stability for inrush and external faults with a high sensitivity for internal faults. In addition to the features described above, the new system can be configured and set in a flexible way for different types of applications with an advanced configuration tool.

PLATFORM

The basic idea in building the new protection system platform is coming from two points: the design of new hardware and software platforms must be possible to cover quite wide range of applications and it should be open for future upgrading as in Hillstrom et al (1). According to this requirement, the PowerPC family of microprocessors has been selected for the protection applications (2). PowerPC microprocessors are based on RISC (Reduced Instruction Set Computer) technology with built-in pipeline parallelism for instructions. The on-chip cache provides a means for higher speed calculations. The main advantages of PowerPC are due to its high floating performance and low power consumption. For communication with high speed modules such as analogue input modules and high speed serial interface, the PowerPC is equipped with a CompactPCI bus (3). For communication with low speed modules such as binary input and output modules, a CAN bus interface is used. The remote HMI can be connected via different communication buses such as SPA and LON. The system is provided with continuous self-monitoring and diagnostics.

In order to fulfil the application requirements for different types of flexible protection purposes, the following modules are available within the hardware platform:

- Two analogue input modules (AIMs), each module includes 10 analogue inputs with built-in analogue to digital converters (A/D-converter).
- Four binary input/output modules (BIM/BOM) can be selected. Among these modules, 24 output relay contacts are available in one binary output module; 16 binary inputs are available in one binary input module and 12 contact outputs and 8 binary inputs are provided in one module known as binary input and output module (BIOM).
- One mA-analogue input module (MIM) used e.g. for tap position indication for on load tap changer control and for temperature reading.
- Power supply module (PSM).
- Numerical module is a high performance PowerPC processor (NUM).

MULTIFUNCTIONAL SYSTEM

In order to build a multifunctional protection and control system, a common mathematical library has been developed and installed. The mathematical library has high operation speed so that different protection functions can be easily performed by picking up the related instantaneous signals or calculated phase values as well as harmonics values to form its own logic. In this way, a common library can be used even for future applications. Following values are examples that are available from the mathematical library in the system:

- instantaneous values of AC currents and voltages,
- fundamental frequency currents and voltages as phasors,
- harmonic components of currents and voltages,
- positive, negative and zero sequence currents and voltages,
- power system frequency.

The available application functions within the system are listed below. Because the system is an open system, it is possible to include more application functions in the near future according to new requirements.

- transformer differential protection for two- and three- winding transformers,
- restricted earth fault protection,
- directional or non directional earth fault protection,
- directional or non directional overcurrent potection,
- overvoltage and undervoltage protection,
- overexcitation protection,
- thermal overload protection,
- voltage control for single/parallel transformers,
- event recorder,
- disturbance recorder.

In addition to these application functions, some logic functions such as trip logic gates, AND/OR gates, logic inverter, logic time pulse, logic timer are also provided for users. New application functions can be built by using the configuration tool provided in the system.

The most important protection function is the differential protection function. Two trip criteria are used. The first trip criterion is based on unrestrained differential trip algorithm for heavy internal faults which will produce a very high differential current so that it is not necessary to check if it is inrush conditions. The second trip criterion is the through fault current restrained differential algorithm which also includes the waveform blocking criterion in combination criteria of second harmonic restrain for inrush and the fifth harmonic restrain for overexcitation. The function is designed to consider stabilisation from up to five groups of three-phase current inputs, which covers most of applications for the transformer differential protection. The vector group and amplitude compensation and the zero sequence current deduction are made internally by software according to the connection group and rated data information for a protected transformer.

ADAPTIVE FUNCTIONS

The adaptive relaying has been formally defined in IEEE working group report (4) as follows: "Adaptive protection is a protection philosophy which permits and seeks to make adjustments in various protection functions automatically in order to make them more attuned to prevailing power system conditions." In the transformer protection and control system, following adaptive functions are provided.

Adaptive Differential Protection Function

Adaptive through fault current stabilisation. The application of transformer differential protection function in one and half breaker scheme or double breaker scheme as shown in figure 1, is known as T configuration application. The differential protection function will meet stability problem for an external fault F1 in figure 1, if two groups of current inputs (CT1 and CT2) are simply summed externally and connected into the differential protection as one group of currents. On the other hand, there is a risk that the sensitivity of the differential protection will considerably be reduced for an internal fault F2, if all current inputs are connected separately in a traditional way as restrain signals. The modern differential protection function has an adaptive feature that considers both stability and sensitivity by investigating the original current inputs so that a reasonable restrained current is calculated adaptively for each individual fault. Finally a special adaptive feature in this algorithm is that the sensitivity will be automatically reduced in case heavy external faults are detected.

Adaptive on load tap changer compensation. The transformer differential protection function has a spill current due to the on load tap changer influence. Normally, the control range of an on load tap change might be around ±15% of rated voltage so the contribution of spill current can often be around 15%. In order to keep the security and avoid unwanted operations of the differential protection, it is common to set the minimum sensitivity level above 30% of rated current. The sensitivity of the differential protection will be very poor and in most cases it is not possible to detect inter-turn faults in transformer windings.

In the new differential protection function, the tap changer position is measured and used in the algorithm so that the transformer turns ratio can be calculated. Because of the adaptive calculation of the differential current, it is possible to considerably increase the sensitivity and the possibility to detect inter-turn faults in the transformer. To prevent an unwanted operation if the reading of the tap changer position is lost during normal operation, the differential protection function will change its sensitivity and will not issue any trip signal when the calculated differential current is less than 30% of rated current.

Adaptive inrush blocking. Usually the inrush current stabilisation has been based on the second harmonic blocking method. In most countries this is a generally accepted method with good operational experiences. However, there is a risk of delayed operations, in case of heavy internal faults, due to the presence of a second harmonic secondary current caused of saturation of the current transformer. With a combination of a conditionally second harmonic restraint method and a permanent waveform restraint method, it has been possible to gain a protection with both high security and stability against inrush effects and at the same time maintain high performance in case of heavy internal faults. The second harmonic blocking criterion will be enabled both when the transformer is not energised and during the first period after the power transformer is energised. The second harmonic blocking criterion will also be automatically enabled for some seconds once a heavy external fault is detected. This will further reduce the risk of an unwanted operation due to recovery inrush current, when the heavy external fault is cleared. The waveform blocking criterion is always activated to detect both initial inrush, sympathetic and recovery inrush.

Adaptive Voltage Control Function

The adaptive voltage control function has a feature in which once the voltage control command is issued, the expected change of voltage amplitude is checked and the next operation will be temporarily blocked if the expected change of voltage amplitude can not be confirmed in the previous action. This feature provides a positive effect in avoiding voltage collapse when the power system is short of reactive power supply as in Taylor (5).

Frequency Adaptive Function

Power systems normally work under the fundamental frequency. There is a possibility to have a power system working in a condition with its frequency above or below the rated frequency due to sudden load changes or power unbalance, especially in the area close to generator stations. On the other hand, the numerical transformer protection functions are mainly based on the algorithm in frequency domain, which means that a lot of values are calculated from the Discrete Fourier Filter (DFF) tuned to the rated frequency. If the power system fundamental frequency changes, the calculated results will have errors so that the accuracy of protection settings will be influenced. As a consequence, the dependability and security of protection functions are affected. In order to provide correct measuring, an adaptive DFF has been developed as in Hillstrom (1). These adaptive DFF has been patented and implemented in the protection and control system. Within the frequency range, 33 Hz to 61 Hz for 50 Hz systems and 39 Hz to 73 Hz for 60Hz systems, the maximum error in the measured currents and voltages is less than 2%.

With the help of the adaptive DFF, all the protection functions can keep their dependability and security even if the power system frequency deviates from its rated values.

FLEXIBILITY

The most important protection function is the differential protection function (DIFP) which has many output signals and setting options so that different applications can be used. Two typical setting options are the zero sequence component subtraction enable (ZSCSub) and cross blocking enable (CrossBlock). This means that the users can select the DIFP function with or without above possibilities so that special application conditions can be applied. All protection and control functions in the new system in one or another way use the values set under “Power Transformer Data”. Therefore it is possible to adjust this data in order to obtain some extra functionality. One example in flexible application is the use of differential protection for a special railway transformer protection, which is shown in figure 2 where the transformer data are set in a special way. The differential currents in figure 2 are calculated as below.

$$Idiff\_L1 = I_M + \frac{\frac{\sqrt{3}}{2}U_{HV}}{U_{LV}} \times I_B \tag{1}$$

$$Idiff\_L2 = 0 \tag{2}$$

$$Idiff\_L3 = I_T + \frac{\frac{U_{HV}}{2}}{U_{LV}} \times (I_A - I_C) \tag{3}$$

Here, phase L1 and phase L3 will be used for differential protection, while phase L2 will measure zero current all the time.

The flexibility in the DIFP function can also be seen in using the cross blocking options (CrossBlock). When the "CrossBlock" is enabled, the DIFP function will not issue any trip signal if one of starting phases has met one of restrain criteria. This gives more security for the inrush condition during switching in a power transformer. It is also desirable in some applications to disable the "CrossBlock" so that DIFP function mainly works in a phase segregated way.

The graphic configuration and programming tool provided by the protection and control system is a very powerful tool in which a lot of different applications can be obtained. With the help of this tool, the users for protection application purposes can build their own application scheme since all protection functions, control functions as well as monitoring functions are represented as function blocks.

For example, a logic for open CT (Current Transformer) blocking can be built in the configuration tool by using the starting signals from over current and earth fault protection, in order to block the differential protection function during the open CT period.

The great number of analogue inputs is another key to the great application flexibility of the system. Figure 3 shows an example where the system is used as a protection scheme for a SVC (Static Var Compensation) station.

CONCLUSIONS

The numerical transformer protection and control system described in this paper is a powerful, multi-functional, adaptive, flexible system which provides a lot of possibilities for different applications in transformer protections and similar applications areas such as shunt reactor protections, generator protections, etc. The advanced features in this new system show a further step in the development of modern numerical protection and control systems with improved protection functionality and almost unlimited flexibility for solving most application cases.

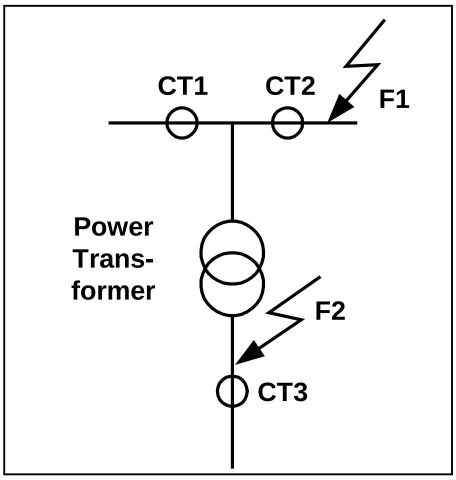

Figure 1: Transformer T configuration Application

REFERENCES

1. Hillstrom B et al, 1998, "Adavances in Power System Protection", 11th International Conference on Power System Protection PSP 98, Bled, Slovenia.

2. Motorola, 1994, "The Programming Environments, PowerPC Microprocessor Family"

3. Wind River Systems, 1995, " Tornado API Guide, 1.0 Beta", IBM Microelectronics.

4. CIGRE Working Group 34.02, August 1995, " Adaptive Protection and Control", CIGRE Final Report.

5. Taylor C W, 1994," Power System Voltage Stability", EPRI-McGraw-Hill, Inc. New York.

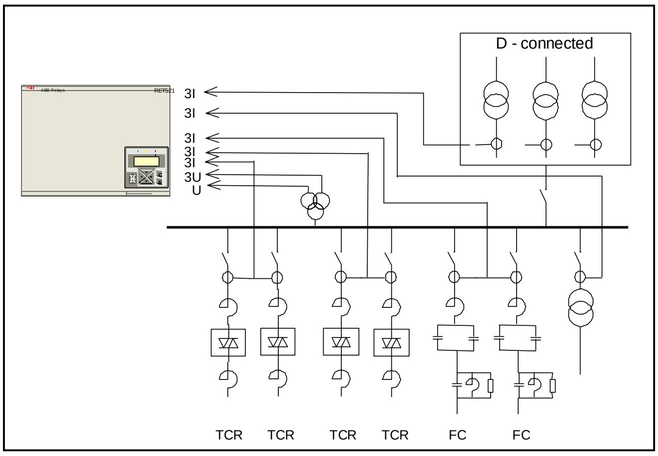

Figure 3: Example of Application Flexibility

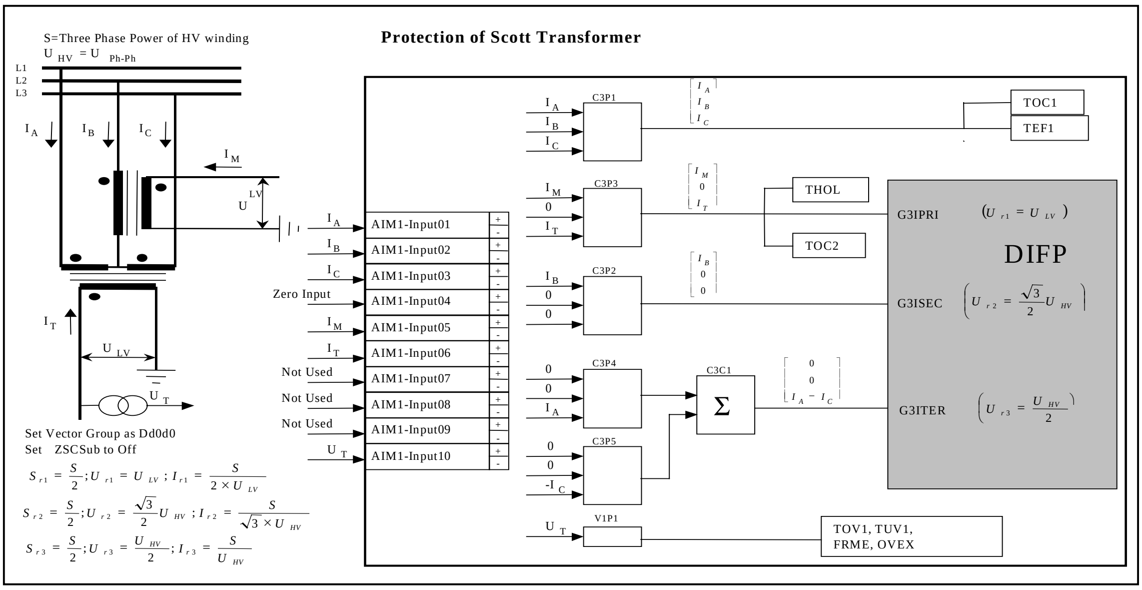

Figure 2: The Protection Scheme for Scoot Transformer