Моделювання одного типового цифрового диференціального реле в MATLAB

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Реле відіграють ключову роль в енергетичних системах. Їхнім завданням є відрізати дефектну частину від інших зон енергетичної установки. Існують різні види реле і кожне реле має окреме застосування. Диференціальні реле використовуються для захисту трансформаторів, датчиків і електричних шин. У минулому, механічні реле використовувалися як диференціальні реле, проте, сьогодні механічним реле на заміну прийшли цифрові реле. Прогресивні диференціальні реле використовують процентний диференціальний захист з подвійною характеристикою нахилів для запобігання небажаної дії через помилки трансформатора струму. Після моделювання усіх частин реального цифрового реле ці частини були поєднані для утворення реального цифрового диференціального реле. Також, ця модель використовувалася для будівництва цифрового диференціального блоку реле. Оскільки SIMULINK не має диференціального блоку реле в своїй бібліотеці, цей блок може використовуватися в інших імітаціях енергетичних установок як диференціальне реле.

Найголовніші частини реального цифрового реле є наступними: аналогове масштабування, аналоговий фільтр, зразок і фіксація, мультиплексор, аналоговий для цифрового конвертера, цифровий фільтр, процесор.

У статті описано усі частини реального цифрового реле й модель кожної її частини. Також створювалася модель схеми логіки диференціальних реле, що використовуються у мікропроцесорі диференціальних реле. Наприклад, цифрові диференціальні реле можуть компенсувати фазу зсуву трифазових трансформаторів для кожної векторної групи. Ми застосовували матриці, які використовуються в реальних реле для компенсації кожного зсуву фази. Також цифрові диференціальні реле можуть піддаватися натиску і збудженню, досягаючи 2 гармоніки і 5 гармоніки, відповідно. Якщо ці кількості перевищують певні значення, реле шукають вихід з цієї ситуації натиску або збудження та не надсилають перемикачам сигналу відключення.

Нарешті ця модель використовується в одній типовій енергетичній системній імітації для захисту трифазових трансформаторів. Перевірялася дія реле через виклик аварії у двох різних місцях – у захищеній зоні й в іншій - незахищеній. Результати показали, що реле може виявити натиск і перевищення електричного струму, а також розрізняти дефекти в захищеній зоні і в незахищеній зоні. Отже, результати підтвердили правдивість моделі.

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Modeling one typical digital differential relay in the MATLAB

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Differential relays are widely used in the Power networks as a protection for power transformers, bus bars and generators. This paper aims to model one typical differential relay in the SIMULINK environmental. This model has been simulated in the MATLAB program and the results confirmed truth of the proposed model. Also, this model is used to build differential relay block in MATLAB software. Since MATLAB software does not have a differential relay block, this block can be used in other power system's simulations as a differential relay.

Keywords – Digital differential relay, modeling, MATLAB

I. Introduction

Relays have a key role in the power system. They have duty to cut the faulted zone from the other areas of power system. Not too long ago, mechanical relays were employed for the protection duty of power systems [1]; however, with progress in the digital systems, previous mechanical relays have been replaced by the digital relays. Fig.1 shows different parts of a typical digital relay [2].

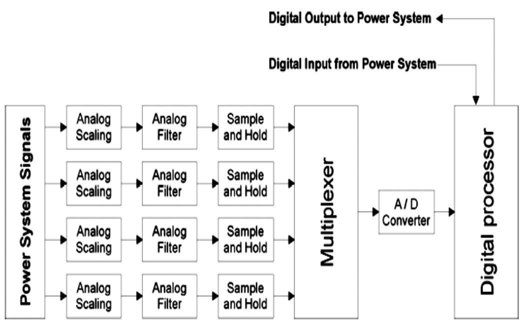

Fig. 1. Different parts of digital relays

Different parts of Fig.1 are common for all digital relays. Analog scaling is used to decrease level of input signals, because processors only can work in the specific range of inputs. Analog filter is used to filter noises from which are come from the power system (due to the switching or faults in the power systems). Since digital processors (such as micro controllers) need analog to digital conversion time, sample and hold circuits are used for sampling and holding the input and sending them at appropriate time to the processor. Since very high speed analog to digital converters are relatively expensive, Multiplexer is used for sending only one input to the analog to digital section of micro controller at the moment, and finally, processor of the micro controller analyses inputs in order to find possible faults.

Differential protection is a very reliable method of protecting generators, transformers, buses, and transmission lines from the effects of internal faults. In a differential protection scheme which has been showed in the Fig.2, currents on both sides of the equipment are compared. The figure shows the connection only for one phase, but a similar connection is usually used in each phase of the protected equipment. Under normal conditions, or for a fault outside of the protected zone, current I_1 is equal to current I_2 . Therefore the currents in the current transformers secondaries are also equal, i.e. $i_1 = i_2$ and no current flows through the current relay. But if i_1 and i_2 do not be identical, differential protection concludes that internal fault has been occurred and then it will separate this section of the power system from other areas. This way of protection is called current differential protection.

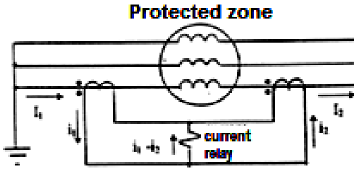

Fig. 2. Differential protection scheme

The disadvantage of the current differential protection is that current transformers must be identical; otherwise there will be current flowing through the current relays for faults outside of the protected zone or even under normal conditions. Sensitivity to the differential current due to the current transformer errors is reduced by percentage differential relays. In percentage differential relays, the current from each current transformer flows through a restraint coil. The purpose of the restraint coil is to prevent undesired relay operation due to current transformer errors. Fig.3 shows scheme of percentage differential relay.

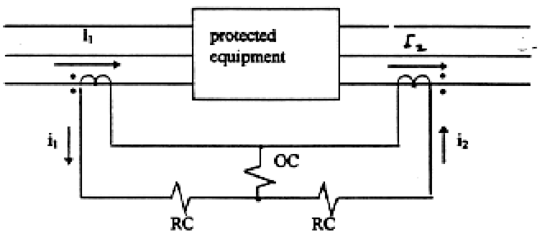

Fig. 3 Percentage Differential protection scheme

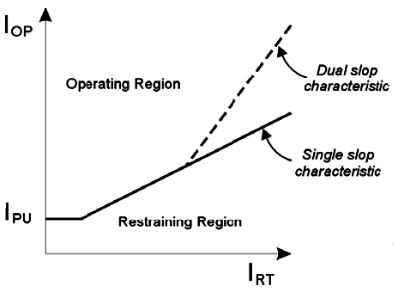

Fig. 4. Differential relays trip characteristics

The operating coil current $| i_1 - i_2 |$ required for tripping is a percentage of the average current through the restraint coils. Digital differential relays use trip characteristic which is showed in the Fig.4. It shows 2 different characteristics for digital differential relays. Single slope characteristic is used in ordinary applications. Since progressive digital relays use dual slopes characteristics, we used dual slopes characteristic in our modeling.

II. Digital differential relay modeling

Here, we present each part of a real digital relay and its model in our modeling.

Auxiliary pt and ct

Auxiliary transformers are used mainly for three following reasons:

1. Decreasing the level of voltage to the suitable level
2. Isolating relay hardware from power system
3. Compensating difference in the phase of primary and secondary inputs (not for digital relays).

Note that the third reason in the digital relays is done by the processor itself.

Since in the differential relays, we only need auxiliary CT (since inputs are only currents), we only modeled it. Figs.5 shows model of auxiliary CT in the MATLAB. Note that MOV (metal oxide varistor) has been modeled with the non linear capacitance.

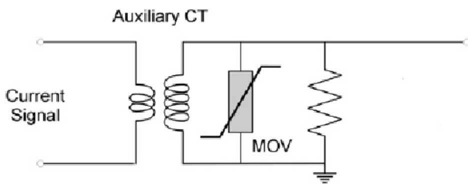

Fig. 5. Auxiliary CT in the differential relay model

Current to voltage converter

For analyzing data in the micro controller (or other digital components), the inputs should be voltage. In many relays, an accurate 1 ohm resistor is used for current to voltage conversion.

Anti aliasing filter

Low-pass filters are used to avoid the phenomena of aliasing in which the high frequency components of the inputs appear to be parts of the fundamental frequency components. The analog inputs must be applied to low-pass filters and their outputs should be sampled and quantized. The use of low-pass filter is necessary to limit the effects of noise and unwanted components of frequencies.

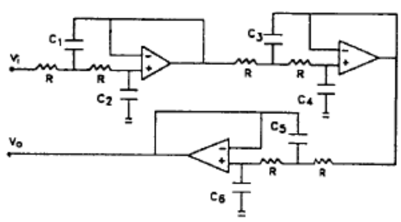

Fig. 6. Anti aliasing filter

The filter is designed to remove any frequencies existing on the input signal which are greater than half the sampling frequency. Common analog low-pass filters used in these relays are of third to fifth order with cutoff frequency of about 90 Hz. The cutoff frequency of 90 Hz implies that a sampling rate of at least three samples per cycle (180 Hz) must be used in order that the information needed to perform the differential relay functions is retained and errors due to aliasing are avoided. In practice, the sampling rate must be at least four samples per cycle (240 Hz). Fig.6 shows model of anti aliasing filter which is used in the digital relays.

Sample and hold

The purpose of the sample and hold circuitry is to take a snapshot of the sensor signal and hold the value. The ADC must have a stable signal in order to accurately perform a conversion. Fig 7 shows an equivalent circuit of sample and hold circuit.

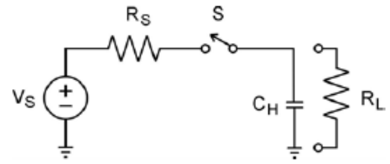

Fig. 7. Sample and hold model

Sample and hold is controlled by the processor. Processor sends signals to the sample and hold chip and it determines that sample and hold chip hold the input or send it to the multiplexer.

Analog multiplexer

A very cost-effective way to implement an A/D conversion board is to use a single A/D converter component (ADC) and multiplex different combinations of signals to the ADC's input. This technique can accommodate a large number of inputs and it is used in the digital relays, so the final cost of relay is more economic. Fig.8 shows the proposed model for 6 channel analog multiplexer which is used in the 3 phase differential relay.

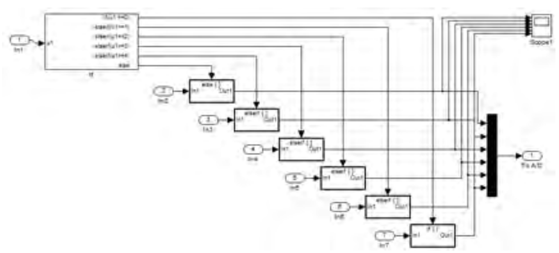

Fig. 8. Multiplexer model

Analog to digital converter (A/D)

An analog to digital converter (A/D converter or ADC) takes the instantaneous value of an analog voltage and converts it into an n-bit binary number that can be easily manipulated by a microprocessor. In general, most high performance numeric relays use 12, 14 or 16 bit ADCs (IEE, 1995). The n-bit number is a binary fraction representing the ratio between the input voltage and the full-scale voltage of the converter. A number of techniques can be used to achieve this conversion. The full input voltage ranges for an ADC are typically 0 to +5 or 0 to +10 volts for unipolar operations, and –5 to +5 or –10 to +10 volts for bipolar operation. We used embedded MATLAB editor block for modeling 12 bit bipolar analog to digital converter (i.e. we wrote A/D code for modeling analog to digital section).

Digital filter

Digital filters have, for many years, been the most common application of digital signal processors. There are two basic forms of digital filters, the Finite Impulse Response (FIR) filter and Infinite Impulse Response (IIR) filter. The main draw back to the use of IIR filters in digital protection relays is that the group delay cannot be specified in the design process. This makes their use in protection somewhat onerous; in general, FIR filters are usually the preferred type. So we modeled a simple FIR filter which is used in the digital relays. Fig 9 shows this simple model.

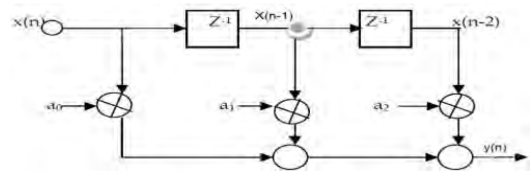

Fig. 9. Digital Filter model

The processor and the trip logic

The processor analysis inputs which have come from A/D. It calculates restraint coil current and operating coil current. Then it evaluates these currents in the dual slope characteristic. If it concludes that relay is in operating region, it will send trip signal to the switches; otherwise, it does not send any signal to the switches.

There are two important matters in differential protection for transformers:

1. Inrush current of transformers does not pass through the transformer, so in the first seconds relay concludes that internal fault has been occurred. This problem is solved in the digital relays by using DFT (discrete furrier transform). Since the inrush current has a great amount of 2^{nd} harmonic, digital relay calculates 2^{nd} harmonic of primary currents and if its 2^{nd} harmonic become more than specific value, it consider this current as inrush current and it does not send trip signal [3].

2. Three phase transformer's differential protection needs phase shift compensation. In the digital relay, compensation is done numerically in the processor. Certain matrices are used for omitting phase shift which is caused by the various configurations of three phase transformers [4].

In our model, we used DFT block in the SIMULINK library for calculation of 2^{nd} harmonic. By knowing percent of 2^{nd} harmonic in the primary current, we can be able to prevent mistake trips due to inrush current. Also, we used MATLAB function block in order to embed transform matrices for omitting phase shifts. The other parts of the processor such as dual slopes characteristic are modeled with embedded MATLAB editor block.

III. Differential relay block

After modeling different parts of differential relay, we combined these parts as a whole (see Fig.10). Then, we made digital differential relay block in the SIMULINK environmental. Setting menu of this new block has been showed in the Fig.11. As it can be seen, setting menu allows user to set his desired setting. For example, user can define his trip characteristic by setting Id min and slope 1 and slope 2. User also can adjust percent of 2nd harmonic in inrush current and percent of 5th harmonic in the over excitation current. Furthermore, user can select transformer vector group for correct compensation of phase shift in the three phase transformers.

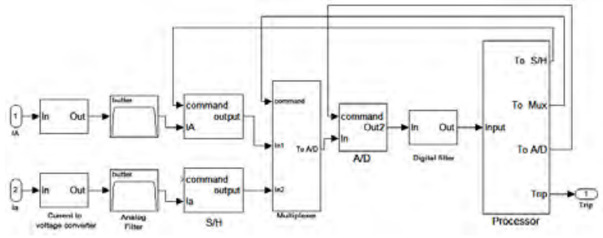

Fig. 10. Differential relay model in SIMULINK for one phase

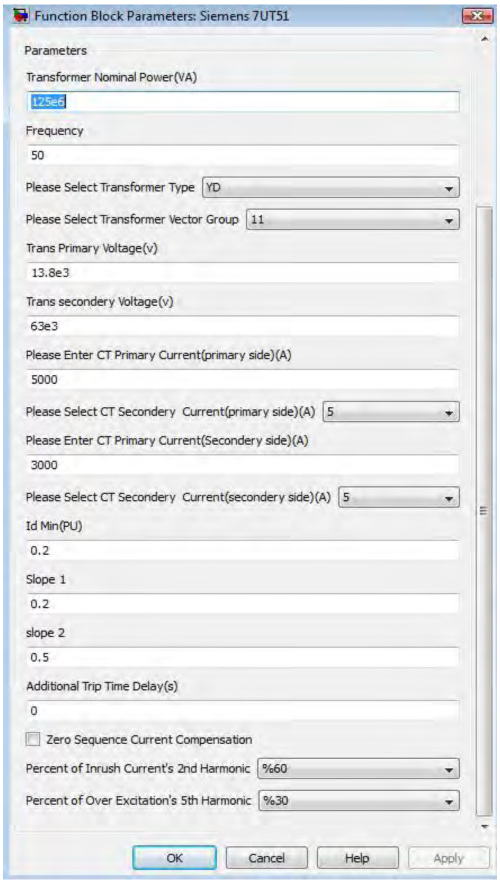

Fig. 11. Setting menu of the proposed differential relay block

IV. Simulation results

We used differential relay block in the simulation of one typical power system which consists of three phase transformers and three phase generators. three phase fault applied in two different places, one in the protected zone and another in unprotected zone.

Figs 12 and 13 show the results of applying differential relay block on protection of a three phase transformer in the simulated power system. Transformer's type is YD and its vector group is 11. As it can be seen, under normal conditions or faults in the outside of protected zone, relay does not send trip signal. But for the faults in the protected zone, it sends trip signals to the switches for separating faulted zone from other parts. Also, results show that differential relay can recognize inrush and over excitation currents due to their high amount of 2nd harmonic and 5th harmonic, respectively. Relay does not send trip signal if 2nd harmonic or 5th harmonic exceeds the adjusted value in the setting menu.

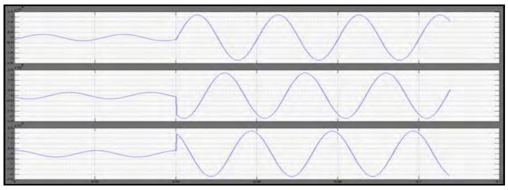

Fig. 12. Currents under fault in unprotected zone

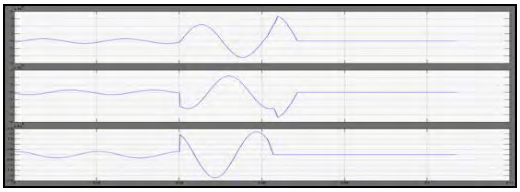

Fig. 13. Currents under fault in protected zone

Conclusion

This paper proposed a model for one typical digital differential relay in the SIMULINK environmental. All parts of the digital differential relay have been described and model of each part has been showed. This model also was used for building differential relay block in the SIMULINK which does not have differential relay block. At last, the model was tested in one faulted power system and results showed the truth of model.

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