Realization of Distance Relay Algorithm using EMTP MODELS

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Abstract – **Digital technology has advanced very significantly over the years both in terms of software tools and hardware available. It is now applied extensively in many area of electrical engineering including protective relaying in power systems. Digital relays have many advantages over the traditional analog relays. The digital relay is able to do what is difficult or impossible in the analog relays. However, the complex algorithms associated with the digital relays are difficult to test and verify in real time on real power systems. Although non real-time simulators like PSCAD/EMTDC are employed to test the algorithms, such simulations have the disadvantage that they cannot test the relay dynamically. Hence, real-time simulators like RTDS are used, but the latter needs large space and it is very expensive.**

This paper uses EMTP MODELS to simulate the power system and the distance relay. The distance relay algorithm is constructed and the distance relay is interfaced with a test power system. The distance relay's performance is then assessed interactively under various fault types, fault distances and fault inception angles. The test results show that we can simulate the distance relay effectively and we can examine the operation of the distance relay very closely including debugging by using EMTP MODELS.

Keywords – Distance Relay, EMTP, EMTP MODELS, Relay Model, Digital Simulation, Protection, Power System

I. INTRODUCTION

Most functions of digital relays are realized by the program code of a microprocessor. The large number of functions and complexity of the digital relays program requires the tools to verify and test the algorithms increasingly.

The developed relay algorithms have been tested with the waveform signals generated by the non real-time simulator like PSCAD/EMTDC, this approach has the disadvantage that they cannot be tested dynamically. Some researchers have used the real-time simulation like RTDS(real time digital simulator) to test the relay algorithm dynamically, but, this method needs additional hardware which is rather expensive [1]-[4]. Methods of model interface are classified as playback or open-loop simulation, and real-time or closed-loop simulation. Open loop simulation means that it is impossible to feed any trip signal from the relay under the simulation process. On the other hand, closed loop simulation is made by running the simulation in real-time and therefore any trip signal is provided by the relay under the simulation process. EMTP MODELS is a PC-based closed loop simulation tool, simulation can be tested dynamically, and also the cost is low.

This paper presents a technique whereby the algorithm of distance relay is verified and tested by EMTP MODELS dynamically.

II. EMTP MODELS

A. EMTP MODELS

The EMTP(electromagnetic transient program) is the simulation tool that is used to simulate the electro-magnetic transients phenomenon, and it is one of the most widely used programs in the electric utility [5]-[8] [11]. But, it can be used only in the static state of power system or in the preset sequential state, that is, it cannot simulate the system in response to the result of the simulation under the simulation. The system diagram of EMTP operation is shown in Fig. 1. The preset sequence data of Fig. 1 changes the state of EMTP power system, and the voltage and the current of power system is simulated according to the changed state of the power system. Its results are recorded in the computer file, and the play-back waveforms are used by the relay model. The EMTP is used as a signal generator. It is called the open-loop(also called play-back) simulation [9].

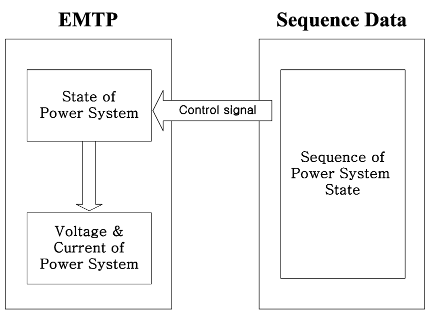

Fig. 1. Operation of EMTP without using MODELS

MODELS is a symbolic language interpreter for the EMTP that has recently gained popularity for the electro-magnetic transients phenomenon modelling. The MODELS provides the monitoring and controllability of power systems as well as some other algebraic and relational operations for programming. MODELS is able to change dynamically the states of power system in response to the simulated results of EMTP power system. The system diagram of EMTP MODELS operation is shown in Fig. 2. The voltage signals and the current signals of EMTP power system enter the input of MODELS. These signals are processed by the program coded with MODELS and the output signals by MODELS change the states of EMTP power system. This process is repeated until the simulation is completed. MODELS makes it possible to simulate the interaction between the power system and the measuring or control system. It is called the closed-loop simulation [9].

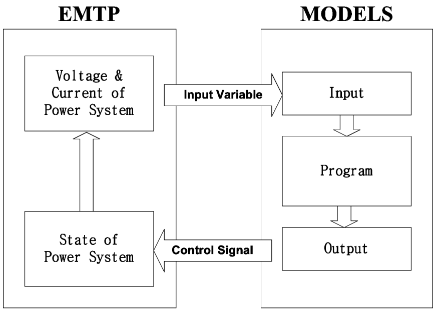

Fig. 2. Operation of EMTP using MODELS

B. Implementation of Distance Relay by MODELS

Fig. 3 shows the system diagram that the distance relay is constructed by the MODELS. The signals of the node voltage values and the node current values are sent to the inputs of the MODELS and the parameter settings are used in the algorithm of MODELS. The fault is detected by the algorithm of MODELS. If the fault is detected and the trip of circuit breaker is decided by the algorithm, then MODELS sends the opening command of the EMTP switch to the EMTP main simulation. The states of the power system, the operating state of the internal algorithm, the state of the inputs and outputs of the relay are recorded in the computer file during the simulation. After the simulation, all the states can be analysed with the recorded file minutely. So, when the newly developed algorithm of the distance relay does not operate correctly, we can diagnose the problem and debug it easily.

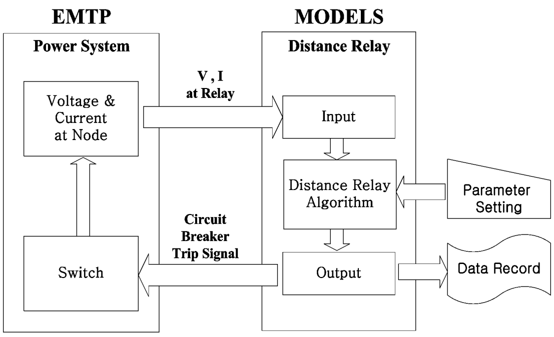

Fig. 3. System diagram of relay structure by MODELS

The example codes of EMTP MODELS are shown in Fig. 4. The a and b in Fig. 4. are the connecting parts between EMTP codes and MODELS codes. In 'a', the node voltage values(*B1U*, *B1V*, *B1W*) in EMTP are sent to the input variables(*v_b1u*, *v_b1v*, *v_b1w*) in MODELS and the currents(*RAU*, *RAV*, *RAW*) of switch in EMTP are sent to the input variables(*i_au*, *i_av*, *i_aw*) in MODELS. In 'b', the trip signals of the circuit breakers are sent to the signal of the switch in the EMTP.

In 'c' and 'd', the algorithms of the distance relay are executed using the input signals of 'a' and 'b'. Several similar relays can be simulated using the USE statement.

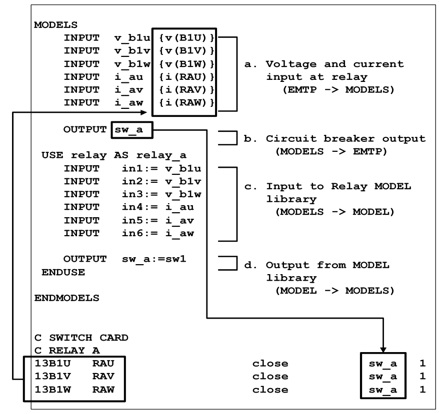

Fig. 4. EMTP code when constructing the relay in MODELS

III. STRUCTURE OF DISTANCE RELAY

The structure of distance relay used in this paper is shown in Fig. 5. The signal processing module generates the signals of the apparent impedances, the rms values of current's symmetrical components, the derivative values of voltage and the derivative values of impedance phasor angle. The generated signals in the signal processing module are analysed in the fault detection module to detect the faults. The parameter values control each module.

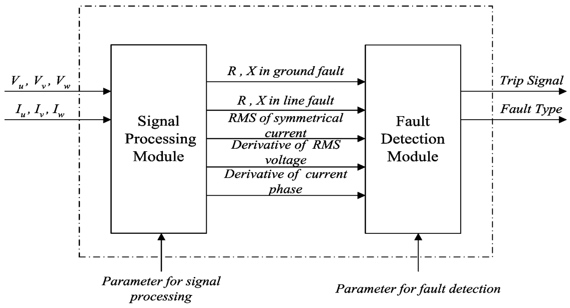

Fig. 5. Structure of distance relay

A. Signal Processing Model

The input signals of the voltage and the current in each phase are transformed into the signals that are needed in the fault detection module. The signals that can be used in the fault detection module to detect the fault, are the instantaneous values of the voltage and the current, the rms values of the voltage and the current, the symmetrical components of the current, the apparent impedance and the derivative of the impedance angle in both the line-to-line and the line-to-ground faults, the frequency of the voltage and the current.

Fig. 6. shows the structure of the signal processing module that is used in this paper. The output signals are the derivative of the voltage, the rms values of the current's symmetrical components, the apparent impedance and the angle derivative of the apparent impedance in both the line-to-ground and the line-to-line faults.

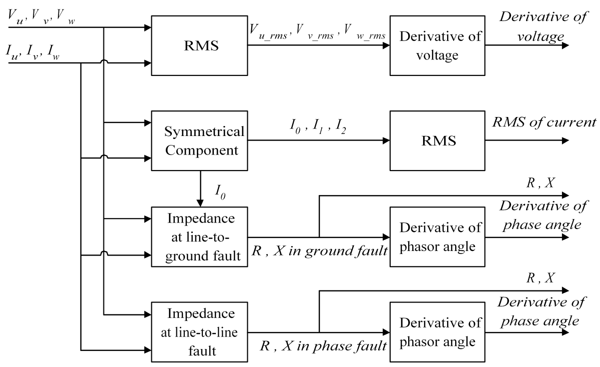

Fig. 6. Block diagram of signal processing module

B. Fault Detection Module

The processed signals in the signal processing module are transferred to the fault detection module. The signals are analysed by the algorithm in the fault detection module. The algorithm decides whether it trips a circuit breaker or not.

One of the methods to detect the type of the fault is using symmetrical components of the current. The symmetrical components of current vary with the types of faults. It can be used to determine which type of fault occurs. But, it does not provide any information to determine which phase is faulted. The methods to determine faulted phase are given as [10]:

1) Method to use over-current in phase.
2) Method to use apparent impedance.
3) Method to use apparent impedance and angle of impedance.

After detecting the fault type and the faulted phase, the apparent impedance is calculated according to the fault type and it is applied to the impedance characteristic to determine whether the fault is within protected area or not, and to set the delay time of the trip.

IV. SIMULATION RESULT

A. Simulation Method

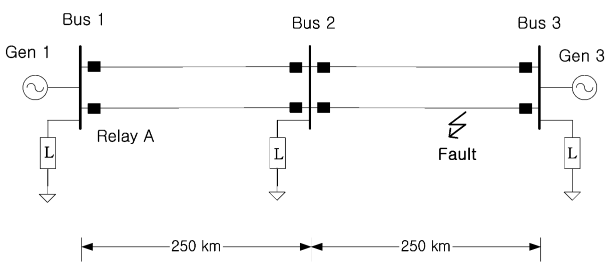

Fig. 7. Model of power system

A set of simulation tests were carried in the test model of a power system as shown in Fig. 7. The model of power system is connected with model of distance relay designed with EMTP MODELS.

B. Simulation of Distance Relay

In the simulation the fault between bus 2 and bus 3 occur 2.5s after the start of the simulation. The results of simulation show that the relay model detects faults correctly and generates trip signal.

1) Three Phase Fault

The apparent impedance of relay A, the logic signals of the timer operation and the circuit breaker trip are shown in Fig. 8, when three phase fault occurs at a fault distance of 110% at the fault inception angle 0° and 90°. Fig. 8 shows that the timer starts on fault inception and the trip signal is generated 0.2 seconds (zone 2 time) after the fault occurs.

The resistance and reactance are generated in the signal processing module, and the timer and CB trip signals are generated in the fault detection module using the signals from the signal processing module. The fault is detected by the impedance algorithm for line-to-line fault. Fig. 8 shows that the timer start signal, that is the inner variable of the relay, can be investigated closely during the fault.

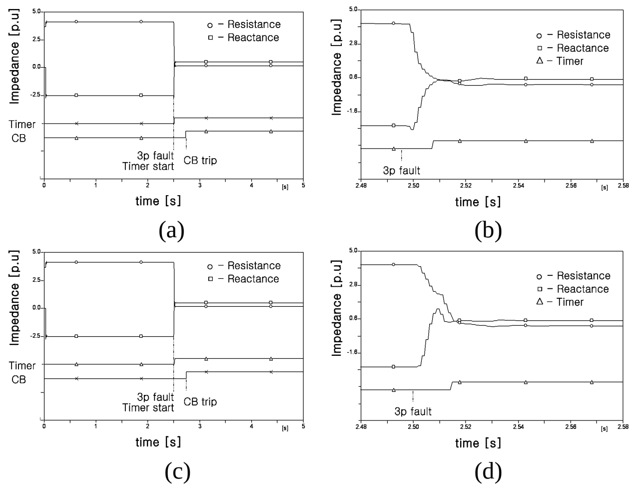

Fig. 8. Result of dynamic simulation of distance relay using EMTP MODELS(3-phase fault, fault distance 110%)
(a) fault inception angle 0° (b) enlarged view of (a)
(c) fault inception angle 90° (d) enlarged view of (c)

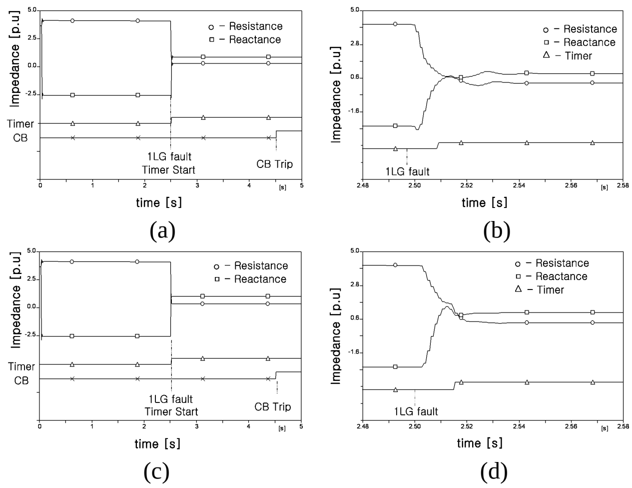

Fig. 9. Result of dynamic simulation of distance relay using EMTP MODELS(single line-to-ground fault, fault distance 130%)
(a) fault inception angle 0° (b) enlarged view of (a)
(c) fault inception angle 90° (d) enlarged view of (c)

2) Single Line-To-Ground Fault

The apparent impedance of relay A, the logic signal of the timer operation and the circuit breaker trip are shown in Fig. 9, when single line-to-ground fault occurs at a fault distance of 130% at fault inception angle 0° and 90°. Fig. 9 shows that the timer starts at the occurrence of the fault and the trip signal is generated 2 seconds after the fault occurs, it is zone 3 time.

As in the case of the previously described 3-phase fault, all signals processed by the signal processing module or the fault detection module are monitored fully. The fault is detected by the impedance algorithm for line-to-ground fault.

3) Double Line-To-Ground Fault

The apparent impedance of relay A, the logic signal of the timer operation, the logic signal of the circuit breaker trip are shown in Fig. 10, when a double line-to-ground fault occurs at a fault distance of 150% at fault inception angle 0° and 90°.

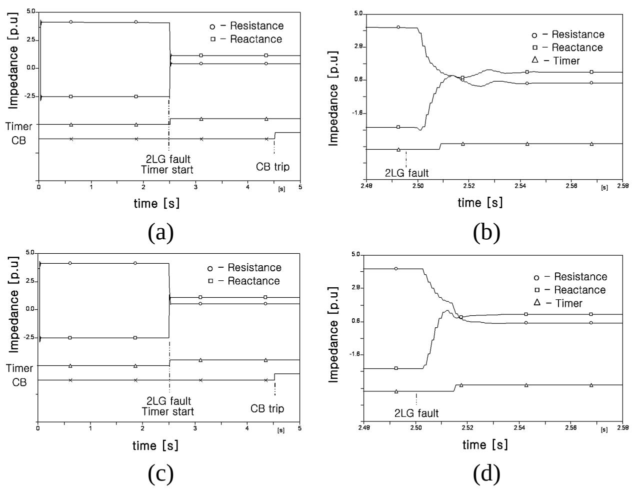

Fig. 10. Result of dynamic simulation of distance relay using EMTP MODELS(double line-to-ground fault, fault distance 150%)
(a) fault inception angle 0° (b) enlarged view of (a)
(c) fault inception angle 90° (d) enlarged view of (c)

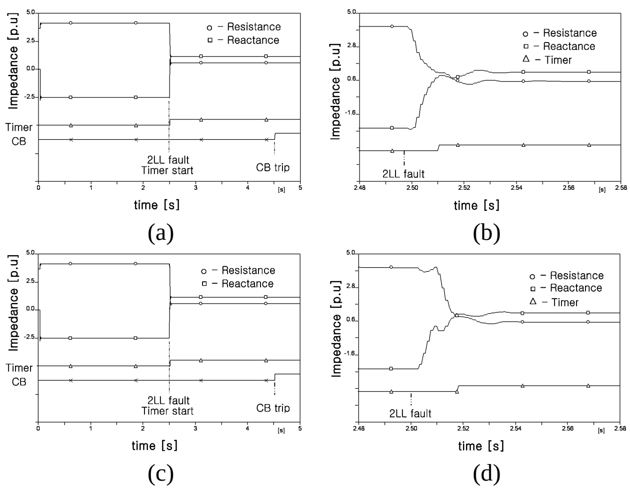

Fig. 11. Result of dynamic simulation of distance relay using EMTP MODELS(double line-to-line fault, fault distance 170%)
(a) fault inception angle 0° (b) enlarged view of (a)
(c) fault inception angle 90° (d) enlarged view of (c)

4) Double Line-To-Fault

The apparent impedance of relay A, the logic signal of timer operation, the logic signal of the circuit breaker trip are shown in Fig. 11, when a double line-to-line fault occurs at a fault distance of 170% at fault inception angle 0° and 90°. Fig. 11 shows that the timer starts on fault occurrence and trip signal is generated 2 seconds after the fault occurs.

V. CONCLUSION

This paper demonstrates that EMTP MODELS can be used to simulate the distance relay, the algorithm of the distance relay can be constructed by EMTP MODELS, and the model of the distance relay operates correctly.

Although EMTP MODELS is unable to simulate it in real- time, it has the advantage that it is able to examine the inner operation of the distance relay and to simulate it more simply using a personnel computer. With this approach of close examination, the detection of any bugs in the protection algorithm is facilitated. In this respect, in the real relay using a microprocessor, it is always more difficult to find the problems with the algorithm. The simulation facility described herein can thus be employed as a very useful tool in the testing of existing relay algorithms and/or in the development of any new ones.

VI. ACKNOWLEDGEMENT

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