TROUBLE SHOOTING OF GENERATOR DIFFERENTIAL RELAY OPERATION USING DIGITAL SIMULATORS

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Abstract– This paper gives an example of the protective relay operation evaluation using digital simulators. A generator differential relay protecting a 1500 MVA generator was found to be tripping under in-rush current conditions caused by energizing an adjacent power transformer. A digital simulator was used to recreate the conditions using Electromagnetic Transient Program (EMTP) simulation. The waveforms generated by the simulator were applied to trouble shoot the relay operation. It was also used to test two more relays to finally select the one that will not be sensitive to the inrush conditions.

Keywords: Generator Differential Protection, Digital Simulator, EMTP, Protective Relay Testing

INTRODUCTION

Recent developments of digital power system simulators for relay testing have resulted in several solutions developed so far. The use of those simulators in evaluating protection relay designs and applications is becoming an established practice [3–4].

One of the main characteristics of digital simulators is to enable detailed modeling of power systems. Several established electromagnetic transient programs are used today for this purpose. The use of these programs in simulating fault conditions also requires detailed modeling of current and voltage transformers [5–6]. Once the models are made available, digital simulations producing quite accurate waveforms corresponding to actual faults and other transient operating conditions can be carried out. Digital simulators enable replaying of these waveforms into relays for detailed evaluation of the relay performance.

This paper gives an example of the use of digital simulators in evaluating operation of various differential relays. The simulator is first used to troubleshoot an undesired relay operation under inrush current conditions. After that, two other relays are evaluated under the same conditions in order to select the one that is not sensitive to the in-rush and can be applied in the future.

The first part of the paper gives a brief description of the problem. Next, a description of the EMTP modeling and simulations of the power system and its operating conditions is given. The use of the digital simulator to evaluate three different relays is discussed next. Conclusions are outlined at the end.

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PROBLEM DESCRIPTION

A simplified one line diagram of the power system section of concern is given in Figure 1. The differential generator protection had a false operation under no-fault conditions, as described below.

While unit #2 was at full power, breaker "A" (which is not equipped with pre-insertion resistors) was closed, energizing unit #1 generator step-up and unit auxiliary transformers. The unit #2 generator differential relay (87) operated two seconds after breaker "A" was closed. Subsequent investigation found that the inrush current to the transformers contained a DC component which had a long

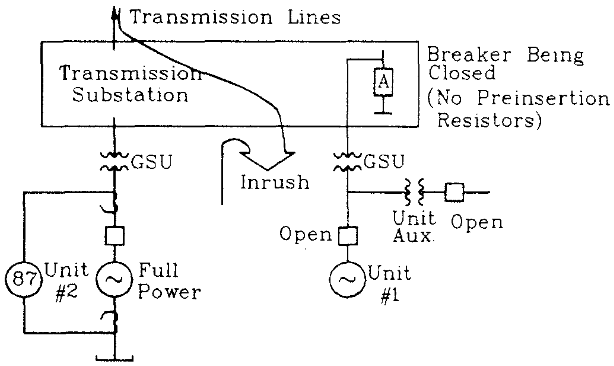


Figure 1. Power System Configuration

time constant. In addition, it was found that the current transformers connected to the unit #2 generator differential relay had different transient response characteristics. With the Digital Fault Recorder (DFR) installed, primary inrush current, secondary currents at both ends, and current through the differential branch of the relay were recorded. Location of the measurement points is shown in the detailed one-line diagram given in Figure 4.

The time domain waveform representing the current flowing through the differential branch of the protection relay is shown in Figure 2. Due to the needed length of the record (> 7 seconds), only the onset of the fault is shown if Figure 2(a), and the distorted transient waveforms after 2 seconds is shown in Figure 2(b).

The frequency content of the waveform as a function of time is given in Figure 3. This simple assessment shows an excessive harmonic content and the second harmonic build up generated by DC offset which has very likely caused the relay undesired operation.

EMTP MODEL DEVELOPMENT

The subsystem selected for EMTP simulation is comprised of a 1500 MVA generator, two 700 MVA power transformers connected in parallel, operating as step-up transformers; 345 kV bus; transmission line; 150 MVA reactor; power circuit breaker with pre-insertion resistors; one 650 MVA and one 700 MVA power transformer connected in parallel (their energizing phenomena needs to be investigated). A detailed one-line diagram of the system is given in Figure 4.

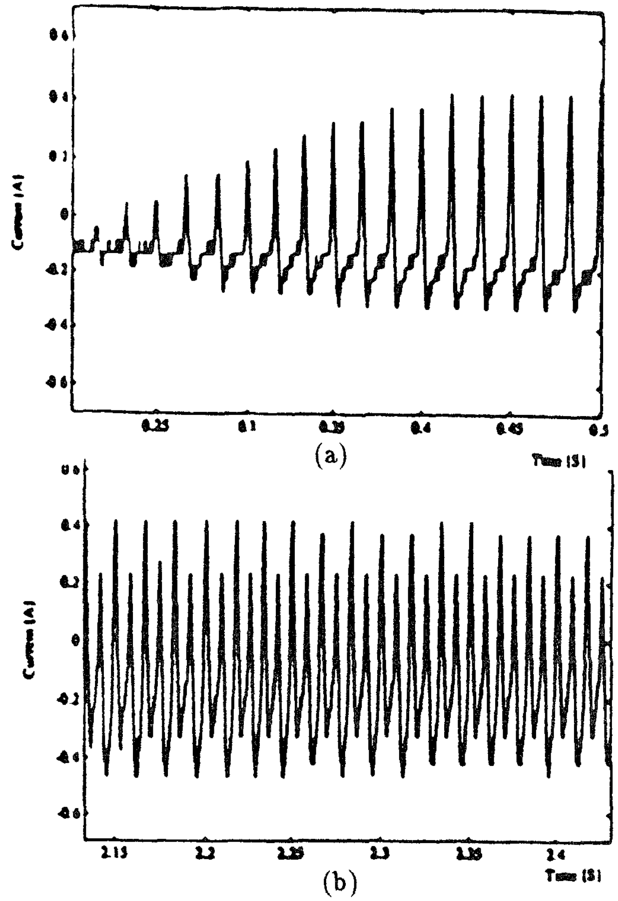


Figure 2. Time Domain Signal Representation, (a) Initial Inrush Signal, (b) Inrush Signal after 2 Seconds

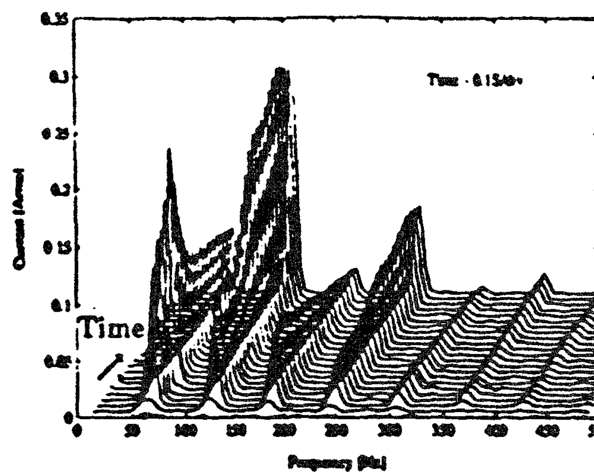


Figure 3. Frequency Domain Signal Representation

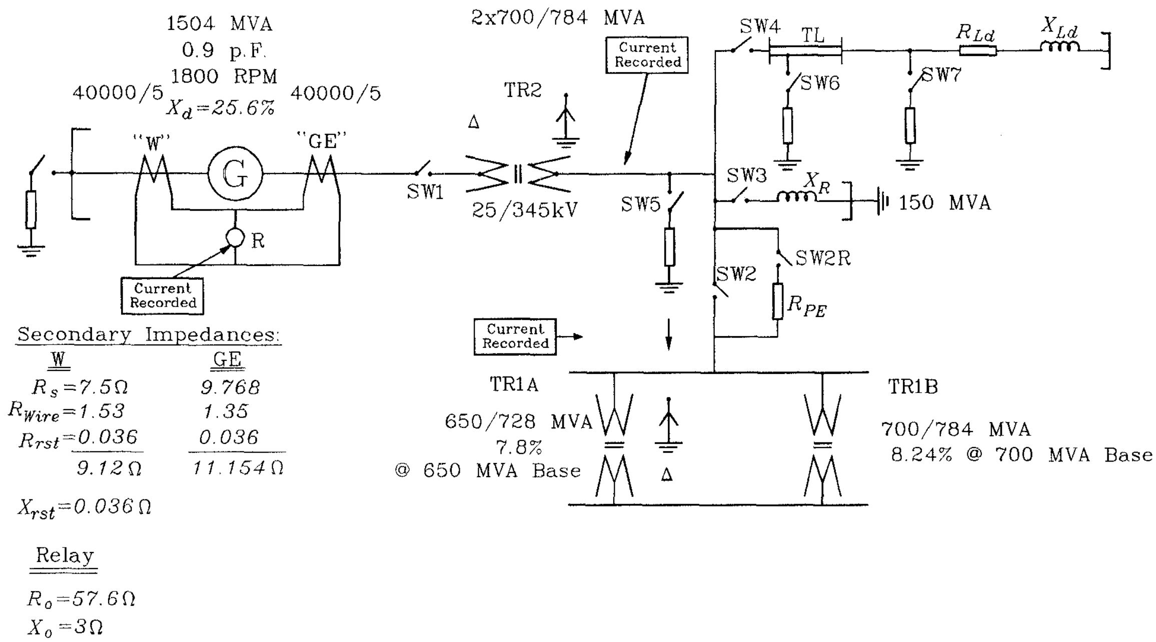


Figure 4. Single–Line Diagram of the Power System Model

The generator is represented by its impedance and the CTs are located at both ends of the impedance. An AC source, required for the system supply, is located at the point where one side can easily be grounded. A resistor of 0.154Ω, which exists in the actual grounded generator neutral, is not represented. This assumption does not have significant influence for the reference study. The simulations obtained by using this model have shown that further detailing is not needed.

Power transformers TR2, TR1A and TR1B are of the same design. Transformers are modeled as single–phase units since data needed for three phase modeling were not readily available in the manufacturer's documentation due to difficulties in performing the required measurements to obtain this data.

Rector 150 MVA is represented as a linear reactor.

Transmission Line 345 kV is modeled using frequency dependent parameters.

Circuit breaker located on the 345 kV bus bar has been simulated with and without pre–insertion resistor.

Current transformers (CTs) models are based on standard EMTP modeling techniques.

The CTs are located at both ends of the generator. The differential relay is connected on their secondary side as shown in Figure 4.

V–I curves of the CTs are not the same, as evident from Figure 5.

EVALUATION OF RELAY APPLICATIONS

A number of different EMTP simulations were performed generating current waveforms reflecting various fault and switching conditions.

Three different relays were applied and their performance was evaluated. Relay "A" is currently installed in the system. An operating current of 200 mA is required to operate this relay in the current range 0 up to the rated current. This is the range of the inrush current magnitudes.

Relays "B" and "C" are low impedance relays. The operating branch resistance is below 0.1Ω. Due to the smaller resistance of the operating branch, differential current magnitude and waveshape are quite different from the ones for relay "A". These relays are designed with the harmonic restraint.

Relay "A" Application

This relay was tested using a DFR record of an actual event that caused an undesired operation of the generator differential relay. The test results are shown in Figure 6. The results show the waveforms and the trip signal generated as a result of applying this waveform to the relay. These results have confirmed the relay behavior as recorded in the field.

The same test was repeated with a waveform generated using EMTP simulation. The system conditions and power system model were resembling the actual situation as close as possible. The test results are shown in Figure 7. It can be observed that the relay behavior was again the same, as expected.

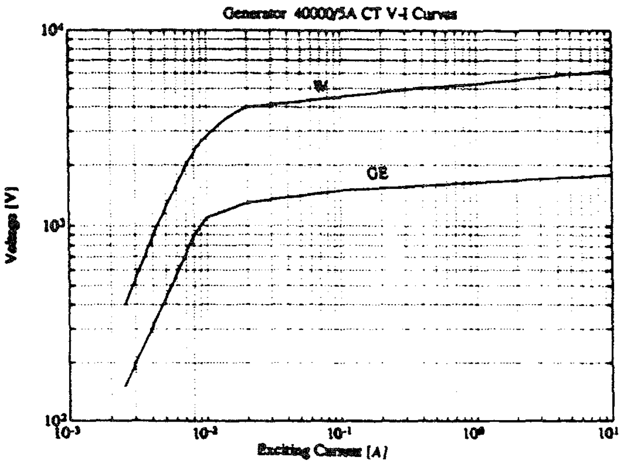


Figure 5. V–I Curves of the CTs

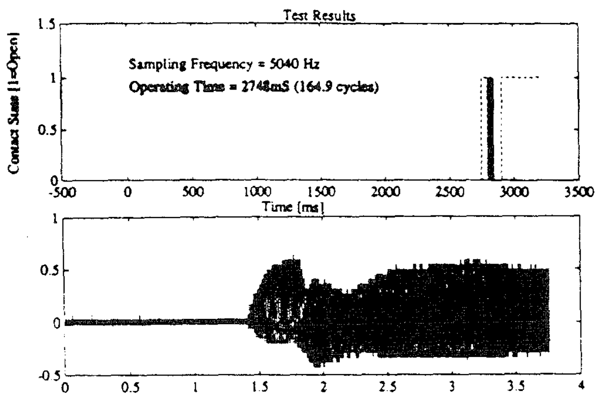


Figure 6. Test of Relay "A" using DFR Record

A variety of other application conditions were created using EMTP simulations and relay "A" operated correctly for all other cases except for the inrush situation described.

Application of Relays "B" and "D"

These relays were tested only using waveforms obtained through EMTP simulation since the corresponding DFR records with these relays installed were not available. Both relays were tested for a number of application conditions and they behaved similarly.

Test results for the system conditions equivalent to the ones considered for tests on Relay "A" are shown in Figure 8. It can be observed that neither the Relay "B" nor Relay "C" did operate under these conditions.

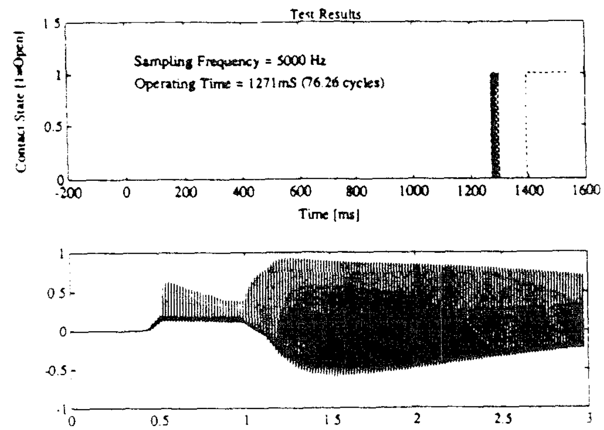


Figure 7. Test of Relay "A" using Data File Obtained from EMTP Simulation

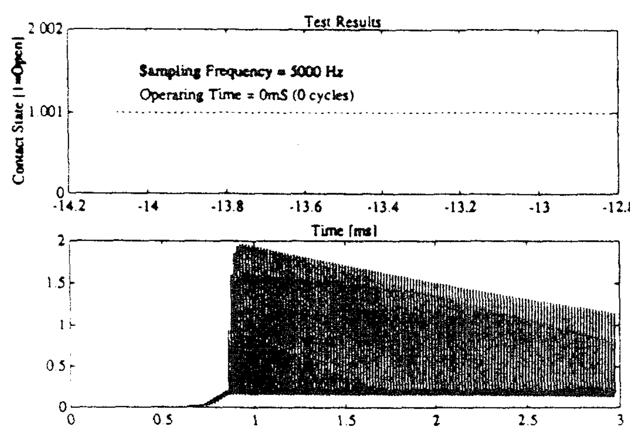


Figure 8. Test of Relays "B" and "C" using Data File Obtained from EMTP Simulation

ANALYSIS OF TEST RESULTS

Application of the digital simulator enables a step-by-step analysis of the nonlinear phenomenon associated with the in-rush. Such an analysis is possible since the waveforms at various locations in the system can be generated, recorded, and analyzed.

In order to better understand what are the system components that contribute to the waveforms seen by the relays, the following waveforms were generated by EMTP and observed:

- generator primary current
- in-rush current
- Westinghouse CT secondary current
- G.E. CT secondary current
- current in the relay operating branch

The waveforms of the generator primary current, in-rush current and CT secondary currents for Westinghouse and G.E. CTs are given in Figures 9–12, respectively.

The analysis of the waveforms given in Figure 9 and 10 explains how the harmonics were generated. These harmonics are also contained in the outputs of the CTs as shown in Figures 11 and 12. The resulting generator differential relay differential current is shown in Figure 13(a) in the time domain and in Figure 13(b) in the frequency domain.

CONCLUSIONS

The results presented in this paper lead to the following conclusions:

- Digital simulators are very useful in trouble-shooting relay operations.

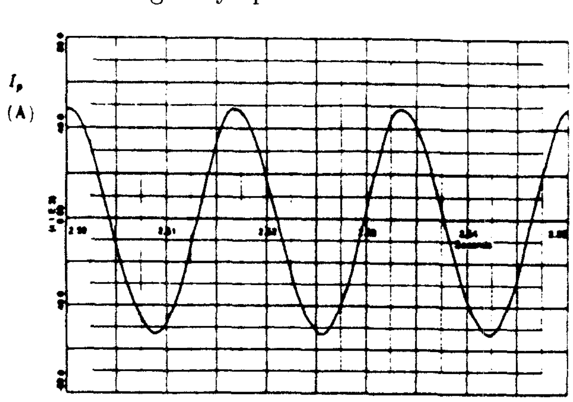


Figure 9. EMTP Simulation of the Generator Primary Current.

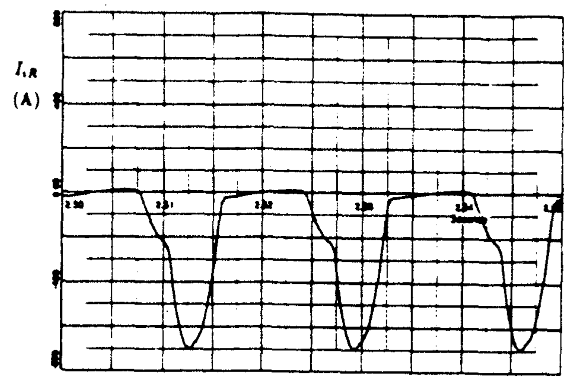


Figure 10. EMTP Simulation of the In-Rush Current.

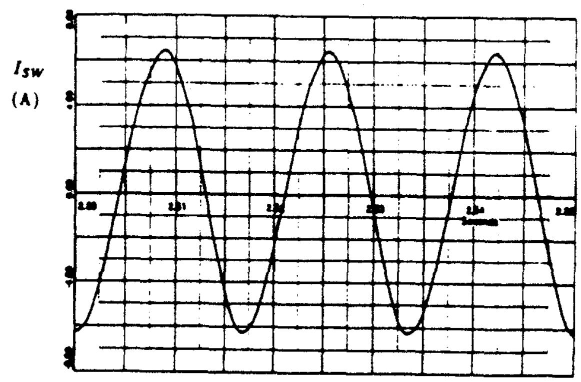


Figure 11. EMTP Simulation of the Westinghouse CT Secondary Current.

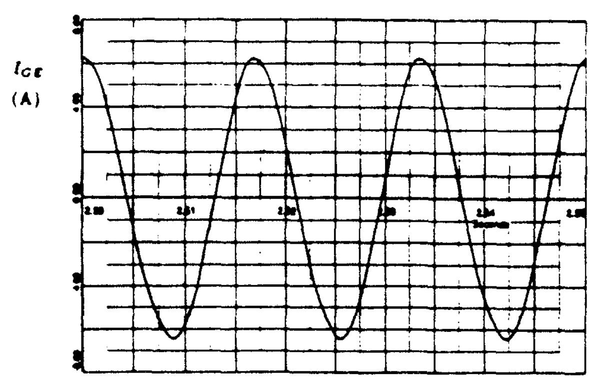
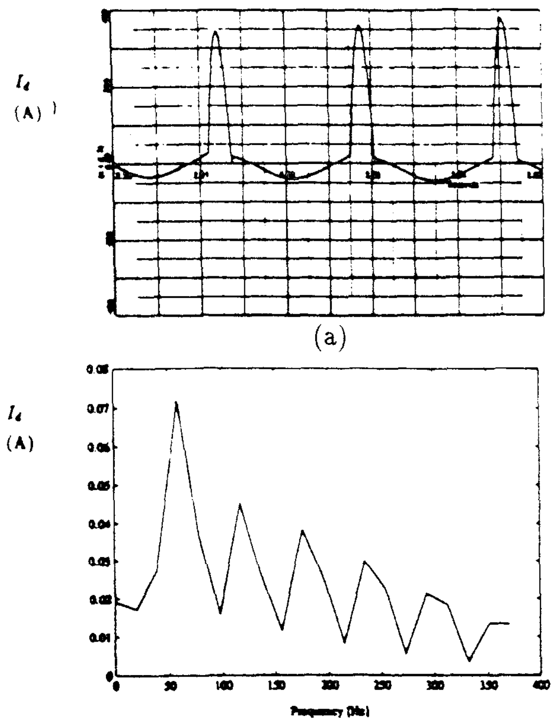


Figure 12. EMTP Simulation of the G.E. CT Secondary Current.



(a)

(b)

Figure 13. EMTP Simulation of the Generator Relay Differential Current: a) Time Domain Representation; b) Frequency Domain Representation

- Digital simulations may be the only approach generating the test waveforms if the recordings are not available.
- For the examples given, digital simulators have enabled analysis of the reasons for the undesired relay operation as well as selection of the suitable solution.

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