COMPUTER BASED HARMONIC SIMULATION AND TESTING FOR DIRECTIONAL DISTANCE RELAY

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ABSTRACT

This paper addresses the effect of harmonics on the operation of Directional Distance Relay(OHM unit only). The testing facility consists of a computer-based three phase harmonic source, programmable three phase voltage and current amplifiers, and a digital to analog interface board. The software generates the harmonics and detects any trip action by the relay. Extensive experiments were performed in which the relays were subjected to a matrix of distortion frequencies, magnitudes, and phases. The results of these experiments are discussed, and suggestions on the applications of the relay are given.

INTRODUCTION

In recent years there have been considerable developments in industrial processes that rely on power electronic for their operation, and therefore generate current and voltage harmonics[1]. A recent survey of Kansas utilities revealed that customers intend to install vast numbers of power electronic devices in the near future. These devices produce distortion in voltage and current waveforms during normal operation and during fault conditions. And since these relays are one of the most important normal and emergency controls, they must retain their normal basic operation such as fault detection, fault location and fault interruption under distorted environments to provide complete protection and reliability needed by the distribution system. And since most of the U.S relay manufacturers calibrate their relays and publish performance data based on pure sine-wave currents and voltages.

Therefore the response of the protective relays to distorted waveforms is poorly documented. So for these reasons a relay testing system and a software package were developed at The Wichita State University (WSU) to test relays for their response to distortion.

Since harmonics in current and voltage waveforms, can distort or degrade the operating characteristic of protective relays, depending on the design features and principles of operation. And since distance relays are built to variety of designs. It is not practical to generalize on their response to distorted currents and voltages. However, by applying basic principles to a specific relay, one should be able to predict the general effect of waveform distortion on that relay. A canadian study documents the effects of harmonics on mechanical relays as overcurrent, overvoltage, balanced beam impedance relays and some others. Our paper addresses the operation of a distance relay, when distortion is introduced to the system.

RELAY

The relay is a high speed directional distance relay intended for the protection of transmission lines. It consist of two units, the OHM unit and the STARTING unit. The OHM measures the reactance, and the STARTING unit determines whether the fault is in the tripping direction. Since it operates on reactance and therefore unaffected by arc resistance. This type of relays are used primarily to give protection against single phase to ground faults and three phase faults. They will also provide protection against phase to phase faults and double phase to ground faults.

RESULTS - OHM unit

The results of testing are shown in Figures 1 through 10. Figures 1, 2,3 and 4 show the effect of current distortion only; voltage is pure 60 Hz. Figure 1 and 2 shows the change in trip impedance when current has 100% total harmonic distortion (THD) at various frequencies. The results of varying the THD level at selected frequencies are presented in Figures 3 and 4. Each curve in Figures 3 and 4 represents distortion at a different frequency. The effect of distorted voltage, with pure 60 Hz current, is shown in figures 5,6 and 7. Figures 5 and 6 shows the change in trip impedance when voltage has 100% total harmonic distortion (THD) at various frequencies. The results of varying the THD level at selected frequencies are presented in Figure 7. Each curve in Figure 7 represents distortion at a different frequency. When both voltage and current distorted, the relay operates as shown in Figures 8,9, and 10. Figures 8 shows the change in trip impedance when voltage and current have 100% total harmonic distortion, for low frequencies, the phase has a great effect on the tripping impedance. The results of varying the THD level at selected frequencies are presented in Figure 9. Figure 10 shows the results of varying the phase between the fundamental and the harmonic waveform.

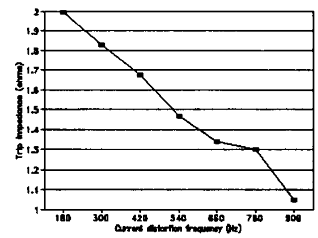

Figure 1. Trip impedance with 100% current THD.

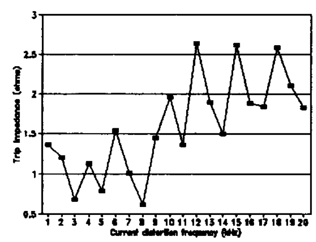

Figure 2. Trip impedance with 100% current THD.

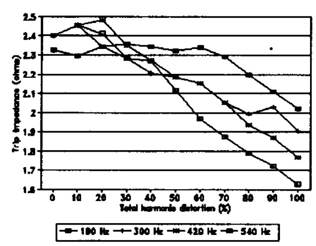

Figure 3. Trip impedance with varying current THD.

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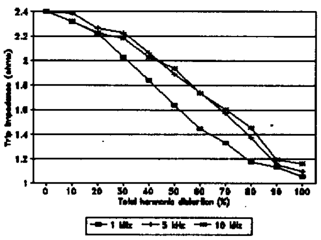

Figure 4. Trip impedance with varying current THD.

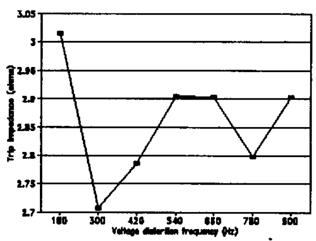

Figure 5. Trip impedance with 100% voltage TH D.

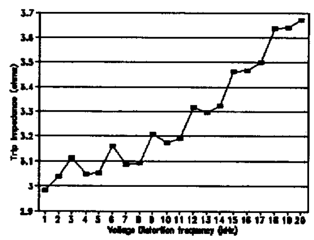

Figure 6. Trip impedance with 100% voltage TH D.

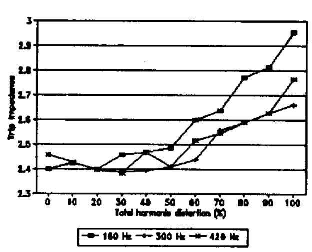

Figure 7. Trip impedance with varying voltage THD.

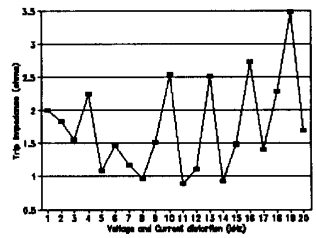

Figure 8. Trip impedance with 100% current and voltage THD

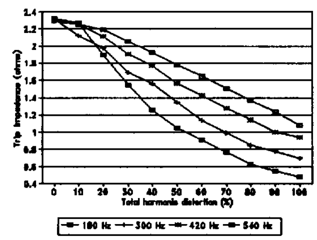

Figure 9. Trip impedance with varying current and voltage THD.

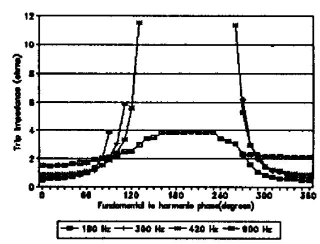

Figure 10. Trip impedance with 100% current and voltage THD.

Current Distortion

Total Harmonic Distortion Effects

The trip impedance decrease significantly when the THD in the current is more than 30%. When THD is at 100%, and distortion is at frequencies 8 kHz or greater, the trip impedance will increase in random way reaching maximum of 2.7 ohms. For this relay tripping unit, harmonic current distortion for frequencies lower than 8 kHz, with pure 60 Hz voltage, always causes the required trip impedance to decrease from manufacture's specifications.

Frequency Effects

Distortion at frequencies below 8 kHz can effect the trip impedance of this relay. Current distortion at frequencies greater than 1 kHz, trips the relay at a random impedance values.

Phase Effects

When current is distorted, the phase angle between the fundamental current and harmonic current does not affect the trip impedance.

Voltage Distortion

Total Harmonic Distortion Effects

Significant changes from manufacturer's specifications in trip impedance occur when distortion in the voltage waveform is 50% or more.

Frequency Effects

Voltage distortion at any frequency increases the trip impedance.

Phase Effects

When only voltage is distorted, the phase angle between the fundamental voltage and the harmonic voltage does not affect the trip impedance.

Voltage and Current Distortion

Total Harmonic Distortion Effects

The trip impedance decrease significantly when THD in the current and voltage is more than 20%.

Frequency Effects

Current and voltage distortion at any frequency can produce changes in the trip impedance.

Phase Effects

The phase between the fundamental and harmonic waveform affects the tripping impedance, for frequencies around 2 kHz or lower the phase has a great affect,in particular phases between 180° and 260°, but this affect gets smaller for higher frequencies.

CONCLUSION

The operation of this relay is affected by the presence of the harmonic distortion. Test results show that the relay will report a wrong fault location. The relay is frequency sensitive up to 20 kHz, the highest testing frequency, and it is a phase sensitive when voltage and current are distorted. When distortion is present at multiple frequencies, the THD value for all frequencies combined, and the single frequency at which the largest change in fault location occurs, should be used in evaluating the application.

The results presented in this paper apply only to the one relay tested. A number of other relays have been tested at WSU, and it has been found that each responds differently. Detailed results are available for each relay tested, and testing continues on other relays.

REFERENCES

[1] Ward T. Jewell, Rafat Abu Rob," Computer Based Harmonic Simulation and Testing for Transformer Differential Relays," submitted to 35th Midwest Symposium on Circuits and Systems 1992.

ACKNOWLEDGMENTS

The authors wish to express their thanks to Mr. Pete Loux and Ms. Lois Tully-Gerber of the Kansas Electric Utilities Research Program, and Mr. Mike Sauber of WestPlains Energy for their help in this research.