INFLUENCE OF VOLTAGE HARMONICS ON OVER/UNDER VOLTAGE RELAY

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Abstract—The effects of nonsinusoidal voltages on the performance of an over/under voltage relay were experimentally studied. The frequency, and amplitude of individual harmonics were adjusted with a programmable power source and the operating times of the relay are examined. The relation between the harmonic voltages and relay behavior is determined. The measurements show that the relay may operate slower or faster than expected when distorted voltages have third harmonic component.

Keywords: Feeder protections, over/under voltage relay harmonic distortion.

1. INTRODUCTION

Protective relays have a critical role in the electrical power systems. When an abnormal condition (faults, overload, loss of system synchronism and etc) occurs, protective relays take an action.

Microprocessor based relays have some advances in protection when compared to old-electro-mechanical relays, such as: lower installation and maintenance costs, better reliability, improved protection and control, and faster restoration of outages.

Microprocessor-based relays provide technical advances and cost savings in several ways [1]:

- To reduce and simplify wirings the relay uses.
- The relay protects breaker for faults,
- The relay can measure voltage and/or current, so reduce the need of measurements.

In the last two decades, there has been an increase of non-linear devices in electrical systems. These devices distort current and voltage waveforms. Due to increase of these distortions, the reliability of protection devices may be sacrificed. This situation has led to a great interest in determining network voltages at harmonic frequencies.

Protective relays are designed to operate at rated fundamental frequency (50-60 Hz) and pure sine wave. Most microprocessor relays use different types of digital filter to find the fundamental component of the voltage/current signals. Due to protected relays connected to power systems all times, they experience voltage and current distortions. This paper deals with harmonic voltages.

In the literature effects of harmonic currents on over current protection relay is widely studied. In [2] a method to quantify the effect of disturbances on a protection relay was investigated. Both solid state and digital over current relays were tested under various measured disturbances.

An article by Wan & Bollen stated the possible effects of inter harmonic, 182 Hz on protection relays.

Ref [4] answers the question "Should relay react to, or filter out harmonic distortions". The tripping times of electromechanical and microprocessor based relays are discussed when the relays are subjected to various levels of harmonic currents.

This paper summarizes the results of a comprehensive study of the behavior of protection equipment, over/under voltage relay, under nonsinusoidal voltages. To fully appreciate the harmonic problem, first pure sine waveform is examined and then compared with harmonic rich waveforms. The goal of this paper is to maximize the availability of protection by showing the risk of relay misoperation under distorted voltages.

To obtain how microprocessor based over/under voltage relay respond to distorted voltages, the harmonic components are added to fundamental by an AC programmable power source respectively. The relay tripping times are recorded for different time characteristic operations of the protection relay. The test results draw a conclusion as to the level of voltage distortion.

2. OVER/UNDER VOLTAGE RELAY

The over/under relay is a secondary relay which is connected to the system via voltage transformers. The relay operation is based on phase-phase voltage of the system. When the measured voltage exceeds or goes below the set values of the relay, it trips the circuit breaker and/or provides a signal for annunciator equipment. The operation of the combined over/under relay is shown in Fig. 1.

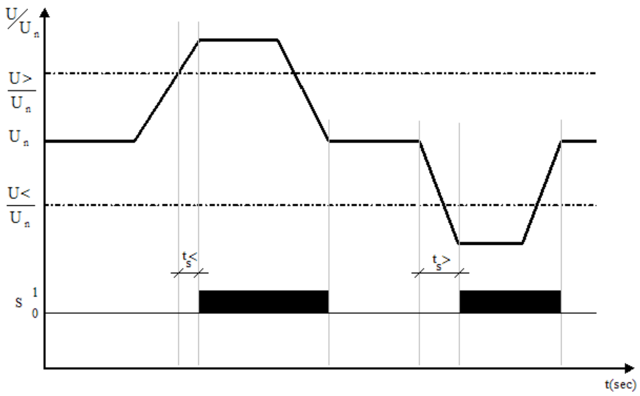


Fig. 1. Operation scheme of the over/under relay

Protective devices should operate as fast as possible to limit the effects of faults to upstream customers and customers on adjacent feeders fed from the same bus. Over/under relays may have both definite time characteristic and inverse time characteristics depending on manufacturer. Instantaneous or fast definite time operations will have fewer effects than inverse operating time characteristic. When definite time characteristic is used, the relay operation time is constant. At inverse time characteristic, the operation time depend on the deviation from the setting value. A relay engineer must determine the settings according to the system immunity to voltage deviations.

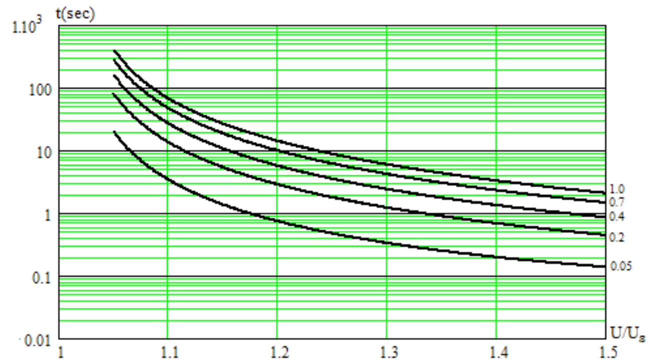
The relationship between time and over/under voltage can be expressed in Eq. (1) and (2), respectively [5]:

$$t = \frac{k \cdot a}{\left[b.\left(U/U_s - 1\right) - 0.5\right]^p} + c \quad (1)$$

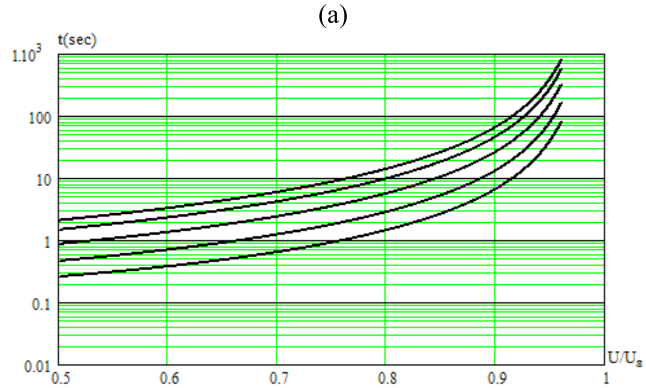
$$t = \frac{k \cdot a}{\left[b.\left(1 - U/U_s\right) - 0.5\right]^p} + c \quad (2)$$

where,

t	:operating time (sec)
k	:time multiplier
U/U_s	: multiplies of relay tap setting
a, b, c	: manufacturer defined constants
p	: inversity constant



(a)



(b)

Fig. 2. Inverse time characteristics of the relay at
a) over voltage b)under voltage stage

The inverse time curves at over/under voltage stages are shown in Fig. 2. The relay operates when the measured voltage is exceeds or falls below set value.

3. RELAY TESTS

The microprocessor based over/under voltage relay was tested with modern relay voltage injection test instruments as shown in Fig. 3. Various levels of harmonic voltages created by a Programmable AC Power Source were applied to the relay. To define the effects of voltage harmonic orders on different time characteristics of the relay, the tripping times were recorded as the relay was subjected to the distorted voltages for both over/under voltage stages. The relay parameters were set to 1.05 pu for over voltage and 0.6 pu for under voltage limits. Voltage distortion levels are selected as 5% and 10% of the fundamental voltage while keeping the RMS value of the voltage constant.

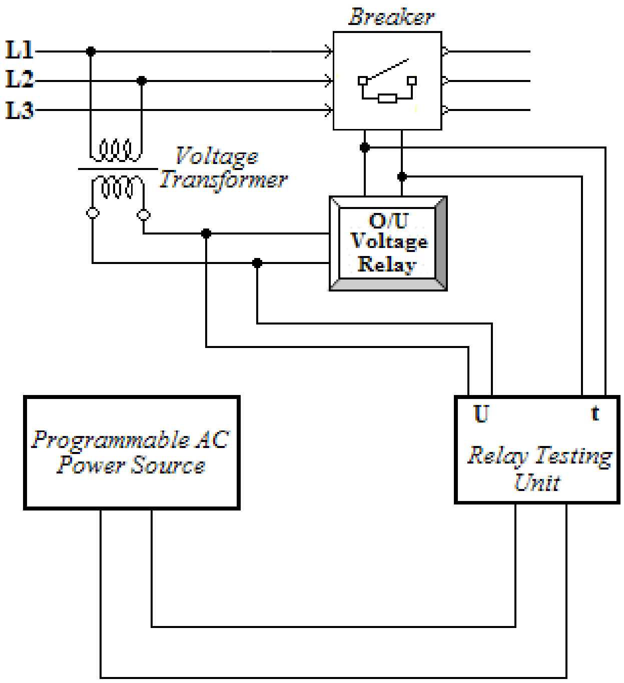


Fig. 3. Circuit diagram of the relay test system

A-Definite Time Characteristic

The test results of definite time characteristics are shown in Fig 4. The trip time of the relay is set to 5 sec. The voltages that are applied by the Relay Testing Unit are 1.06 pu & 0.63 pu.

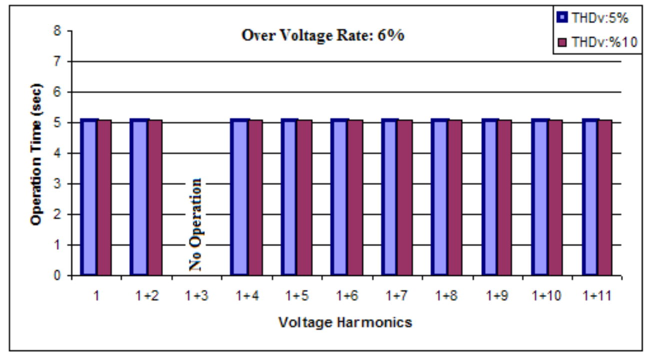
The tests show that either over voltage or under voltage stages when the third harmonic voltage is added, the relay operation fails. It leads to failure to trip at over voltage and mal function trip at under voltage.

B-Inverse Time Characteristic

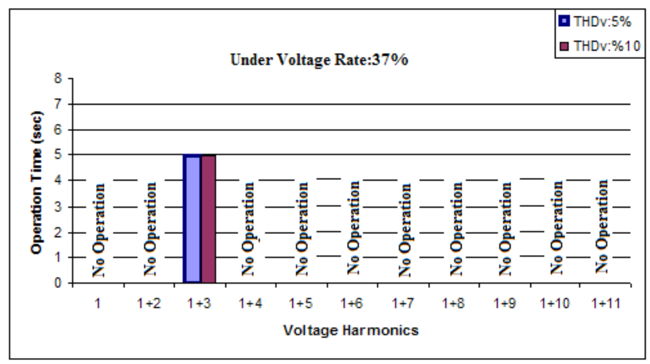
To define the influence of voltage harmonic distortions on over/under relay inverse time characteristic, 130% and 50% of nominal voltages were applied to the relay by Relay Testing Unit. The time multiplier (k) is taken 0.4 for both over and under voltage.

If the applied voltage is pure sine wave, the tripping time of the relay can be easily found from the characteristic curves, given in Fig. 2, which is 3 sec for either over voltage or under voltage.

Fig. 5 shows the recorded tripping times of the inverse tripping time characterized over/under voltage relay. In normal operation, except third harmonic component, the measurement output of the relay provides the expected operation. When a third harmonic component occurs, the measurement circuit of the relay fails to operate. As seen in definite time characteristic tests, the relay operates fail to trip at over voltage and mal-trip at under voltage.

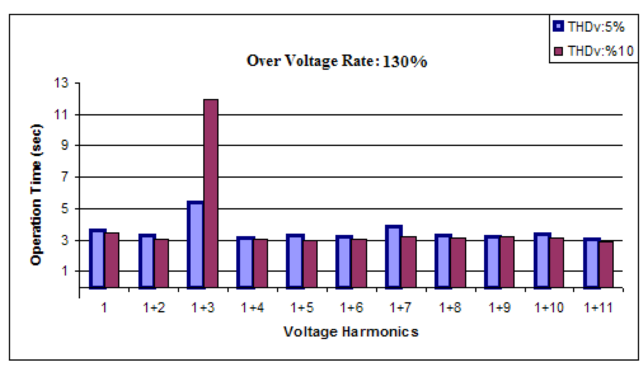


(a)

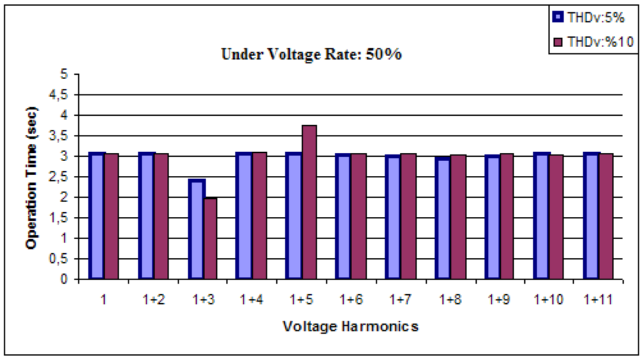


(b)

Fig. 4. Relay behavior at definite trip time (5sec) characteristic (a) over voltage (b) under voltage case



(a)



(b)

Fig. 5. Relay behavior at inverse trip time characteristic (a) over voltage (b) under voltage case

CONCLUSIONS

From the test results presented, the following conclusions can be drawn

- The microprocessor based over/under relays designed to operate with pure, undistorted fundamental waveforms are affected form voltage disturbances.
- Third harmonic voltages lead the relay to mal-trip or fail to trip.
- The magnitudes of third harmonic affect operating time of the relay.
- Both definite time and inverse time characteristics are invalid when the measured voltages of the protected equipment have third harmonic components.

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