Effects of Nonsinusoidal Voltage on the Operation Performance of a Three-phase Induction Motor

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Abstract–This paper uses a real load test to investigate the effects of each order of harmonic from 2 to 13 under various Voltage Distortion Factors (VDF) on the performance of a three-phase induction motor. The investigation includes input current, power factor, efficiency, temperature rise, and their impacts on the consumers and utility companies. Since the life span of the motors is dramatically affected by the temperature rise, a new derating factor is proposed in this paper. Besides, the impacts of harmonics on electricity energy, consumers and the life span of a motor, are also discussed, respectively. Finally, it is strongly suggested that even order harmonics and harmonics having an order below 5 should be considered in related regulations of harmonics control and limits.

Keywords: Induction motor, Harmonic order, Operating characteristics, Temperature rise, Voltage distortion factor, Derating factor.

1. Introduction

Harmonic pollution problems on the power system have long been bothering power companies, manufacturers and customers. The originations of harmonics can be classified as follows: (1) power electronics devices, with the recent advances in power semiconductor technology, more and more power electronics devices, such as phase controllers, inverters, cycloconverters, are widely used for motor electrochemical loads in the industry; (2) the application of saturable reactors for isolating DC components when the load to be controlled doesn't require DC; (3) the operation of arc furnaces and electric arc welders, etc., these non-continuous loads result in significant current distortion and the appearance of even harmonics in the transmission and distribution systems; (4) shunt capacitor banks for power factor correction and voltage regulation in a distribution system; (5) using series inductors to reduce the short circuit current of a transmission line. Inductors and capacitors do not produce harmonics, however, they may result in the potential for resonant problems which can magnify existing harmonic levels.

In a power system, induction motors are the largest component of the load and they are widely used in industrial, commercial and residential applications. Once the power system suffers the pollution of harmonics, the operation characteristics of induction motors will be affected first. Therefore, to study the impacts of induction motors under harmonics voltage has drawn the attention of many researchers. The study of this issue has been found since the 1960s. Klingshirn proposed a three-phase induction motor performance under a nonsinusoidal voltage source[1]. In 1972 and in 1979, Linders investigated the effects of poor quality power sources on ac motors and proposed the hidden costs and containment due to the electric wave distortions[2, 3]. In 1986, Cumming simplified the harmonic equivalent circuit and proposed a method to estimate motor loss and temperature rise[4]. In 1987, Fuchs investigated the sensitivity of appliances to harmonics[5]. In 1990, Sen, according to the material of an induction motor, proposed derating operation under waveform distortion[6]. In 1985 and in 1993, Ortmeyer, et al, and Wagner, et al, respectively presented a summary of the state-of-knowledge about the effects on power system equipment and load under harmonics[7-8]. However, several important issues were not considered and discussed in the previous researches:

(1) Provide a quantitized comparison of the effects of each order harmonic from order 2 to 13 on the operation performance of three-phase induction motors, particularly including even order harmonics, zero-sequence harmonics and harmonics with an order below 5.
(2) Investigate the adequacy and adoptability of relative regulations relative to the voltage harmonic limits.
(3) Use the temperature rise curve obtained by a real full load test to define/revise the new derating factor of an induction motor.

This paper provides an extensive discussion of the three afo-mentioned issues.

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2. Related definitions and classification of harmonics

It is well-known that power system nonsinusoidal voltage and current waves can be formed by a number of sources in the power network. Theoretically, any