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A %THD analysis of industrial power distribution systems with active power filter-case studies

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ABSTRACT

Increasing use of variable speed drives in industry causes harmonic proliferation in industrial power distribution supply system. Harmonic currents generated by the variable speed drives interact with power system impedance to give rise to harmonic voltage distortion. Thus it is essential to analyze, evaluate and introduce appropriate mitigation techniques for harmonic reduction in the power system networks. In this paper, %THD harmonic load flow analysis for different industrial power system networks in the presence of harmonic loads has been carried out using DIgSILENT software. From the %THD harmonic profile of different feeders and buses of the power distribution system, it is observed that there is more %THD present at certain feeders and buses where nonlinear loads are connected. In order to reduce the %THD within the allowable limits as per IEEE standards, both passive and active filters are designed and installed in the power system networks. Simulation results are presented to validate the proposed scheme. From the results, it is observed that the reduction of %THD is more in power system networks at various buses and feeders with active power filter compared to passive filter.

1. Introduction

Now a days electric power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage. Due to increasing use of nonlinear loads, such as rectifiers, variable speed drives, and Electric arc furnaces, harmonics pollution is taking place in power distribution system [1]. The Harmonics cause reactive power burden, excessive neutral current, Low power factor, low energy efficiency, interference by EMI and distortion of the line voltage, etc. [2]. These nonlinear loads are prime sources of harmonic distortion in a power distribution system. Harmonics in a power system caused by highly nonlinear devices degrade its performance. IEEE 519: 1992 recommends practice and requirements for harmonic control in electric power system [3]. Harmonic currents produced by nonlinear loads are injected back into power distribution systems through the Point of Common Coupling (PCC). As the harmonic currents pass through the line impedance of the system, harmonic voltages appear, causing distortion [4].

Harmonic distortion in power distribution systems can be suppressed using harmonic filters [5]. There are two types of harmonic filters passive and active Power filters. The passive filtering is the simplest conventional solution to mitigate the harmonic distortion. Although simple and least expensive, the passive filter have drawback of bulky size, component aging, resonance and fixed compensation performance. These provide either over- or under-compensation of harmonics, whenever a load change occurs. In order to overcome these problems, active power filters (APFs) have been developed [6]. Active power filter has been recognized as a viable solution [7]. There is a need to design an active power filter, which is capable to maintain the THD well within the IEEE norms, under variable load conditions [8]. In APF design and control, calculation of compensation current and reference signal generation is main task. Filtering characteristics strongly depend on the accuracy of reference signal and its speed of computation [9].

Before adopting harmonic solution, it is necessary to do detailed harmonic study of the power system network. Harmonic analysis has been widely used for system planning, operation criteria development, equipment design, troubleshooting, and verification of standard compliance. Over the past two decades, significant efforts and progress has been made in the area of power system harmonic analysis. Harmonic study is becoming an important aspect of power system analysis and design [10].

In this paper, %THD harmonic load flow analysis has been carried out for two industrial power distribution systems, from the %THD harmonic load flow, harmonic distortion levels in terms of %THD were determined, based on the harmonic data, harmonic filters i.e. passive and active filters have been designed and installed

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at PCC. Results are presented for both the cases, from the results, it is very clear that harmonic content is reduced to greater extent with the installation of the active power filter compared to the passive filter.

2. Design of harmonic filtering units for industrial power distribution systems

2.1. Brief description of design of passive filter

Passive filters are the most commonly used filters in industry.

The passive filter presents very low impedance at the tuning frequency, through which all current of that particular frequency will be diverted as shown in Fig. 1. The design of a passive filter requires a precise knowledge of the harmonic-producing load of the power system network. The resonant frequency of the passive filter can be expressed by the following expression:

$$f_o = \frac{1}{2\pi\sqrt{LC}}\ \text{Hz} \tag{1}$$

where f_o is the resonant frequency in hertz, L the filter inductance in henrys, C the filter capacitance in farads.

The impedance of the filter branch is given by:

$$Z = R + j\left[\omega L - \frac{1}{\omega C}\right] \tag{2}$$

where R, L and C are the resistance, inductance, and capacitance of the filter elements, respectively, and ω is the angular frequency of the power system.

Single tuned passive filter is considered here. The passive filter consists of a capacitor in series with a reactor. The single tuned filter is good for trapping a specific harmonic. The formulas listed below can be used to design a single tuned filter:

Reactive power of the filter is taken based on total reactive power required for improving bus voltage of the bus where the passive filter to be connected. Q_C is calculated from Eq. (3) and then capacitance of the filter is determined from Eq. (4)

$$\text{Reactive power of the filter } (Q_F) = \frac{h_n^2}{h_n^2 - 1} \times Q_C \tag{3}$$

$$\text{Capacitive reactance } (X_C) = \frac{kV^2}{Q_C} \tag{4}$$

The frequency at which the filter is tuned is then defined by the value of ω that makes inductive and capacitive reactance cancel one another in Eq. (2). If we make 'h' the ratio between the harmonic and the fundamental frequencies of the system, the inductive and capacitive reactance at the harmonic frequency can be expressed as:

$$X_{Lh} = h * \omega_L \tag{5}$$

$$X_{Ch} = \frac{1}{(h * \omega_c)} \tag{6}$$

Assuming zero resistance, the condition for the impedance in Eq. (2) dropping to zero at the tuning frequency requires:

$$X_{Ch} = X_{Lh} \tag{7}$$

Substituting Eqs. (5) and (6) in Eq. (7) and solving for 'h', we get:

$$h = \sqrt{\frac{X_c}{X_L}} \tag{8}$$

$$\text{Inductive reactance } (X_L) = \frac{X_C}{h_n^2} \tag{9}$$

$$\text{Characterstic reactance } (X_n) = \sqrt{X_C * X_L} \tag{10}$$

$$\text{Single tuned resistor } (R_S) = \frac{X_n}{Q} \tag{11}$$

where h_n is tuning order, Q is quality factor.

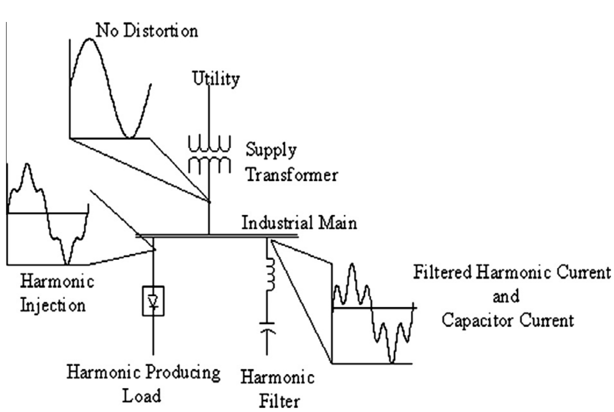

Fig. 1. Connection of passive filter.

2.2. Brief description of control strategy of active power filter

Block diagram of active power filter in a power distribution system is shown in Figs. 2a and 2b. PQ control strategy has been used for controlling of the active power filter. The active power filter currents are obtained from the instantaneous active and reactive powers p_L and q_L of the nonlinear load. This is achieved by calculation of the mains voltages and the nonlinear load currents in a stationary reference frame, i.e., in $\alpha\beta$ components by Eqs. (12) and (13). A null value for the zero voltage components is assumed. The zero current components are also null since the absence of neutral wire is considered.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{12}$$

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \end{bmatrix} \cdot \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \tag{13}$$

The instantaneous active and reactive load powers are defined as

$$\begin{bmatrix} p_L \\ q_L \end{bmatrix} = \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix} \begin{bmatrix} i_{L_\alpha} \\ i_{L_\beta} \end{bmatrix} \tag{14}$$

where p_L and q_L contain harmonic component (oscillatory) and dc component terms and can be written as $p_L = \tilde{p}_L + P_L$ and $q_L = \tilde{q}_L + Q_L$. Under balanced and sinusoidal mains voltage conditions the average power components are related to the first harmonic current of positive sequence, i_{1h}^{+}, and the oscillatory components represent all higher order current harmonics including the first harmonic current of negative sequence, $i_{nh}^{\pm} + i_{1h}$. To achieve harmonic elimination and unity power factor, the ac term $\tilde{p}_L$ and imaginary power q_L have to be eliminated. The compensation power $\tilde{p}_L$ could be obtained by filtering of the harmonic components from p_L. Thus $p_c^* = -\tilde{p}_L^*$ and $q_c^* = -\tilde{q}_L^*$. The DC voltage