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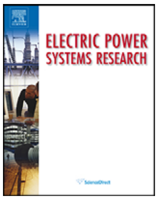

Curve-fitting-based method for modeling voltage–current characteristic of an ac electric arc furnace

Yu-Jen Liu, Gary W. Chang*, Rong-Chin Hong

Department of Electrical Engineering, National Chung Cheng University, 168 University Rd., Min-Hsiung, Chia-Yi 621, Taiwan, ROC

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ABSTRACT

Field measurements of voltage and current are the most effective way for characterizing the electric response of an ac electric arc furnace that describes its nonlinear behavior. Sufficient measured information can be adopted to determine the background harmonic level in a power system, to characterize specific sources of harmonics, and to develop an appropriate nonlinear voltage–current characteristic. In this paper, a curve-fitting-based method called cubic spline interpolation is proposed to model the voltage–current characteristic of an ac electric arc furnace in the steady state. Meanwhile, the actual measured data are collected for modeling use. Two classic methods, harmonic current injections and equivalent harmonic voltage sources, for modeling the electric arc furnace load are reviewed and used to evaluate the performance of proposed model. Results obtained from the measured data and computer simulations of the three electric arc furnace models are then compared according to the voltage and current waveforms, as well as the voltage–current characteristic. It is shown that the proposed model is more accurate than the two classic approaches for harmonic assessment of electric arc furnaces and can be used for modeling similar types of nonlinear loads in the harmonic penetration study.

1. Introduction

Electric arc furnaces (EAFs) have been widely used in steel-making industries. The EAF employs high temperatures produced by the low-voltage and high-current electric arc existing between the electrodes and melting material to smelt scrap iron raw materials. Nowadays, EAFs are designed for very large power input ratings. Due to the nature of the electric arc and the meltdown processes, these devices cause significant waveform distortions such as harmonics, interharmonics and flickers in the supply network. Therefore, electric utilities and their customers always pay much attention to mitigate power quality (PQ) problems associated with EAF loads. For an effective mitigation of PQ problems occurred, obtaining the time response of the EAF becomes of great importance to investigate the impact of the nonlinear and time-varying load to the connected power system. Meanwhile, an accurate EAF model is necessary for assessment of the usefulness of different solutions for PQ problems associated with EAFs.

Usually, the steel-making from EAFs is a batch type of operations, which generally needs to add raw materials two to three times during the complete process which takes about 2–3 h. Fig. 1 shows a measured power variation of the EAF during a typical process. There are three distinct periods included in the steel-making process: striking, melting, and refining [1]. In the striking the three-phase electrodes of the furnace are lowered and contact with the scrap steel, which lead to the electric arc build-up. The melting is then started. Finally, the whole process ends in stably refining.

However, considering the complexity of the EAF operation and the randomness associated with each operation period, it is very difficult to develop an accurate deterministic model for describing the dynamic behavior of an EAF during the striking and melting periods. Figs. 2 and 3 show example waveforms of the measured 20 cycle arc voltages and currents during striking and melting, respectively, where a nonstationary stochastic phenomenon can be observed.

Traditionally, most research efforts of EAF models focus on steady-state modeling used to describe the operation of EAFs during refining. Factors that affect EAF operations usually include the melting or refining materials, the electrode position, the electrode arm control scheme, and the supply system voltage and impedance. Modeling the EAF load depends on several parameters (e.g. arc voltage, arc current, and arc length) which are determined by the positions of electrodes [2]. Thus, it is of importance to know the electric responses of EAFs to develop an appropriate EAF model for PQ study.

In reality, some physical responses of EAFs are not easy to derive from the theoretical study and assumptions are often made to simplify the modeling task. The most effective and simplest manner for obtaining the electric responses of EAF loads is the field

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* Corresponding author. Tel.: +886 5 2428302; fax: +886 5 2720862.
E-mail address: wchang@ee.ccu.edu.tw (G.W. Chang).

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