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New reactive power calculation method for electric arc furnaces

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ABSTRACT

In this study main reactive power calculation methods are evaluated and compared. Furthermore, a novel simple method that can be used for calculation of reactive power in electric arc furnace (EAF) plants is proposed. The focus here is on their application in the control system of static VAr compensators (SVCs). SVC can compensate only the fundamental harmonic component. So the reactive power signal used in the control system should be sensitive only to the main harmonic component. In addition, the reactive power calculation should be fast enough that SVC can follow the quick changes of the load to mitigate the flicker efficiently. To compare various reactive power calculation methods and to evaluate the proposed method, the simulated known loads are used beside huge amount of practical data recorded in Mobarakeh Steel Company in Isfahan/Iran. Results show the proposed method has the best performance for SVC control system.

1. Introduction

In power systems the increment of large loads, notably time varying and non-linear ones such as electric arc furnaces (EAFs) is significant. Reactive power variations in such loads cause voltage fluctuations in their nearby electric network that have a dual effect, first it has a negative effect on the same load and second, it downgrades the electrical power quality of the system [1]. Fig. 1 shows reactive power variations relevant to one of the considered EAFs in this study during one second.

In order to reduce the voltage fluctuation arising from time varying loads, static VAr compensators (SVC) which are classified into thyristor switched capacitor (TSC) and thyristor control reactor (TCR) are employed. Fig. 2 shows schematic of a typical reactive power compensation system. As shown in this figure, the control system includes two control loops. The first loop is the fast control loop (its delay is about 10 ms), which uses the EAF reactive power in a feed forward manner to indicate the required reactive power that should be supplied by the SVC. The second loop measures the reactive power supplied by the main grid. The measured reactive power is given to a PI controller, which is dynamically slower than the first loop (the time constant is about 200 ms). By using the output of this PI controller in a feedback loop, the steady state error of the system tends to zero. The main drawbacks of this control system are the delays associated with the calculation of reactive power and the inherent delays of thyristor firing system. These time delays lead to reduction of bandwidth of the control system, which in turn results in the incomplete compensation of the reactive power variations [2].

Hence the reactive power calculation unit is the most essential part of the SVC control system which should have three characteristics:

1. Due to fast changes of these loads (for example, EAF load is changing in frequencies between 2 and 25 Hz), reactive power should be calculated with the minimum time delay so SVC can efficiently follow the load

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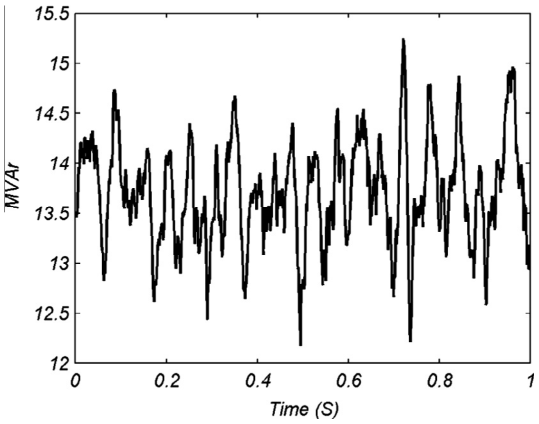

Fig. 1. Reactive power consumption of an EAF.

variation to reduce voltage variations. The time delay of the reactive power calculation strongly limits the ability of SVC in flicker mitigation [3].

2. Since the SVC can compensate only the reactive power of the fundamental frequency component, the calculated reactive power used in SVC control system should only be related to the fundamental component of voltage and current signals. In other words, it should be insensitive to other harmonic components.
3. For a better response to varying loads like EAFs the step response should be a linear monotonic trajectory that initiates from zero to its final value. The linear monotonic response causes the calculated reactive power to have the same variation shape as the actual reactive power of load.

Various reactive power calculation methods that prepare suitable signals for the SVC control system are known. In [4] a time domain method for power line reactive energy measurement is introduced. Also, a frequency domain reactive power measurement based on electronic shifter and stochastic signal processing is proposed in [5]. A wavelet-based reactive power and energy measurement in the presence of power quality disturbances is discussed in [6]. In [7] the measurement of reactive power is done by using neural networks. In [8] a combination of instantaneous reactive power theory and fuzzy PID provides signals for SVC Control system. In [9] new method for reactive power measurement based on a frequency-controlled power-to-pulse-rate conversion suggested. In that paper, in order to achieve high pulse-rate output, the benefit of high resolution is added to the method by introducing a phase-locked loop.

In the other hand there are various studies regarding the time varying nature of EAF reactive power and compensation such variations which leads to less fluctuations of voltage. In [3], reactive power variation of an EAF is modeled using Auto Regressive Moving Average (ARMA) models. In [10], it is shown that the ARMA coefficients of EAF reactive power variations should be updated frequently. Online genetic evolutionary algorithm is employed to update ARMA model coefficients in [11]. In [12], Artificial Neural Network (ANN) and in [13] Grey model are also utilized in order to predict reactive power of EAFs. In [14], a rolling Grey method in combination with Markov chain is used for the prediction. The nonlinear characteristics of the EAF reactive power variations are investigated in [15].

The main focus of our paper is to present a proper method that can be used in the SVC control system for EAF reactive power compensation. In this paper, the main reactive power calculation methods taking into account the three aforementioned characteristics are studied. To compare various reactive power calculation methods, two sets of signals are used. The first set is three kinds of simulated signals that present step load, harmonic load and time varying load. The ideal reactive power is known for these signals. They are used to evaluate the step response of the various methods beside their sensitivity to harmonics and their response to time varying loads. The reactive power calculation methods are evaluated by comparing their response with the ideal response using five indices. The second set is practical signals of instantaneous three-phase voltages and currents which are recorded for three months from eight EAFs installed in Mobarakeh Steel Company (MSC) in Isfahan/Iran.

Furthermore, a method for reactive power calculation which is suitable for EAF plants is proposed. The proposed method is an appropriate combination of two previous methods. The proposed method has a linear monotonic

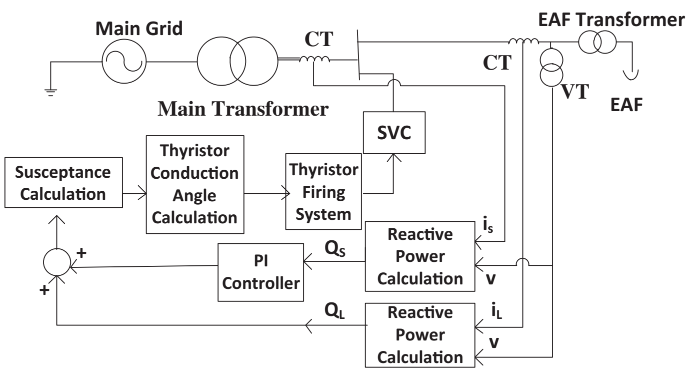

Fig. 2. SVC control system.