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Research on Power Quality Issues in Electric Arc Furnace and Its Mitigation Techniques

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Abstract

Power quality issues of electric arc furnace are a major concern for the industry. The electric arc produced during the operation behaves as a nonlinear ohmic resistance. It injects harmonics, inter-harmonics, voltage fluctuation, voltage flicker and creates voltage/current imbalances in the power system. The quick changes in reactive power requirement of electric arc furnace causes voltage flicker at point of common coupling. This paper presents an overview of power quality problems created by electric arc furnace and some of its mitigation techniques to improve power factor of the furnace supply system. The paper concludes that the unified power quality conditioner is best suited for harmonic reduction in electric arc furnaces.

Key words: *Electric Arc Furnace, Flicker, Harmonics, Power factor, Reactive power.*

1. Introduction

An Electric Arc Furnace (EAF) transfers electrical energy to thermal energy in the form of an electric arc to melt the raw materials held by the furnace. Electrical power is supplied to the electrodes of EAF by an adjustable voltage tap transformer. The heat generated by electric arc striking between the electrodes and the scrap melts the steel. This arc is characterized by a low voltage and a high current. The normal operation of an arc furnace can be divided into meltdown and several refining stages. In the meltdown stage the electrode is lowered through an actuator system to keep a stable arc and which makes the arc furnace draw active power from the supply system required for the process. The random movement of the melting material has a consequence that no two cycles of the arc voltage and current waveforms are identical. Due to large and highly nonlinear and time varying behavior, arc furnace represents one of the most intensive and disturbing loads in the power system [1].

The maximum electrical power to heat conversion occurs for a particular length of electric arc and any deviation from this optimum length affects the power utilization efficiency [2]. The major part of power quality problems occurs in the initial melting stage of EAF. The sudden initiation and interruption of current flow provides a source of harmonic currents and causes considerable disturbance to the power system [3]. In addition, the non-linearity of the arc due to the variability of the arc length produces harmonics that fluctuate in a random manner during tapping operation. The amount of harmonic generation is dependent on the stage in the melting process [4]. Harmonics generated by EAF leads to overheating of conductor, transformer, capacitor bank failures, inadvertent equipment circuit breaker tripping and malfunction of electronic equipment [5].

The various mitigation techniques used in electric arc furnaces are addressed in [6-9]. The authors in [6] describe a mitigation technique using passive filters. The paper concludes that this method is less expensive but ineffective in filtering second harmonic components. An electronically controlled technique is explained in [7] which keep the reactive power consumed by the furnace constant, thus reducing flicker. A distribution static compensator used for reducing voltage flicker and harmonics mitigation is described in [8]. It needs energy storage device to keep the voltage constant at PCC. A unified power quality conditioner using series and shunt compensator is explained in [9] which reduce both harmonics and voltage flicker at PCC by generating reference current.
This paper deals with comparison of various mitigation techniques and concludes that the unified power quality conditioner is the best method to compensate for voltage flicker and harmonics produced due to operation of electric arc furnace. The rest of the paper includes following sections. Section 2 describes power quality issues in electric arc furnace, section 3 includes mitigation techniques and section 4 presents the conclusion.

2. Power quality iIssues in Electric Arc Furnace

The perturbations caused by electric arc furnaces are of random nature and it varies from a frequency range of DC to a few hundreds of Hz. Depending on power supply (AC or DC) of EAF, there are unbalances, harmonics, inter-harmonics or voltage flicker in the frequency range between 0-30Hz [1]. At the instance of lowering the electrodes and the ignition of the arc, very high variations of voltage in the AC electric arc furnace take place. Arc length changes as a result of the electromagnetic force and the continuous movement of the molten pool. This produces quick changes in the reactive power consumption, thus resulting in flicker. The development of the flicker phenomenon in AC electric arc furnaces is explained by means of the circle diagram, based on the Heyland circle used in AC machinery. The active power absorbed by the furnace is given by equation (1).

$$P = \frac{V_{pcc}^2 (R_t + R_a)}{(R_t + R_a)^2 + X_t^2} \qquad (1)$$

where V_{PCC} is the voltage at the common point of coupling, R_t and X_t are respectively the resistance and the inductance of the supply system and R_a is the arc resistance. Thus the active power consumed by the load is maximum when $R_t+R_a=X_t$ and is given by equation (2).

$$P_{max} = \frac{V_{pcc}^2}{2 X_t} \qquad (2)$$

The operating diagram of the AC furnace drawn in the (X, R) plane shown in Fig.1.

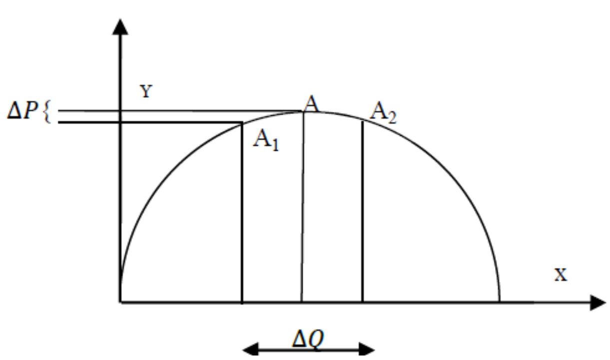

Fig.1. Operating Diagram of AC Electric Arc Furnace [1].

Arc furnaces consume consequently large quantities of reactive power which should be compensated. If the operating point moves from A_1 to A_2 as shown in Fig.1, the variation of the reactive power can be up to ten times larger than the variation in active power [1]. This explains why the variation of the reactive power consumption of an arc furnace produces flicker phenomena.

The total harmonic distortion (THD) produced by furnace will be maximum at the initial stages when the electrodes are bored into the scrap steel. During refining the furnaces particularly generate third and fifth harmonic voltages and produce a more consistent THD since steel bath is already established. Even harmonics are also present in the power system because of the irregular arcing inside the EAF. As the use of EAF increasing in the industry, it is necessary to minimize its effect on power quality. The next section describes the harmonic mitigation techniques for electric arc furnaces.

3. Mitigation Techniques

The fluctuating reactive power drawn and the nonlinear behavior of arc during operation of EAF results in voltage flicker at the PCC and harmonics being produced in ac mains. Hence, to keep the total harmonic distortion and voltage flicker within limits various mitigation techniques are used. Some of the techniques are discussed here with their advantages and disadvantages.

3.1 Passive filter

Unwanted harmonic currents could be prevented from flowing through the power system by diverting them through a low-impedance shunt path. The shunt filter is an effective way of minimizing voltage distortion caused by arc furnace operations. The most practical and less expensive solution is to use a single-tuned or a high-pass filter. Existing capacitor banks could be converted to filter banks by adding series reactors to detune harmful resonant conditions in the system. Passive shunt filters of carefully designed SVCs can successfully filter out harmonic current components produced by EAFs except second harmonic. The widely applied passive shunt filter topologies have experimentally proved to lead to amplification of second harmonic [6].

3.2 Using Power controller and a booster Transformer

This is an electronically controlled mitigation technique used to keep the reactive power requirement constant and results in reducing voltage flicker. This is achieved by associating with a conventional power system of the EAF with current controllers and a booster transformer. By regulating the reactive power input with the help of this new control method, any disturbances in the power system can be reduced to a minimum and hence reducing flicker at the PCC. In this method, distortion and fundamental reactive power is compensated using static var compensator. The power system current can also be maintained at a constant value [7].

3.3 DSTATCOM

A DSTATCOM consists of a voltage source converter (VSC) shunt connected to the distribution network through a coupling transformer as shown in Fig.2. It is controlled to inject the non-sinusoidal current required by the load current. Hence, the phase currents taken from the supply are nearly sinusoidal.

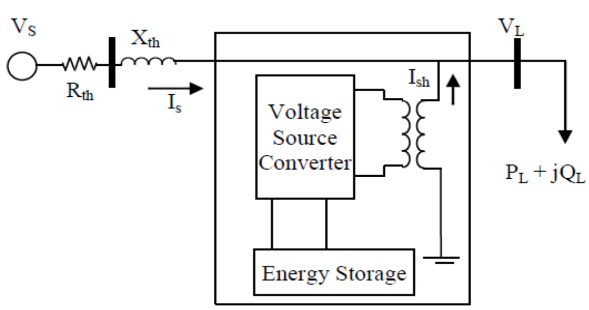

Fig.2. Schematic representation of D-STATCOM [8].

If D-STATCOM does not contain any active power storage it only injects reactive power. Limited voltage sag mitigation is possible with the injection of reactive power, but active power is needed if both magnitude and phase angle of the pre-event voltage need to be kept constant [8].

3.4 Unified power quality conditioner

A Unified Power Conditioner (UPQC) comprises a combined series and shunt active filter sharing a common dc link as shown in Fig 3. It mitigates voltage disturbances, compensate for reactive power, harmonics and inter-harmonics. As the voltage at PCC contains frequencies other than fundamental frequency conventional methods cannot be used for extracting the reference signal. So in this method reference signal is generated by processing active power signal. Control of UPQC consists of detecting reference signals and controlling series and shunt active filters. Shunt active filter output voltage is generated to reduce source reactive power. A hysteresis current controller determines the switching pattern of the inverter devices to achieve the required compensating current. The main task of the series active filter is to mitigate the voltage disturbances at the PCC.

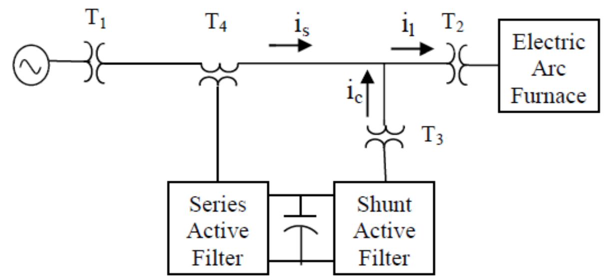

Fig- 3: System Configuration for UPQC [9]

4. Conclusion

This paper presents the comparative study of power quality issues related to Electric Arc Furnace and discusses some of its mitigation techniques. It shows that passive filters are not an effective means of harmonic mitigation, since EAF contains variable frequency harmonics and voltage flicker at PCC. Active filters like DSTATCOM compensate for the reactive power requirement of EAF and use conventional methods to generate the reference signal for the control purpose. Unified Power Quality Conditioner extracts the reference signal from active power signal and is used to mitigate voltage at PCC and load current disturbances. It also compensates for reactive power, harmonics, inter-harmonics and imbalance. Thus UPQC is the best technique to mitigate voltage flicker at PCC and for harmonic reduction in electric arc furnaces.

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BIOGRAPHIES

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