Harmonics generated by Electric Arc Furnace in Electric Power System - A Review

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Abstract

An electrical power system is designed to operate at the frequency of 50 Hz or 60 Hz. But there are certain loads which generate voltage and current that are the integer multiple of 50 or 60 Hz. Those higher frequencies form electrical network pollution called as power system harmonics. An Electric Arc Furnace (EAF) is one of such load when operated on AC affects the power quality of the power system. The power quality is degraded mainly due to the poor power factor, current and voltage harmonics and voltage fluctuation. The problems due the harmonics is getting worsen day by day due to the introduction of power electronics equipments and voltage fluctuation arise by the use of large industrial load such as EAFs and LMF (Ladle Melt Furnace) in steel meting shop. Also connecting rolling mill and forging shop generate harmonics in the adjacent electrical power system. In this paper, an extensive review of harmonics generated in EAF is presented .

1. INTRODUCTION

Harmonics in the power system is not new issue. This phenomenon has been introduced by technocrat throughout in the history of electrical power system. The third harmonic current is the main concern caused by saturated core of electrical machines. An introduction to the voltage and current harmonics fundamental and the definition of Total Harmonic Distortion (THD) are explained in [1-2].The acceptable limits set by the international standards [3-4] gives the guide lines of the methodology of the harmonics analysis for the harmonic content in the power network. The electric arc furnace is the most disturbing load which produces strong disturbing effects featured by non-symmetries of currents and voltages, harmonics, flickers, voltage drops and over-voltages, characteristic parameters of power quality. Largest single load usually encountered on an electric utility grid is often an electric arc furnace (EAF). The EAF can be served without causing problems to other existing or future loads on the grid. The main source of concern from the utility for an EAF load is often flickering and with good reason. Because of its constant and randomly changing power levels, a single load of this magnitude is certainly a potential cause of widely varying voltage changes on the system. To insure that the EAF operation won't cause these problems on the utility grid, it must be adequately studied to insure compliance with the flicker standards used by the utility. For many varying loads, the task of performing flicker studies is fairly straightforward. The main reason is that their varying load pattern is somewhat consistent and well defined. As those who have dealt with the problem well know, the varying load pattern of an

EAF is anything but well defined. Therefore, proper model of an EAF is required to anticipate the electric arc furnace characterization.

2. EAF AND ITS AUXILIARIES IN A STEEL PLANT

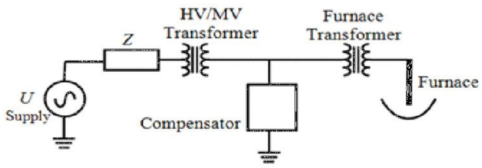

Fig.1: AC Operated Arc Furnace

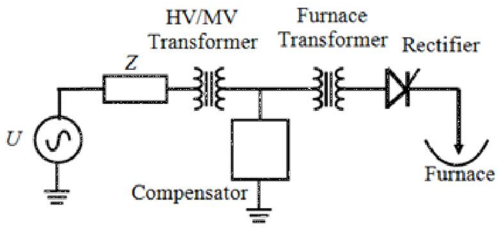

Fig.2: DC operated Arc Furnace

2. REVIEW OF HARMONIC GENERATED BY EAF IN POWER SYSTEM

Disturbance in form of harmonics and voltage flickers namely are propagated into the distribution system when the electric arc furnace is operated. The cause of components of harmonics are due to the non linear behavior of the current voltage of the electrical arc and the voltage flicker is due the fact that arc length changes during the melting of the scrapes.

The author [5] presents 80MW EAF connected with 30kV/1.1kV, 120MVA furnace transformer, delta- star transformer which is connected with utility transformer rated 230kV/30kV, 120MVA. In this paper, the author has evaluated harmonic distortion by using a distributed constant parameter model where as the voltage flicker simulation, nominal pie model is proposed. The voltage THD at PCC and arc furnace bus are obtained as 0.25% and 35.23% respectively and the current Total Demand Distortion (TDD) at PCC and arc furnace bus are found to be 2.08% and 13.26% respectively.

The utilities and customers have been trying to minimize the effects of arc furnace loads such as harmonics on power quality as far as possible. Obtaining time response of EAFs is important in investigating the impact of these nonlinear and time varying loads on power quality of the power system.

A new time domain model [6] of arc furnace simulates both nonlinear and time varying nature of electric arc loads, which create flicker, harmonics, and voltage/current unbalance. In this model, Cassie and Mayer equations are used in three-phase mode and the effects of arc furnace transformer tap changer and mutual inductances of the flexible cables are taken into considerations. The proposed model takes into account the system inter-relation of parameters and arcing conditions.

The author [7] proposed a technique to minimize the harmonic distortion in a steel factory by field measurement and filter design. Power system harmonic was carried out in North Star Steel plant Beaumont, Texas at 13.8kV and 34.5kV voltage level in the power system. The voltage THD was found 1.51% -8.17% at 13.8% and the current THD in the range of 3.45% -9.86%.The voltage THD was found in the range of 0.53% - 6.30% during the operation. During extreme sporadic condition of arc furnace, the voltage THD was found to be 19.18%. The current THD was in the range of 3.14% -16.08%. The harmonic analysis was carried out by installing the line reactor and 4.7^{th} harmonic filter and it was found that the voltage THD and current TDD were 2.63% and 3.83% respectively.

AC and DC arc furnaces are the most disturbing load in the sub transmission and transmission power system. These arc furnaces are characterized by violent change in power that happens during initial stage of melting. The voltage and current characteristics of the electric arc is non linear which results in harmonic current in the power system.

The author [8] has shown that the use of three phase power analyzer for the power quality analysis and the following quantities are important to be measured such as voltage, current, flicker (IEC 68, IEC 61000-4-15-P_{ST} and P_{LT}), wave shots, THD and harmonics up to the higher orders .In different stages of operation of electrical arc furnace, the TDD–I vary between 1% -21% for the current and 1% -6% for the THD–V. Comparing the value with the international standard, it is observed that the arc furnace does not match with either national or international standard.

The model of the arc furnace [9] is modeled by using probability technique. The author has investigated 33kV arc furnace installation. The furnace is supplied from 275 kV utility networks by two transformers. At 132 kV PCC, a HV/MV transformer feeds the furnace transformer which is delta connected secondary from 229 V to 426 V (tap 13). The furnace is simulated for the both the models at the highest tap during bore down period. The average Total Demand Distortion of the current (TDD) for odd order harmonics 3rd, 5thand 7th are found to be 0.86%, 7.18% and 4.05% respectively. The acceptable TDD-I is 12% and the average Total Harmonic Distortion for voltage for odd order harmonics 3rd, 5th and 7th are found to be 0.3%, 0.7% and 0.5% respectively. The acceptable THD-V is 3%.

An adaptive model [10] of EAF suggested by author, the model is flexible and accurate. The difference between the proposed model and the existing model is the control system is included in the model. As per the author, the adaptive EAF model is composed of two parts, the non linear arc model and the controller model. The arc is represented by a non linear current controlled resistance. The pattern of the arc generated is determined by the arc length which is controlled by the controller. The interaction among three components namely supply system, the EAF load and the control system constitutes the adaptive EAF model. The author has presented only fifth, seventh and eleventh component of harmonics generated. The current harmonics shows the different characterizations in smelting and refining stages. It is found that the contribution of harmonics increases more during the early phase of melting and less in refining stages. The fifth component of harmonic is the greatest component of harmonic and changes with the power input. The voltage harmonic components are found more during refining stage.

There is no big change for 5th, 7th and 11th harmonics during refining stage. In first case the white noise is added to the operating parameter to realize the flicker and in the next case it is observed that the random movement of melting material may change the electrode position which contributes the dynamic phenomena like voltage flicker.

Further as per [11], the new idea was presented for the electrical behavior of EAF by the measurement of electric power in stationary and transient imbalance. The new technique adopted in characterizing the behavior the arc furnace is by using time frequency domain. The actual measurement made in the iron and steel company was compared by the electromagnetic transients AT Draw. The average Total Demand Distortion of the current (TDD-I) for odd order harmonics 3rd, 5thand 7th are found to be 0.86%, 7.18% and 4.05% respectively. The acceptable TDD-I is 12%

for all odd order 3rd, 5thand 7th harmonics. The worst case of EAF voltage harmonics for odd order harmonics 3rd, 5th and 7th are found to be 29%, 10% and 8% respectively. The author in this paper has presented a power quality index as a Total Demand Distortion (TDD) which is the ratio of short circuit current (Isc) and load current I_L and is accepted by IEEE-519-1992 standard. Since the EAFs in the steel plant play vital roles for power quality disturbances. The nonlinear characteristics of the EAF generate significant harmonic currents and flickers flowing through the plant and the utility power system.

As per [12], a harmonic analysis for a steel plant with an AC EAF load by simulation results by using Matlab/Simulink are validated by the actual measuring data. It is shown that the simulation model including the power network and EAF load is relatively accurate in comparing with the actual field measurements. It is observed that the arc voltage and arc current vary during different stages. The TDD-I (%) in melting stage reaches 32.4%. When the melting process enters the refining stage, the arc voltage and arc current found to be more stable and TDD-I (%) is reduced to 14.8%, but this value is still higher than 12% of (Isc/ I_L=50 ~100) limit set by IEEE-519-1992.Based on the measured data, it is observed that the harmonics generated by the steel plant is mainly because of the nonlinear operation of the EAF. Therefore, it is also very important to control harmonic.

In order to understand the arc furnace better, the author proposed an improved three-phase, non-linear, time-variant arc furnace model [13] which is based on arc length, stochastic characteristic and actual arc furnace condition. It is shown that it is possible to simulate accurately arc furnace behavior with a very simple current-voltage characteristic. Emphasis has been put on the time dependent variation of the electric arc voltage rather than the modeling of the voltage-current characteristic. In order to show the stochastic characteristic of the proposed model, system identification technique was used. The model was implemented using the Matlab/Simulink. The dynamic electric arc current and main bus bar current waveforms were obtained and analyzed through on-line FFT analyzer. It was found that TDD-I of electric arc current in all three phase is 22.7%, 12.5 % and 21% which is far above the limit of IEEE 519-1992 standard. The harmonics content at 110kV bus bar of phase-A was 15.9%. The arc produced between the electrode and the material kept in the melting bath is characterized by the low voltage and high current delivered by the furnace transformer.

The author [14] has proposed an arc furnace model based on the power quality point of view. Since electric arc furnace is responsible to propagate the disturbance in the high voltage network due to its dynamic behaviour in melting stage of the operation. Hence such model was required to evaluate the harmonics and the flicker which are the most pronounced and major power quality problems in the power system. The perturbation produced by the arc furnace is of the random nature whether the furnace is supplied by AC or DC. The flicker produced by the arc furnace is variable from one cycle to another. Flickers are found to be of high peaks during the melting stage. The flickers are also dependent on quantity and quality of scrap, amount of oxygen used during the melting and the crumbling of scrap during melting. Due to the variable arc length, harmonics are produced. The third harmonic is predominantly produced in such furnace during and found to be 20% and 10% during smelting and refining as suggested by the author.

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The model of an improved time variant, non linear, three phase electric arc furnace which is based [15] on the stochastic characteristics of arc length and real arc furnace condition. The actual arc furnace installation is not fitted with compensation devices. The arc furnace is a typical load in the power system which injects numbers of harmonic components in the power system whose magnitude changes with the varying loads. The TDD-I of bus bar currents are obtained which are 22.7% for Ph-A; 12.7% for Ph-B and 21.0% for Ph-C. The TDD-I at 110kV bus was also found to be 15.9%.

The new idea proposed by author [16] to present the electrical behavior of the electric arc furnace by the measurement of electric power in stationary and transient imbalance. The new technique adopted by the author in characterizing the behavior the arc furnace is based in time frequency domain. The actual measurement made in the iron and steel company was compared by the electromagnetic transients ATP Draw. voltage harmonics produced by the arc furnace is recorded in table 2.1 below.

Table-1: EAF voltage harmonics [15]

Harmonic	Worst Case % fundamental	Typical% fundamental
2	17.0	5.0
3	29.0	20.0
4	7.5	3.0
5	10.0	10.0
6	3.5	1.5
7	8.0	3.0
8	2.5	1.0
9	5.0	3.0

The author in this paper presents power quality indices namely Total Demand Distortion (TDD-I) of the current which is the ratio of short circuit current (Isc) and load current I_L and is accepted by IEEE-519-1992 standard. Total Demand Distortion of the current (TDD-I) is presented in Table 2.2. Total Voltage Harmonic Distortion flicker propagation in different position (actual conditions) is recorded in table 2.3 The AC electric arc furnaces (EAFs) degrade the power quality of the network by generating disturbances such as flicker and harmonics. These disturbances are due to the nonlinear electromagnetic and thermal field behaviors of the AC arc.

Table-2: Total Demand Distortion of the current (TDD-I) [16]

Indicator	THD Ia1	THD Ia3	THD Ia5	THD Ia7
Average	8.40%	0.86%	7.18%	4.05%
Standard Deviation	3.52%	0.36%	3.49%	1.67%
Min Value	2.02%	0.18%	0.80%	0.61%
Max. Value	12.58%	4.19%	24.02%	13.45%
Acceptable TDD	15%	12%		

Table-3: Total Voltage Harmonic Distortion of the voltage [17]

Indicator	THD Va1	THD Va 3	THD Va 5	THD Va 7
Average	1.1%	0.3%	0.7%	0.5%
Standard Deviation	4.6%	0.1%	0.3%	0.2%
Min Value	0.3%	0.1%	0.1%	0.1%
Max. Value	6.1%	0.7%	1.8%	0.9%
Acceptable THD	5%	3%		

Analysis of such nonlinear nature is required for improving power quality in the network. This model presents a three-dimensional finite element modeling of the electromagnetic fields in an AC three-phase EAF.

The model [17] includes the electrodes, arcs and molten bath. The current density, voltage and magnetic field intensity in the arcs, molten bath and electrodes are predicted as a result of applying the three-phase AC voltages to the EAF.

3. CONCLUSION

Electric arc furnace installations are more challenging in context to the harmonic generated by it in the connecting power system while it is operated. Due to the non-linear characteristic of the electric arc, the electric arc furnace installation interacts with several other non-linear elements, such as the magnetizing characteristics of power transformers and other equipments that show the non linear behavior. The electric arc furnace installation is a three-phase circuit and the early phase of melting of the scrap is a highly irregular process that induces very severe imbalances in the operation of the installation.

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