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Electric Arc Furnace Flicker Mitigation in a Steel Plant Using a Statcom

P.M.Sarma, Dr.S.V.Jayaram Kumar
Professor in Electrical and Electronics Engineering,
Gokaraju Rangaraju Institute of Engineering & Technology, Hyderabad and
JNTUH College of Engineering, Hyderabad

Abstract— Electric Arc Furnaces are used in steel plants for producing high quality steel. Modeling of the electric arc furnace with all its features is accomplished using a technique developed based on Fourier series. It is demonstrated in this paper that Statcom gives the best performance of all possible solutions.

***Index Terms*— Electric Arc Furnace (EAF), Reactive Power Compensation, Flicker.**

I. INTRODUCTION

Electric arc furnaces (EAFs) are the worst offending loads from the point of view of polluting the power systems. Their bad effects include, among other things, voltage flicker. The other bad effects are generation of all harmonics including even, odd and inter harmonics. Also reactive power fluctuates wildly causing system bus voltages also to fluctuate. Efforts to increase power quality in the power supply systems of steel plant and other heavy power consuming industries only result in additional investment costs for the industry. It is felt that Static Var Compensator ,Shunt Active Power Filter, Statcom etc.are un necessary and should be avoided where ever possible due to cost considerations .In this paper performance of Statcom is highlighted w.r.t industrial polluted power especially in steel plants. Power quality in the supply system, and in particular the installation of a well designed Statcom, is advantageous investment for heavy industry and may bring substantial gains from the production point of view because of reduced outages and more economical operation. It is important to note that when designing a steel plant power installation the installation of a Statcom should be considered at the initial stage preferably.
Large steel plants produce their own power mostly and only partly depend on utilities; they may suffer the bad effects of polluted power and also disturb other consumers in the neighborhood. The sudden heavy loads, as may occur in rolling mills and large electric arc furnaces (EAFs) with their rapid fluctuations in both active and reactive powers disturb each other. The interconnection point in the grid between the power utility and the steel plant, generally called PCC or Point of Common Coupling is the place where utmost care has to be taken in containing pollution of power.

II. PROBLEMS ASSOCIATED WITH ARC FURNACES

The most important problems concerning Electric Arc Furnace operation are voltage flicker, harmonic injection and severe voltage unbalance. Because of the random motion of the electric arc, just as arc length varies during melting process, severe oscillations in supply system occur. When the frequency of this variation is around1-25 Hz, flicker is said to occur. Because of the interaction of time delay in arc ignition and the arc extinction ,severe nonlinear v-i characteristic of the arc, harmonics and inter harmonics are generated .Nonlinear, time-variant and random nature of Electric Arc Furnace operation and high electric energy consumption of these loads, make it all the more difficult to study or simulate the phenomena.

III. CONTROL OF ARC FURNACES

An arc furnace is challenging to control from the power engineers' point of view. Reasons for this are explained in the following an arc furnace converts electrical energy to heat energy in the form of an electric arc and the scrap is molten which is charged into the furnace. The arc is established between electrodes and the molten steel which is of a low voltage and high current. The normal operation of an arc furnace can be divided into melting and l refining stages. In the melting stage the electrodes are lowered by means of an automatic control system to maintain a stable arc making arc furnace draw as much active power as possible from the power system. The electrodes are moved up

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and down by means of an automatic control system to control the current. The condition for maximum active power drawal is that real and reactive powers should be equal. The random movement of the melting material causes arc voltage and current waveforms to fluctuate randomly. These large variations have a direct impact on the power quality of the connected power system. The disturbances caused by electric arc furnaces are stochastic in nature ranging from DC to hundreds of cycles. In addition the power supply to the electric arc furnace is affected by unbalanced voltages, harmonics, inter-harmonics and voltage flicker in the frequency range between 0-30Hz.When electrodes are lowered and the arc is ignited, very high fluctuations of voltage in the AC electric arc furnace occur. Each time scrap is loaded the flicker is severe.

IV.VARIOUS MODELING TECHNIQUES

An arc furnace is modeled as an inductor in series with a resistor for study and simulation. This equivalent circuit is not sufficient to cover the variety of behaviors of the furnace exhibits and its impact on power systems. Many models are developed to conduct power quality analyses. The models can be are described briefly here under.

A. Nonlinear Resistance Model: approximation of the V-I characteristic of the arc is normally used. The approximation can be performed by linearization of the characteristic. Simplification of the V-I characteristic is the main approach in this method. This method solves the differential equation which is used to describe the furnace system with the assumed V-I characteristic.

B. Current Source Models: An electric arc furnace is normally modeled as a current source for harmonic studies. The source current can be represented by the Fourier series where the Fourier coefficients may change randomly during every period. The coefficients can be selected as a function of the following items:

a) The actual measured arc furnace current data

b) The harmonics observed actually in arc furnace currents;

c) The probability distributions of the current harmonics;

This model is perfectly suited to determine the size of filter capacitors and to evaluate voltage distortions resulting from the harmonic currents injected into the power system. The stochastic behavior of the furnace is correctly taken into account. This model with some variation **is** implemented in the present paper.

C. Voltage Source Models: The voltage source can be modeled in different ways. This method loses the stochastic characteristics of arc furnaces like the nonlinear resistance model does. A more precise way to account for the stochastic characteristics of the arc furnace is to model the voltage source as square waves with modulated amplitude. The new value for the voltage amplitude is generated after every zero crossing of the arc current when the arc must reignite. This model can simulate the arc furnace statistically correctly.

D. Modeling of Arc Furnace: In this paper the data obtained from Fourier analysis of practical arc voltages and currents are used to describe the arc electrical behavior. Practical model of EAF based on random variables is proposed. Then, voltage flicker that appears from EAF's operation is also implemented by modulation at the appropriate frequency from 5 to 30 Hz. Using typical measurements of arc furnace currents and conducting harmonic analysis that the harmonic content of the currents is as given in the following table.

Harmonic Order	Melting Stage	Refining Stage
2	5.0%	2.0%
4	3.0%	2.0%
5	10.0%	10.0%
6	1.5%	1.5%
7	6.0%	6.0%
8	1.0%	1.0%
9	3.0%	3.0%
11	2.0%	2.0%
13	1.0%	1.0%

The simulation in MATLAB consists of creating a current source whose control input is given an input that is sum of the above harmonics for the melting stage or refining stage as the case may be and applying a modulation equivalent to the flicker frequency. A schematic showing simulation of the arc furnace is shown below:

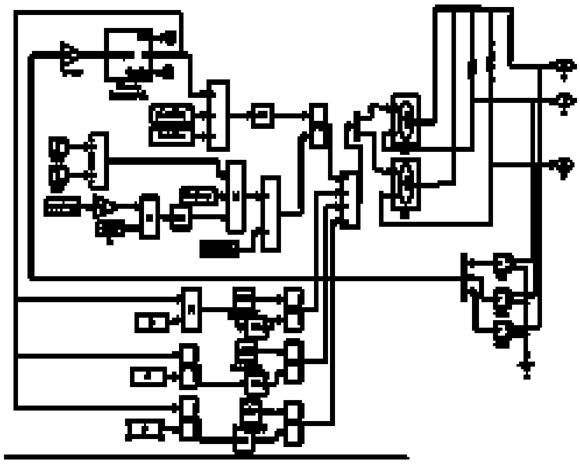

Fig1. Diagram Showing Simulink Model of the Arc Furnace

The system that is studied for the purpose of mitigation of flicker and other impact on power quality aspects is given below as a single line diagram in fig.2. Power is supplied to the arc furnace by means of a 25 kV/600 V transformer which n turn receives power from at 25 kV via a long transmission line which also supplies other steel plant loads. The point of interest is the effect the arc furnace has on the power system and in turn on other loads.

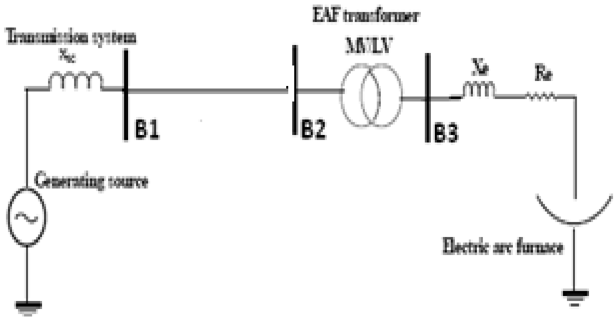

Fig.2. Single Line Diagram of Electric Arc Furnace Power Supply System

It is found that the current waveforms and voltage waveforms have a lot of harmonics as shown in fig.3and fig.4in addition arc furnaces cause flicker also to occur.

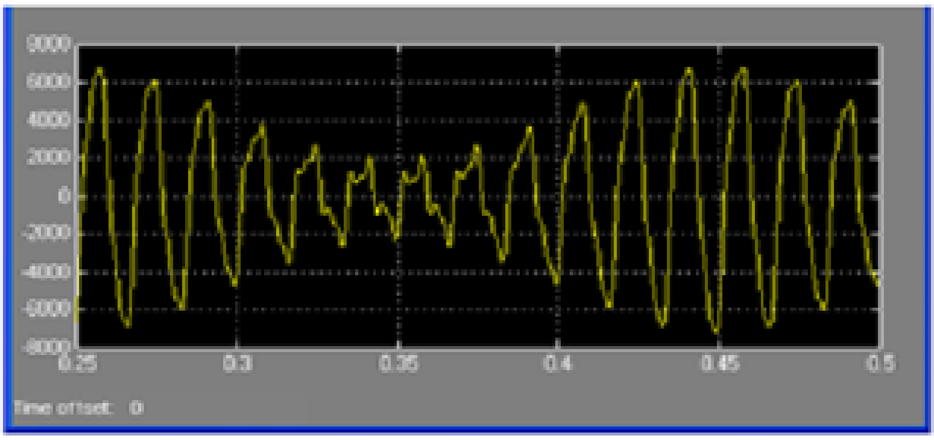

Fig.3. Arc Current Waveform When Statcom When Statcom is Disconnected

The generating source is a remote power station supplying the steel plant through a long transmission line. Arc current waveform of one of the phases shows distorted sine wave and also shows some modulation of the amplitude. Harmonic analysis of this wave form shows that the second, third and fifth harmonics are predominated component and harmonics of less than 60 Hz is also seen. The harmonic analysis also shows all even and odd Harmonics. This is a characteristic feature of arc furnace currents.

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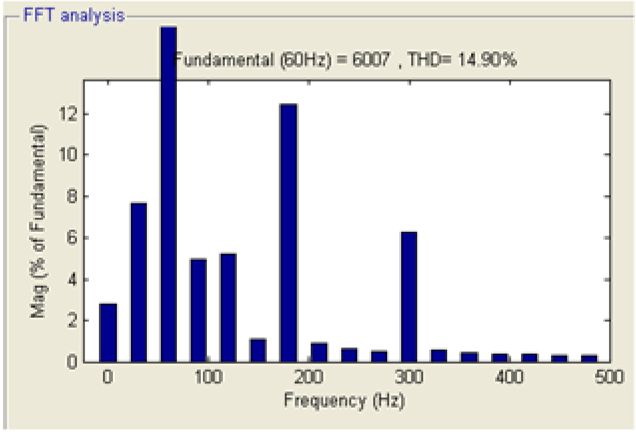

Fig.4.Harmonic Analysis of Arc Current Waveform When Statcom is Disconnected

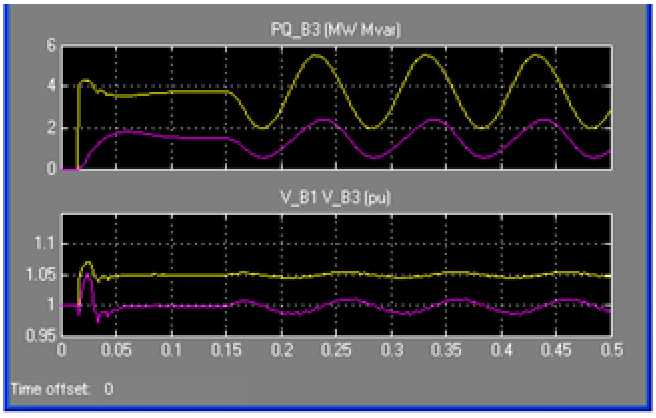

Fig.5. Active And Reactive Powers and Voltage At Point Of Common Connection at Flicker Frequency Of 10 Cycles

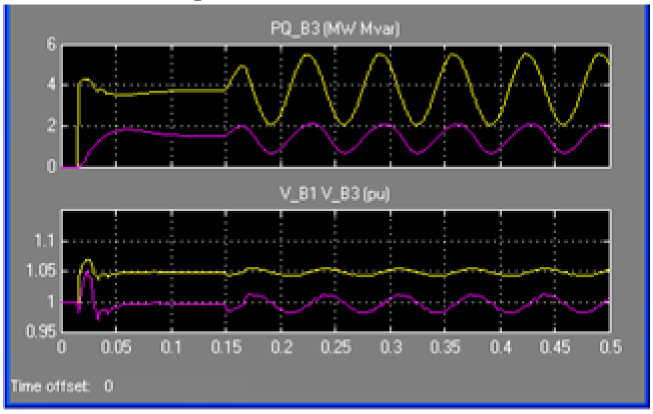

Fig.6. Active and Reactive Powers with Statcom and Flicker Frequency 15 Cycles

Flicker is the low frequency modulation occurring on the RMS valu of the voltage. This may vary from 5 to 30 Hz. It can be seen from above graph that the fluctuation in rms value of voltage causes fluctuation of real power. Statcom operating in voltage control mode contributes reactive power and keeps the system voltage stable there by mitigating flicker. This helps the steel plant bus B2 having other heavy loads connected to it have a very stable voltage. This is demonstrated for a flicker frequency of 10 Hz and 15 Hz. The flicker frequency may range from 5 cycles to 25 cycles. When the Statcom was switched on it is found that the flicker content of 10 cycles and 15 cycles was also mitigated but the harmonic content remained the same. So the Statcom is having a very good application as far as mitigation of flicker is concerned. In addition the Statcom is also helpful in controlling the voltage to the required level under conditions of sudden dip in the voltage. The Dip could have been caused by a sudden switching of heavy load somewhere in the power system or it might have been caused by the arc furnace itself. In order that an arc furnace should work inside a steel plant without affecting other heavy loads which are equally

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sensitive to voltage fluctuations it is imperative that some means must be provided to tackle problems created by arc furnace.

V. RESULTS

It is found that the current waveforms and voltage waveforms have a lot of harmonics as shown in fig—and fig—in addition arc furnaces cause flicker also to occur . The flicker frequency may range from 5 cycles to 25 cycles. When the Statcom was switched on it is found that the flicker content of 10 cycles and 15 cycles was also mitigated but the harmonic content remained the same. So the Statcom is having a very good application as far as mitigation of flicker is concerned. In addition the Statcom is also helpful in controlling the voltage to the required level under conditions of sudden dip in the voltage. The Dip could have been caused by a sudden switching of heavy load somewhere in the power system or it might have been caused by the arc furnace itself. In order that an arc furnace should work inside a steel plant without affecting other heavy loads which are equally sensitive to voltage fluctuations it is imperative that some means must be provided to tackle problems created by arc furnace. A typical feeder feeding an arc furnace and other steel plant loads such as rolling mills is shown below. The bus nearest the arc furnace (B3) is the PCC or point of common connection where statcom is also connected.

VI. CONCLUSION

Though a statcom is only intended to supply reactive power as per the desired power factor many times it is used to control the bus voltage which may actually be more beneficial to the system. If a fixed capacitor providing a base reactive power that may be needed to compensate for the power factor improvement purpose the dynamically changing reactive power may actually be supplied by statcom. The following figure gives s an idea about the same.

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