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Voltage Flicker Mitigation in Electric Arc Furnace using D-STATCOM

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Abstract: **The major power quality issue of voltage flicker has resulted as a serious concern for the customers and heavy power companies. Voltage flicker is an impression of unsteadiness of visual sensation induced by a light source whose luminance fluctuates with time. This phenomenon is experienced when an Electric Arc Furnace (EAF) as load is connected to the power system. Flexible AC transmission devices (FACTS) devices were gradually utilized for voltage flicker reduction. In this paper the FACTS device of Distribution Static Synchronous Compensator (D-STATCOM) is used to serve the purpose of mitigating voltage flickering caused by electric arc furnace load, which is efficiently controlled by Icos control algorithm. The model of electric arc furnace is considered as a current source controlled by a non linear resistance, which had been simulated and performance was analyzed using MATLAB/SIMULINK Software.**

Keywords: **EAF – Electric arc furnace, D-STATCOM – Distribution Static Synchronous Compensator, Voltage Flicker, THD – Total harmonic distortion,Power Quality**

1. INTRODUCTION

The quality of power is a great concern for the heavy power companies and end users. There are many power quality issues such as sag, swell, harmonics, switching transients, interruptions, overvoltage, under voltage, voltage flicker, low power factor etc. The quality of power has an economic impact on consumers. Nonlinearity in the loads causes harmonics which can cause drastic effects on the power supply and adversely affect the performance of other electrical equipments. Electric Arc Furnace is one of such equipments, when it is connected to the grid system results in voltage fluctuations which lead to power quality problem of voltage flicker, power factor reduction, and harmonic distortion in the electric grid. These problems are reducing the electrical equipment efficiency. To minimize the problems caused by electric arc furnace can be solved by many techniques, here D-STATCOM has been selected for mitigating voltage flicker and reactive power compensation. Traditionally, SVC (Static Var Compensators) were used to solve the problem of voltage flicker, reactive power compensation and factor correction but it had few disadvantages that it generates lower order harmonics and takes longer response time compared to D-STATCOM. The D-STATCOM is an IGBT-based voltage source inverter which delivers faster response, power factor improvement and harmonic reduction since it uses highly advanced power switches. D-STATCOM benefits in reducing the losses by maintaining high power factor at the load end, which eliminates voltage sags, swells and transients. If a D-STATCOM is well designed it serves to be an advantageous investment for the power companies and can bring productive gains for the company as well as customers.

The control algorithm decides functionality of D-STATCOM, various control strategies have been reported in literatures. The conventional algorithms were taking more computational times and slow in response which makes necessicity of new faster control strategy for D-STATCOM. In this paper IcosΦ control algorithm has been used for D-STATCOM to mitigate voltage flicker and power factor correction. This control algorithm is very simple and involves less comptutional time which makes targets to limiting the voltage flicker at the source side. The detailed algorithm has been reported in [2] and its application to renewable energy source has been reported in [3].The few modifications have been introduced with IcosΦ control which has been used for control of D-STATCOM.

The power system model with electric arc furnace is shown in the fig.1. The electric arc furnace load is connected to power system introduces flicker. D-STATCOM provides reactive power compensation thereby stabilizing the power system voltage input and reduces the flickering. The modelling of electric arc furnace is described in Section 2. The control algorithm is explained in section 3.The simulation results and conclusion has been presented in section 4 and section 5 respectively.

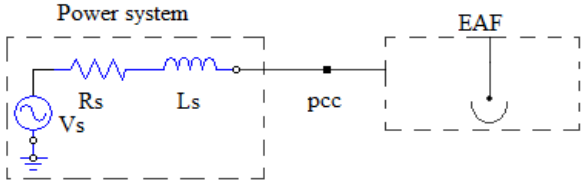

Fig.1. Power system model with Electric Arc Furnace Type Style and Fonts

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2. MODELLING OF ELECTRIC ARC FURNACE

The most prevalent way today to reprocess steel from scrap is electric arc furnace. A wide variety of scrap can be melted in the arc furnace to produce steel with the help of electrodes and current. The electrodes are moved in and out of the furnace and thereby arcing occurs which melts the ore. Since electric arc furnace is a highly nonlinear load, the modeling of electric arc furnace and its equivalent electrical model is difficult task. Many literatures have proposed different models of electric arc furnace such as harmonic voltage source model, time domain model, frequency model etc [7].

The modeling of electric arc furnace mainly depends on the parameters such as voltage, current and length determined by the position of the electrodes which is moved in and out of the electric arc furnace. EAF has both AC and DC models. The operation of EAF can be explained with various stages of arc processes such as the melting and refining. In the first stage the electrode is pushed in and out of the furnace by means of an external control stabilizing the arc. During this processes a momentary short circuit is experienced at the secondary side of the arc furnace transformer. High fluctuation in current is experienced when the arcing occurs. These high fluctuations in the current causes flicker in the voltage.

The electric arc furnace is modelled as a current controlled time varying nonlinear resistance using MATLAB [1]. MATLAB Embedded program takes in two inputs, electric arc furnace current and the derivative of electric arc furnace current to the function giving a time varying non linear resistance as output. The MATLAB embedded program function block is interconnected to the grid by a current controlled source. In real time electric arc furnace is modelled as a dynamic model. The voltage current characteristic is shown in fig. 1. [1] Sinusoidal variation is assumed for the time varying nonlinear resistance.

$$R_{arc}(t) = R_{arc}(1 + m_d \sin(wt)) \quad (1)$$

Where R_{arc} is the arc resistance.
m_d is the modulation coefficient
w is the flicker frequency

$$R_s; for\ 0 \le |i| < i_g and\ \frac{d|i(t)|}{dt} > 0 \quad (2)$$

$$R_{arc} = \frac{V_d + (V_g - V_d)e^{\frac{-(|i|<i_g)}{t1}}}{|i|}; \quad (3)$$

$$for\ |i| \ge i_g and\ \frac{d|i(t)|}{dt} > 0$$

$$R_{arc} = \frac{V_t + (V_g - V_t)e^{\frac{-|i|}{t2}}}{(|i| + i_g)}; \ for \frac{d|i(t)|}{dt} < 0 \quad (4)$$

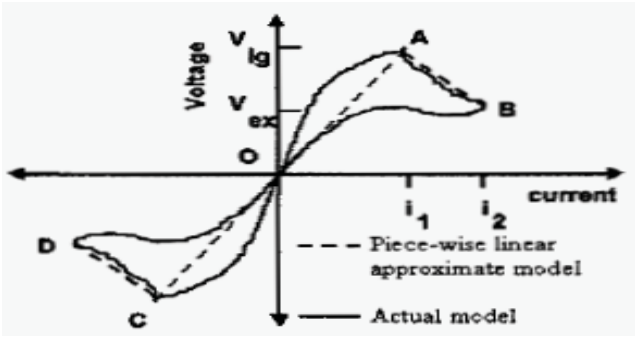

Fig. 2. V-I characteristics of arc

Where

$$V_g = 1.15 * V_d \quad (5)$$

$$i_g = \frac{V_g}{R_s} \quad (6)$$

$$V_t = \frac{(I_{max} + i_g)}{I_{max}} * V_d \quad (7)$$

R_s : Slag resistance
V_g : Arc voltage
i_g : Arc current
t_1 : Time constant during melting process
t_2 : Time constant during arc extinction process

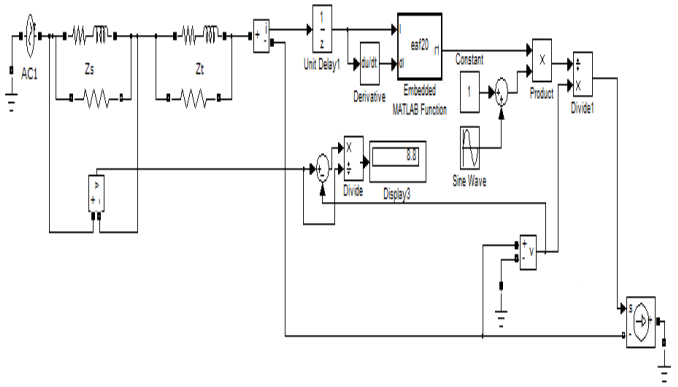

Fig. 3. Simulink model of Single phase EAF model

3. CONTROL ALGORITHM

The D-STATCOM is connected at the point of common coupling and it is driven by Icos□ control algorithm. A simple method for achieving power factor correction and reduction of total harmonic distortion has prompted the proposal of Icos□

control algorithm [2]. The Icos□ is a simple and easy to implement. This algorithm is based on fundamental component of real part of load current .The current measured at the load side and voltage measured at the source side is given as input of controller. When load current passed through a second order low pass filter obtains fundamental load current with a phase shift of 90^0 using bi-quad filter. Unit amplitude source voltage is given to the 'detect fall negative block' which detects the zero crossing instant of the source voltage. Both the above mentioned current and voltage is moved as inputs to the sample and hold circuit. The magnitude of | Icos□| is received as output from the sample and hold circuit which is multiplied with the unit amplitude voltage to produce the desired source reference current at each phase. The desired source reference current is subtracted from the load current to obtain the reference compensation current. While generating compensation current, DC link voltage at the D-STATCOM side is balanced with help of pi controller which is added to the reference compensation current.

For a balanced source, the instantaneous voltages can be specified with a phase difference of 120^0. Equations for phase 'a' are explained below.

e_a =source voltage for phase a.
i_{la}= load current for phase a.
□$_a$ = phase angle of fundamental current in phase a.
$i_{la1}, i_{lb1}, i_{lc1}$= fundamental current amplitude for phase a,b,c.
U_a = unit amplitude of source voltage of phase a.
i_a= magnitude of desired current.
i_{da}=desired current
i_{ca} =compensation current
e_{dc}= dc link voltage at D-STATCOM terminal
e_{dcref}=dc reference voltage

$$e_a = E_m sin\omega t \quad (8)$$

$$|R_e(i_{la1})| = |i_{la}| * cos\phi_a \quad (9)$$

$$U_a = 1.sin\omega t \quad (10)$$

$$|i_a| = \frac{|R_e(i_{la1})|+|R_e(i_{lb1})|+R_e(i_{lc1})|}{3} \quad (11)$$

Error at the nth sampling instant

$$error(n) = e_{dcref} - e_{dc}(n) \quad (12)$$

Error is fed to PI controller to generate i_{caerr}.

$$i_{caerr}(n) = \{ i_{caerr}(n-1) + k_p\,(error(n) - error(n-1) + ki(errorn)\} \quad (13)$$

$$i_{ea} = i_{caerr} + |i_a| \quad (14)$$

$$i_{da} = |i_{ea}| * sin\omega t \quad (15)$$

$$i_{ca} = i_{la} - i_{da} \quad (16)$$

i_{ca} Current is passed to the hysteresis controller to generate pulses for D-STATCOM.

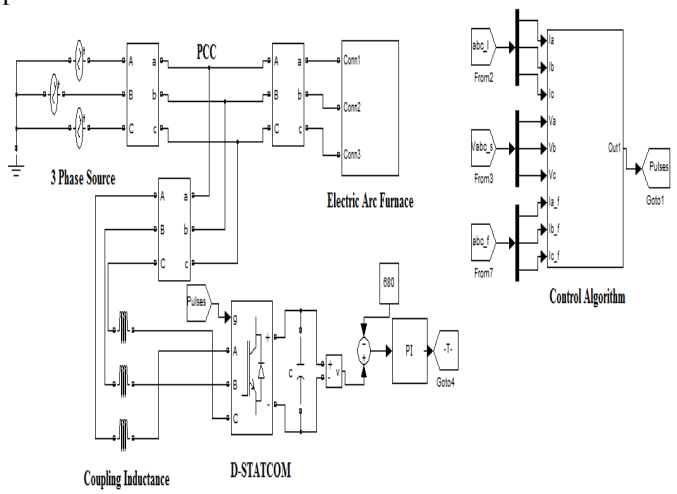

Fig. 4. Simulink model of three phase system supplying Electric Arc Furnace load with D-STATCOM

The electric arc furnace was designed to 30 MW which is connected to the three phase electric grid.The D-STATCOM and its control algorthim were modeled and developed using MATLAB which was presented in Fig.4. The system was designed with simulation parameters shown in Table.1.

Table 1. Simulation Parameters

V_{source}	500V
F	50Hz
Zs	0.000528+j0.00468Ω
Zt	0.0003366+j0.00322Ω
Rs	0.05Ω
Vg	350.75V
Imax	100KA
t1	0.01sec
t2	0.01sec
DC link voltage	680V
DC link capacitor	500000μf
Coupling Inductance	8mH

4. IMULATION RESULTS

The described system was simulated and the results have been analyzed. The fig. 5 depicts the arc furnace load voltage waveform at source side. From fig.5, it was clear that, flickering has been experienced when the electric arc furnace was connected at the load side. The percentage of flickering in

the voltage without connecting D-STATCOM was found to be 8.8%.

The fig.6 shows the arc resistance waveform of arc furnace. Fig.7 depicts the arc current wave- form which has the average magnitude of 60kA.

The fig.8 shows the source voltage waveform when the D-STATCOM was connected to the network at the point of common coupling. From fig.8, it is clear that the source voltage wave is a pure sinusodial without flickering effect.

The arc furnace load current THD analysis has been shown in fig. 9 which contains 20.91% of harmonics before compensation using D-STATCOM. From fig 10, it can be observed that the THD analysis of arc furnace load current after compensation has reduced to 1.69%.

After compensation the source voltage and source current waveform has been depicted in fig 11 which shows that the voltage and current were in-phase with each other .This was evident for power factor correction using D-STATCOM.

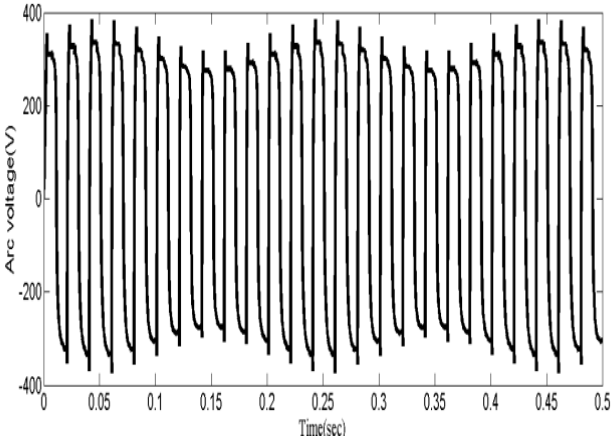

Fig. 5. Arc voltage before compensation

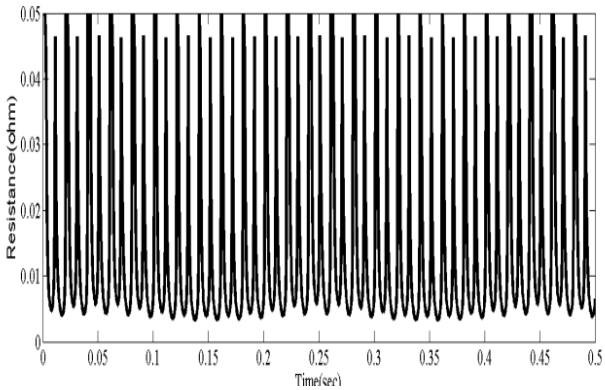

Fig. 6. Arc resistance

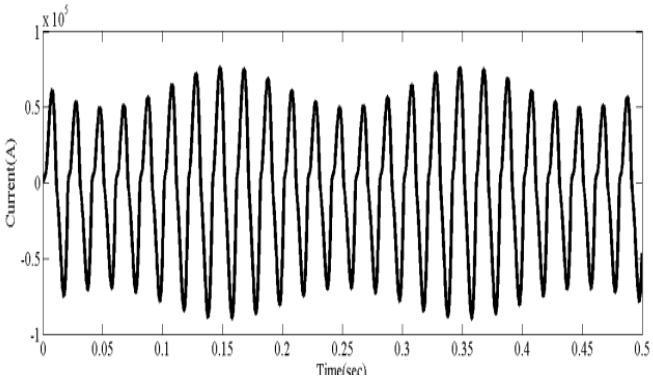

Fig. 7. Arc current

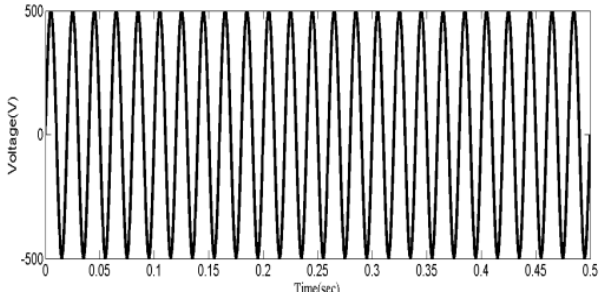

Fig. 8. Source voltage after compensation

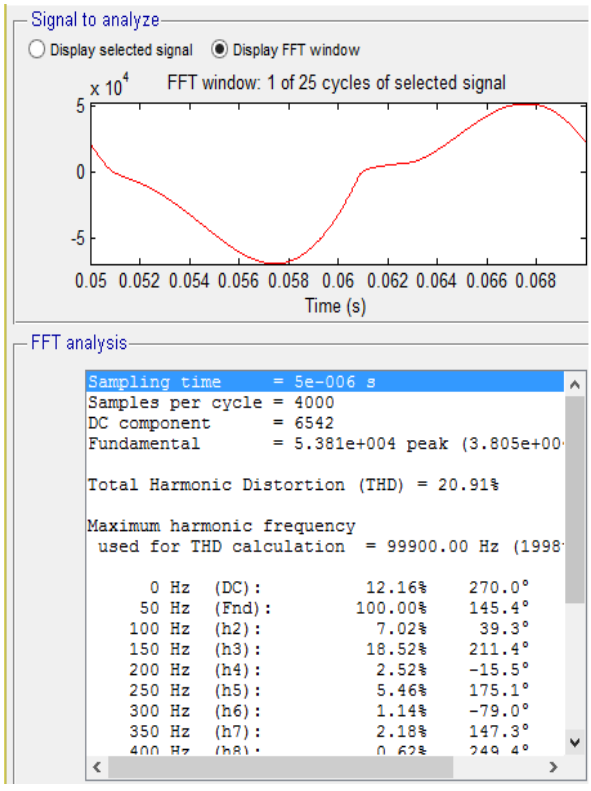

Fig. 9. THD of current before compensation

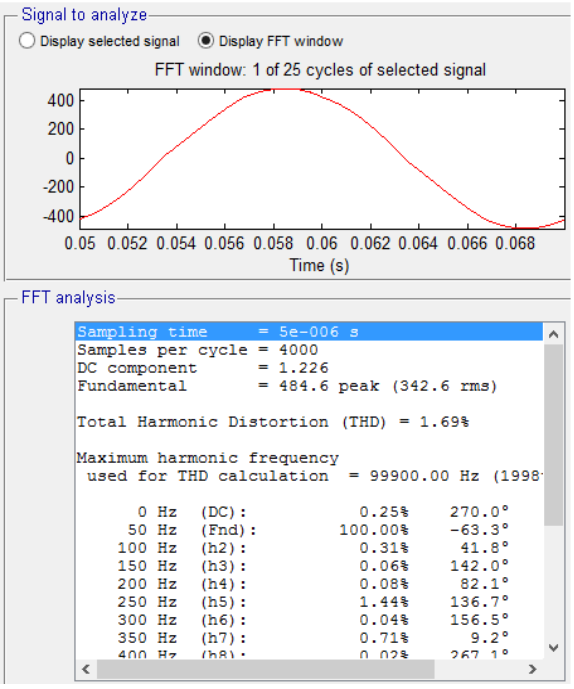

Fig. 10. THD of current after compensation

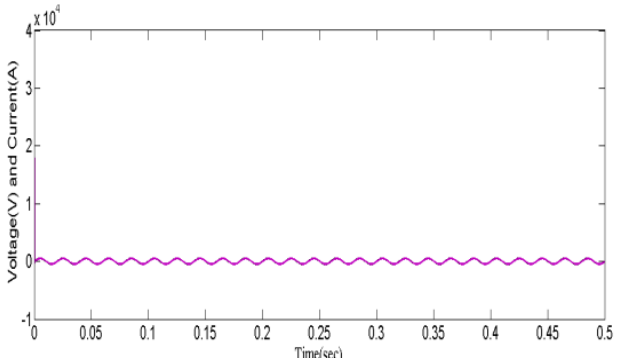

Fig. 11. Source voltage and current

5. CONCLUSION

This paper presents the electric arc furnace model in time domain analysis which was modelled using matlab/simulink and the major power quality issues caused by electric furnace has been studied.The D-STATCOM was used as voltage source inverter which mitigates the power quality issue of voltage flicker created by electric arc furnace. The D-STATCOM control was achieved using Icos□ control algorithm which has been implemented with few modifications to make the controller more effective. From the simulation results, voltage flicker and THD on current were reduced and the power factor correction for arc furnace load was obtained closer to unity.

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