ISSN (Online) 2278-1021
ISSN (Print) 2319-5940

IJARCCE

International Journal of Advanced Research in Computer and Communication Engineering

NCRICT-2017

Ahalia School of Engineering and Technology

Vol. 6, Special Issue 4, March 2017

Harmonic Mitigation using D-STATCOM for Electric ARC Furnace

M. Kombu Selvi[1], P. MahaLakshmi[2], M. Muniya Rajeshwari[3]

UG Scholar, St. Mother Theresa Engineering College, Vagaikulam, Thoothukudi[1,2,3]

Abstract: Arc furnaces are used in industries for induction heating and welding. Due to the rapid growth of non - linear loads, such as power electronic control equipments and Electric arc furnace (EAF) power quality problems such as harmonics and voltage flicker are introduced in the power system. It occurs because of the time-varying and non-linear behaviour of the electric arc furnace operation. Hence an Electric arc furnace model is needed to analyze the power quality. In this paper, a time domain model called hyperbolic model for electric arc furnace is analyzed using MATLAB. The model is used to study its behaviour on the power system using MATLAB. To improve the power quality D-STATCOM is proposed, in which the control strategies used are Direct, Indirect control and Hysteresis controller. Direct control technique uses P-Q theory in which transformation is based on orthogonal reference frame. Indirect control technique uses d-q theory in which transformation is based on synchronous reference frame. Hysteresis controller uses Hysteresis Bandwidth to produce the switching signals.

Keywords: Control strategies. D-statcom, MATLAB/SIMULINK.

INTRODUCTION

SOURCES OF HARMONICS:

Sources of harmonics has two type

1.Harmonics Sources from Commercial Load
2.Harmonics sources from Industrial load

Harmonic Sources from Commercial Loads

Commercial facilities such as office complexes, department stores, hospitals, and Internet data centers are dominated with high-efficiency fluorescent lighting with electronic ballasts, adjustable-speed drives for the heating, ventilation, and air conditioning (HVAC) loads, elevator drives, and sensitive electronic equipment supplied by single-phase switch-mode power supplies

1.1 Single-Phase Power Supplies

Electronic power converter loads with their capacity for producing harmonic currents now constitute the most important class of nonlinear loads in the power system. Advances in semiconductor device technology have fueled a revolution in power electronics over the past decade, and there is every indication that this trend will continue.

1.2 Fluorescent Lighting

Lighting typically accounts for 40 to 60 percent of a commercial building load. Fluorescent lights are discharge lamps; thus they require a ballast to provide a high initial voltage to initiate the discharge for the electric current to flow between two electrodes in the fluorescent tube. Once the discharge is established, the voltage decreases as the arc current increases

1.3 Adjustable-Speed Drives For HVAC and Elevators

Common applications of adjustable-speed drives (ASDs) in commercial loads can be found in elevator motors and in pumps and fans in HVAC systems. An ASD consists of an electronic power converter that converts ac voltage and frequency into variable voltage and frequency. T

II. HARMONIC SOURCES FROM INDUSTRIAL LOADS

2.1 Impact of Operating Condition

The harmonic current distortion in adjustable-speed drives is not constant. The waveform changes significantly for different speed and torque values. two operating conditions for a PWM adjustable speed drive. While the waveform at 42 percent speed is much more distorted proportionately, the drive injects considerably higher magnitude harmonic currents at rated speed. The bar chart shows the amount of current injected

2.2 Arcing Devices

This category includes arc furnaces, arc welders, and discharge-type lighting (fluorescent, sodium vapour, mercury vapour) with magnetic ballasts. the arc is basically a voltage clamp in series with a reactance that limits current to a reasonable value.

2.3 Saturable Devices

Equipment in this category includes transformers and other electromagnetic devices with a steel core, including motors. Harmonics are generated due to the nonlinear magnetizing characteristics of the steel.

ISSN (Online) 2278-1021
ISSN (Print) 2319-5940

IJARCCE

International Journal of Advanced Research in Computer and Communication Engineering

NCRICT-2017

Ahalia School of Engineering and Technology

Vol. 6, Special Issue 4, March 2017

Usage of EAF results in voltage fluctuation which leads efficiency, interference in protection systems and grid.

Advantages of D-STATCOM:
1. Flexible voltage control
2. Improvement in Power factor
3. Harmonic contents can be reduced
4. Fast response

III. ARC FURNACES

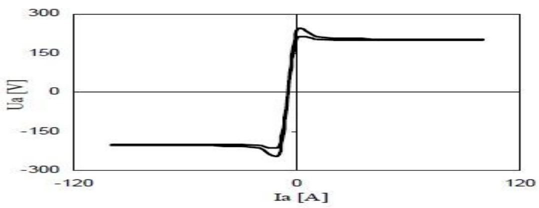
Its structure resembles to that of two electrodes with a charge placed inside a heating chamber. When the air-gap between the electrodes is subjected to maximum voltage stress, contacts between them ionized to make the flow of current which results in the form of arc. Since the electrical arc is a nonlinear and time varying phenomenon, description of its behaviour in the time domain is easier than in the frequency domain.

There are different numbers of models for EAF such as
1. Harmonic voltage source model
2. Time domain model
3. Frequency model

Time domain model is proposed here. Time domain models can be classified into V-I Characteristic (VIC), and Equivalent Circuit Methods (ECM). Based on the V-I characteristic of arc furnace, which is derived from the relationship between arc voltage and arc current VIC method is used. This method is widely used for modelling the static and the dynamic operation of EAF. This paper proposes a new model named as Hyperbolic model of EAF in the time domain. The proposed model of EAF is explained with a good approximation without need of the initial conditions of the EAF[1].
Also, it is used to describe different operating situation of the EAF and power system. The accuracy of the load model is increased by establishing random and sinusoidal noises to have a new model. An EAF flicker model based on a hyperbolic model is simulated in the first part. In the second part, the DSTATCOM with direct and indirect control is simulated.

Hyperbolic Model:
Basically there are two models such as Static and Dynamic model. Simulation of arc is the important issue in the modelling of EAF. There are several methods used to describe the electric arc. Here, Hyperbolic model of EAF is discussed and simulated in the first part [4] and D-statcom with indirect,direct,Hysteresis control is proposed and simulated.

The below figure (Fig2.1) represents the VI characteristics of EAF and actual linear piecewise model [1, 2, 3 and 5]. But the Hyperbolic model discussed is a non-linear one and is modelled according to equation (2.1) & (2.2).



VI Characetistics of EAF – Fig3.1

For static model the VIC of the EAF is considered to be in the form of V=V (i) and it can described as: $V(i)=Vat+(C/D)+i$ (3.1)
Where, V - arc voltage, i - arc current per phase. Vat - threshold magnitude. Vat is the magnitude of threshold voltage to which the voltage approaches as current increases. Its value depends on the arc length which is defined by constants C and D which are of arc power and arc current respectively. Dynamic EAF model is required for real time analysis of the effect of the arc. The dynamic arc characteristic is simulated by varying arc conductance. In general, the variation is of random nature. Two types of variation are considered for the study- sinusoidal and random. In order to study the effect of voltage flicker on the system of EAF, Vat is varied sinusoidally and randomly. In this regard Vat is modulated as follows:
The sinusoidal variation is assumed as:

$$Vat(t) = Vat0[1+m.\sin(\omega ft)] \quad (3.2)$$

Where, m is modulation index and ωf is a flicker frequency. For random flicker generation Vat is modulated with a random signal with the mean of zero. Thus Vat is written as:

$$Vat(t)=Vat0[1+m.N(t)] \quad (3.3)$$

where, N(t) is a band limited white noise with zero mean and variance of one.

Problems of EAF:
Due to the usage of EAF, it creates problems as follows:
1. Harmonics
2. Voltage Fluctuations
3. Flickering
4. Low power factor

Hence the other loads connected also gets affected and also the source voltage. Hence EAF is considered to be the main cause of power quality degradation. Therefore we have to find a solution to improve power quality because at the load point production process gets more complicated and requirement of a bigger reliability level will occur.

Hence we have to avoid this by providing energy without interruptions, without harmonic distortion and keeping the voltage in a very narrow margin. The devices which can fulfil these requirements are the Custom Power devices among wihch D-statcom is proposed here.

ISSN (Online) 2278-1021
ISSN (Print) 2319-5940

IJARCCE

International Journal of Advanced Research in Computer and Communication Engineering

NCRICT-2017

Ahalia School of Engineering and Technology

Vol. 6, Special Issue 4, March 2017

EFFECTS OF HARMONICS:

1. Generators

In comparison with utility power supplies, the effects of harmonic voltages and harmonic currents are significantly more pronounced on generators (esp. stand-alone generators used a back-up or those on the ships or used in marine applications) due to their source impedance being typically three to four times that of utility transformers.

2. Transformers

The effect of harmonic currents at harmonic frequencies causes increase in core losses due to increased iron losses (i.e., eddy currents and hysteresis) in transformers. In addition, increased copper losses and stray flux losses result in additional heating, and winding insulation stresses, especially if high levels of dv/dt (i.e., rate of rise of voltage) are present.

3. Induction Motors

Harmonics distortion raises the losses in AC induction motors in a similar way as in transformers and cause increased heating, due to additional copper losses and iron losses (eddy current and hysteresis losses) in the stator winding, rotor circuit and rotor laminations.

These losses are further compounded by skin effect, especially at frequencies above 300 Hz.

4. Other negative effects of harmonics

a) Power factor correction capacitors are generally installed in industrial plants and commercial buildings. Fluorescent lighting used in these facilities also normally has capacitors fitted internally to improve the individual light fitting's own power factor.

b) Power cables carrying harmonic loads act to introduce EMI (electromagnetic interference) in adjacent signal or control cables via conducted and radiated emissions.

c) Any telemetry, protection or other equipment which relies on conventional measurement techniques or the heating effect of current will not operate correctly in the presence of nonlinear loads.

IV. PROPOSED METHOD

IEEE defines Static Synchronous Generators as self-commutated switching power converters supplied from an appropriate electric energy source and operated to produce a set of adjustable multiphase voltages, which may be coupled to an ac power system for the purpose of exchanging independently controllable real and reactive power. D-STATCOM compensates by generating or absorbing reactive power by using power electronic switching converters.

However, in STATCOM systems, the reactive power is determined by the switching converter part and reactive power can be kept constant irrespective of the supply voltage fluctuations. STATCOM systems are used in distribution and transmission systems for different purposes. STATCOMs are used n transmission systems to control reactive power and to supply voltage support to buses. STATCOM

DSTATCOM

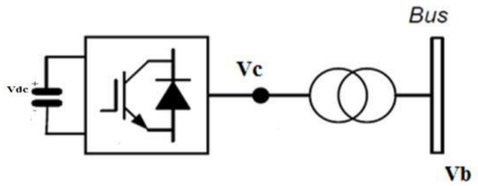
(Distributed static Synchronous compensator) is the proposed model to improve the power quality[2].

Multifunctions preformed by D-statcom are:

Voltage regulation and compensation of reactive power;

Correction of power factor and

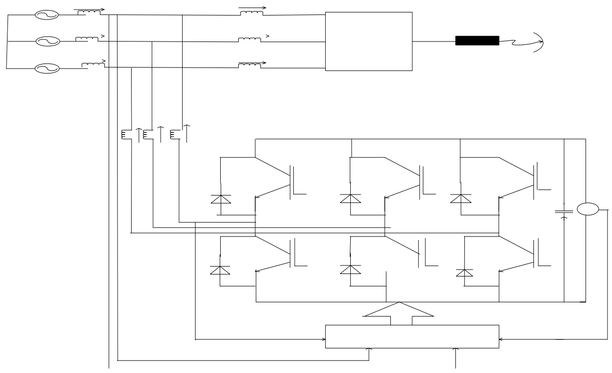
Elimination of current harmonics. Here, such a device is employed to provide continuous voltage regulation using an indirectly controlled converter[3]. Single diagram of D-statcom is shown in Fig3.1



Single diagram of D-statcom - Fig3.1

Description of the proposed system:

The main circuit of the DSTATCOM system with Arc Furnace load connected to 3-phase, 3-wire distribution system together with the measurements needed by the control system is shown in Fig.(3.2). The Arc Furnace is modelled as a Hyperbolic model. Under operation without D-statcom, EAF results in fluctuating load currents and voltage fluctuation at PCC. To compensate the fluctuating load currents and to mitigate it, algorithms based upon Indirect control (d-q theory), Direct control (P-Q theory) [5], Hysteresis Controller is proposed.



Main Circuit of DSTATCOM with EAF load Fig. (3.2)

Compensation strategies: A.Direct control of EAF using D-statcom: Instantaneous reactive power theory (P-Q theory):

P-Q theory transforms the three phase system of voltages and currents from phase co-ordinates to 0-α-

β coordinates by means of Clark-Concordia transformation, which is represented by the following matrix equation (3.1) and (3.2).

$V0$

ISSN (Online) 2278-1021
ISSN (Print) 2319-5940

IJARCCE

International Journal of Advanced Research in Computer and Communication Engineering

NCRICT-2017

Ahalia School of Engineering and Technology

Vol. 6, Special Issue 4, March 2017

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (3.1)$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (3.2)$$

In the case of three-phase three-wire systems Vo=0 and io =0. In the new co-ordinate system using stationary orthogonal reference frame theory, the instantaneous real and imaginary powers are expressed by the following matrix equation (3.3) & (3.4), which finally allows expression of currents as a function of the power quantities.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (3.3)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (3.4)$$

The control algorithm based on pq theory compensation is outlined here under. The three phase source voltages [Vsa,Vsb,Vsc] are transformed to stationary orthogonal reference frame variables [Vsα,Vsβ]. Reference currents (iα*, iβ *) are evaluated based on equation (3.4) by using Vsα,Vsβ and pref and qref. The instantaneous active power (pref) for maintaining dc link voltage constant is obtained by comparing actual dc link voltage with a preset value and by processing the error voltage through a PI controller.

The instantaneous reactive power reference (qref) is set to zero. With the evaluated reference currents in orthogonal frame, the actual source currents in the same frame are compared and processed through PI controllers and reference voltages are obtained in stationary frame which are transformed to abc frame using Clark's reverse transformation for generating gate pulses for the IGBT based voltage source inverter.

B. Indirect control of EAF using D-Statcom: Synchronous reference frame theory: (d-qtheory)

The synchronous reference theory is based on the transformation of the stationary reference frame three phase variables (a,b,c) to synchronous reference frame variables(d,q,o) whose direct (d)and quadrature (q) axes rotate in space at the synchronous speed ωe. ωe is the angular electrical speed of the rotating magnetic field of the three phase supply, given by ωe =2πfs , where fs is the frequency of the supply.

If θ is the transformation angle, then the current transformation from abc to d-q-0 frame is defined as in the following equations:

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (3.5)$$

C. Hysteresis Controller:

Using this control, rapid switching of each switch is done by using the comparison of the measurement of D-Statcom current with the reference current. Basic principle behind this is to produce the switching signals by using the comparison of error signal with the fixed value of hysteresis bandwidth.

Advantages:
- Simple Technique
- Robust
- Fast Response
- Good stability

Generation of Switching signals using Hysteresis controller:

Reference current signals are generated by using d-q transformation. Here the three phase current variables are transformed into synchronous reference frame to synchronize the ac main voltage with the reference frame variables. The above transformation is done by converting the three phase supply variables into d-q variable by using the matrix equation (3.5)

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (3.5)$$

2Reference currents produced by transformation are compared with the D-Statcom current which gives the output as error signal. This signal is compared with the hysteresis bandwidth [6] to generate the switching signals. Tolerable bandwidth is taken as + 2% of reference value of current. Upper switch of that leg will be turned ON, but the lower switches will be in OFF condition when the value of the phase current exceeds theupper bandwidth. Reverse operation will take place when the phase current value falls below the lower bandwidth.

V. SIMULATION RESULTS

This deals about the simulation results for Fig 4.1 shows the output of source output voltage and current with Hysteresis controller of D-statcom.

Fig 4.2 shows the THD output of Hysteresis control using D-statcom.

Fig 4.3 and Fig.4.4 shows the instantaneous active and reactive power with Hysteresis controller of d-statcom.

ISSN (Online) 2278-1021
ISSN (Print) 2319-5940

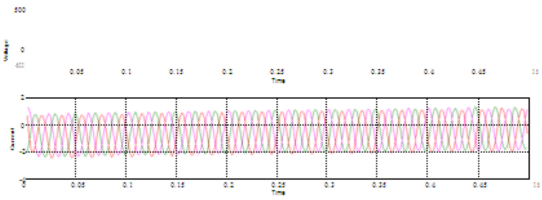
IJARCCE

International Journal of Advanced Research in Computer and Communication Engineering

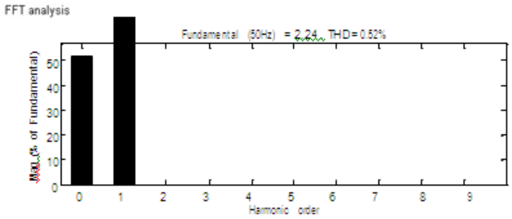
NCRICT-2017

Ahalia School of Engineering and Technology

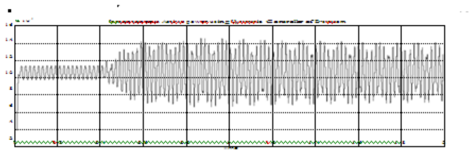
Vol. 6, Special Issue 4, March 2017



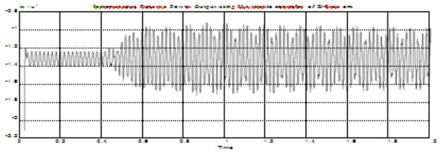
3 Phase Source Output With Hysteresis Controller Of D-Statcom- Fig 4.1



Thd Output With Hysteresis Controller Of D-Statcom - Fig 4.2



Instantaneous Active Power Output With Hysteresis Controller Of D-Statcom –Fig 4.3



Instantaneous Reactive Power Output with Hysteresis Controller Of D-Statcom –Fig 4.4

VI. CONCLUSION

Electric Arc furnace used in industries is concluded as one of the major power quality degradation.
Compensation technique provided with the Hysteresis controller of D-Statcom is discussed here. In this, D-STATCOM controller is derived by using orthogonal reference frame theory, synchronous reference frame theory and Hysteresis controller. The model is simulated using Matlab simulink and D-STATCOM controller's performance is evaluated using Hysteresis control for Total Harmonic Distortion. All the controllers are proven to be effective with improved response. From the results obtained for Total Harmonic Distortion, Hysteresis control of D-statcom is the best one. Future scope is to simulate the D-statcom with the different control technique to have further reduction in harmonics for the new model of EAF.

REFERENCES

[1]. K.Anuradha, B.P.Muni "Modeling of Electric Arc Furnace & Control Algorithms for voltage flicker mitigation using DSTATCOM", IEEE 2009
[2]. Y. Najafi Sarem, M. H. Amrollahi, M. Babanejad, Sh. Mounesirad & M. Abbasi Layegh and Davood habibinia, " Electric Arc Furnace Power Modeling for STATCOM Controller Application", International Symposium on Power Electronics,Electrical Drives, Automation and Motion 2010
[3]. A. Alzate, A. Escobar, J. J. Marulanda, "Application of a D-STATCOM to Mitigate Arc Furnaces Power Quality Problems", I EEE Trondheim Power Tech, 2011 .
[4]. C. Bhonsle, R.B. Kelkar, "Simulation of Electric Arc Furnace Characteristics for Voltage Flicker study using MATLAB", International Conference on Recent Advancements in Electrical, Electronics and Control Engineering, 2011
[5]. M .NagaRaju, Dr .K .Anuradha, Dr. G. R. K. Murthy, A.Santha Kumari," Voltage flicker mitigation by DSTATCOM for voltage source Arc furnace model" IEEE 2011
[6]. Genzhong, "Combined hysteresis current-controlled PWM inverter and robust control for a permanent-magnet synchronous motor", IEEE 2011
[7]. NareshK.Kumari, "Comparitive Evaluation of D-statcom Control Algorithms for Load compensation",IEEE 2012 voltage and Current Output of EAF