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Comparative Analysis of Hysteresis and Sliding Mode Controllers for Effective Reduction of Harmonics in Electric Arc Furnace Using APF

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ABSTRACT:The increased use of the non-linear loads in the distribution system affects the power quality. Some of the major harmonics generating non-linear loads are Induction motor, Electric Arc Furnace (EAF) etc. To overcome from this harmonic problem, the paper presents an Active Power Filter (APF) concept which compensates the systems non-linearity. The work is mainly concentrated on the comparison of different control techniques used in the APF model such as hysteresis controller and the sliding mode controller for a three-phase system having EAF load. The performance analysis of the three-phase system having EAF load has been simulated and analysed for THD reduction with different controllers using MATLAB/SIMULINK software package.

KEYWORDS: Electric Arc Furnace (EAF); Active Power Filter (APF); Hysteresis Controller; sliding mode controller;

I. INTRODUCTION

The non-linear load causes the distortion in the voltage and current waveforms and also increases the reactive power in the distribution system. Due to the use of non-linear loads the power quality of the system gets affected. EAF is considered as the major harmonics producing non-linear load. APF concept gives a best solution to overcome from this harmonics problem. Basically APF consists of a Voltage Source Inverter (VSI) and a dc capacitor is connected parallel to it. There are various control strategies defined in the APF concept, out of which the hysteresis controller and sliding mode controller are mostly used due to there high efficiency. In the hysteresis control technique the reference current band is generated and the actual value of the current is made to pass within this band which generates the PWM pulses required for the inverter switches to operate. The sliding mode controller is considered as the non-linear method which tolerates the system dynamics by applying a discontinuous control signal that forces the system to slide along a cross-section of the system usual behaviour. The dynamic behaviour of the system can be directly changed by the choice of the switching function. The main feature of this sliding mode controller is its robustness, fastness and stability under large load variations. The non-linear and time-varying behaviour of the EAF causes the voltage flickers and harmonics in the system. An EAF model is developed using MATLAB/SIMULINK for the reduction of harmonics. The different control techniques are introduced and the results are compared.

II. WORKING PRINCIPLE OF THE PROPOSED SYSTEM

The proposed block diagram is given in Figure 1. The harmonics injected into the supply system can be reduced using shunt APF. The shunt APF will inoculate compensating current at point of coupling which works on the changes in

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load current with the supply system. The current from the source side is i_s, load current is i_l and filter current is i_f. The supply side current is given by the equation (1),

$$\boldsymbol{i_s = i_f + i_l} \quad (1)$$

The supply side current i_s is made sinusoidal by toting the current from the filter i_f.

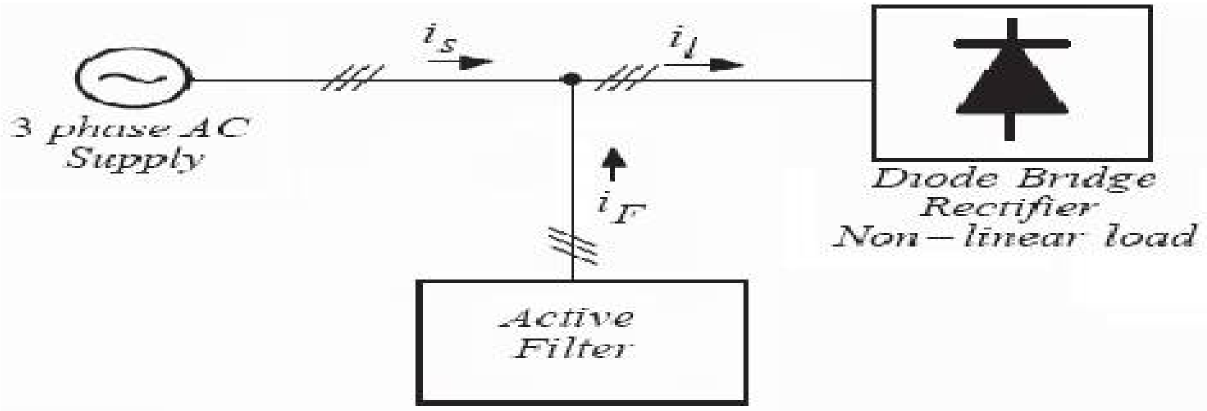

Figure 1**:** Basic block diagram of the proposed system

III. **DESIGN OF SHUNT APF**

The shunt APF is usually connected in parallel to the main system. The harmonic current distortion using shunt APF is as given in figure 2. It comprises of VSI and a dc capacitor parallel to it. The dc capacitor used in acts as the supply for inverter.

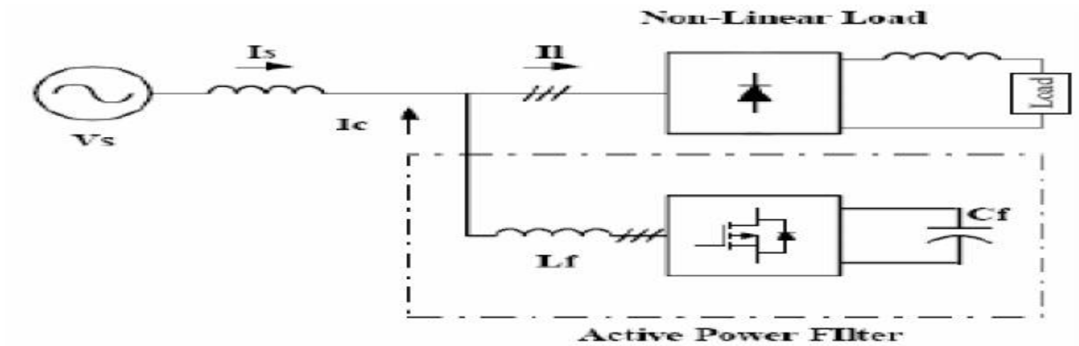

Figure 2: Schematic diagram of shunt APF

There are various control techniques used in the shunt APF's configuration namely, hysteresis control strategy and sliding mode control strategy.

a. HYSTERESIS CONTROLLER

The controller is used for the generation of the gating pulses for the inverter based on the reference current band. Figure 3 represents the basic principle of HBC.

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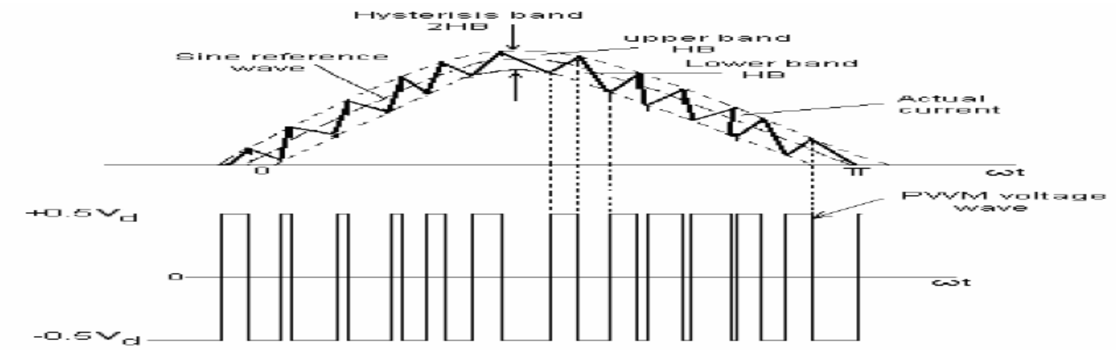

Figure 3: Basic principle of HBC

b. SLIDING MODE CONTROLLER

It is a variable structure system which has ability to switch from one continuous structure to the other. The sliding mode controller senses the dc bus voltage and the reference voltage based on the error output the controller generates the reference current which is then utilized for the generation of firing pulses. Figure 4 shows the block diagram of sliding mode controller.

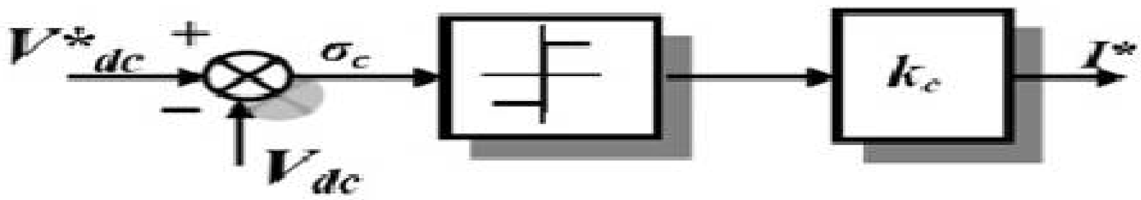

Figure 4: Block diagram of sliding mode controller

IV. ELECTRIC ARC FURNACE MODEL

The structure of EAF bears a resemblance of two electrodes positive and negative having a charge which is placed inside the chamber. There is air-gap between these two electrodes and when this air-gap is subjected to the supreme voltage stress the contacts get ionized to make the current flow, hence arc is struck between the 2 electrodes.

The static and dynamic operation of EAF is modelled using V-I characteristics. The V-I characteristics of EAF is derived from the relation between arc voltage and arc current. It is given by equation (2),

$$\boldsymbol{v(i) = v_{at} + [C/[D + abs(i)]]} \quad (2)$$

Where $v(i)$ is the arc voltage, i is the arc current per phase,
v_{at} is the threshold voltage, C is the arc power and D is the arc current.

For sinusoidal variation of threshold voltage (v_{at}), the effect of voltage flickers on the system is given the equation (3),

$$\boldsymbol{v_{at}(t) = v_{at0}[1 + m sin\omega_f(t)]} \quad (3)$$

Where m is the modulation index and $\omega_f(t)$ is the flicker frequency.

The modulation index (m) has the linear relationship with the flicker voltage. The system non-linearity decreases with the increases in the modulation index (m).

The overall EAF without APF has been shown in Figure 5.

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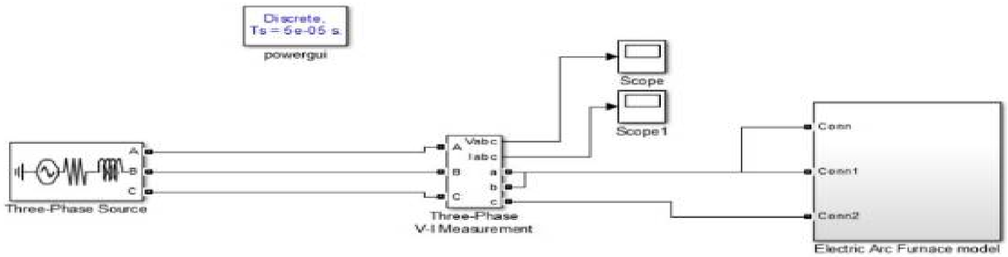

Figure 5: MATLAB/SIMULINK model of EAF without APF

The subsystem block of EAF model is given in figure 6. It has been modelled using the equations (1) and (2).

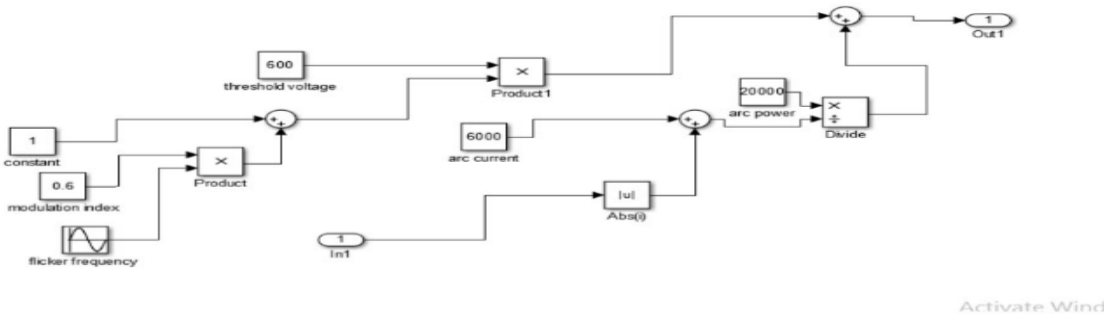

Figure 6: subsystem block of EAF model

The complete EAF model with APF using hysteresis controller for the gate pulse generation is as shown in figure 7.

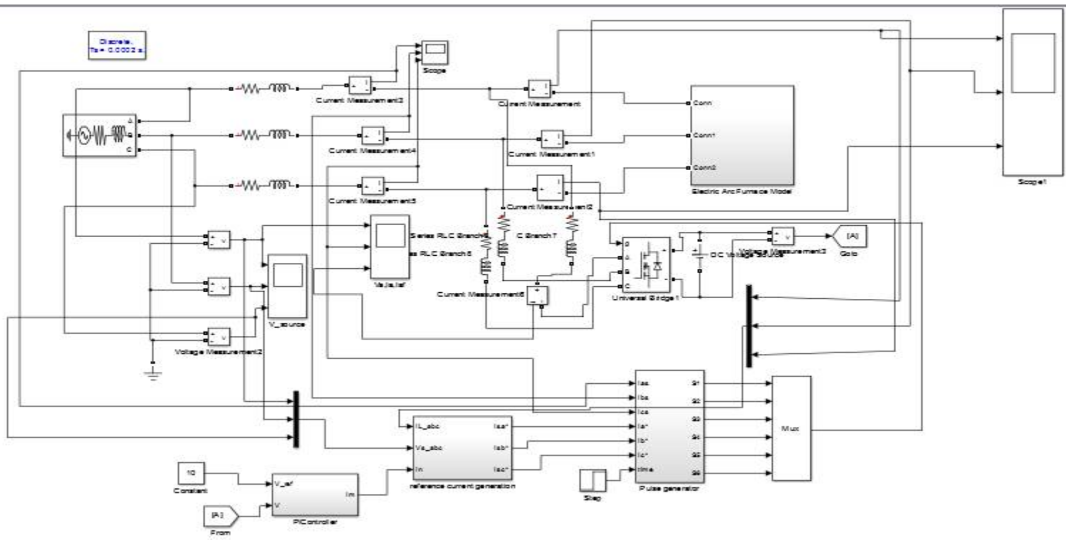

Figure 7: MATLAB/SIMULINK model of EAF with APF using hysteresis controller

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The MATLAB/SIMULINK model of EAF model with APF using sliding mode controller is given by figure 8.

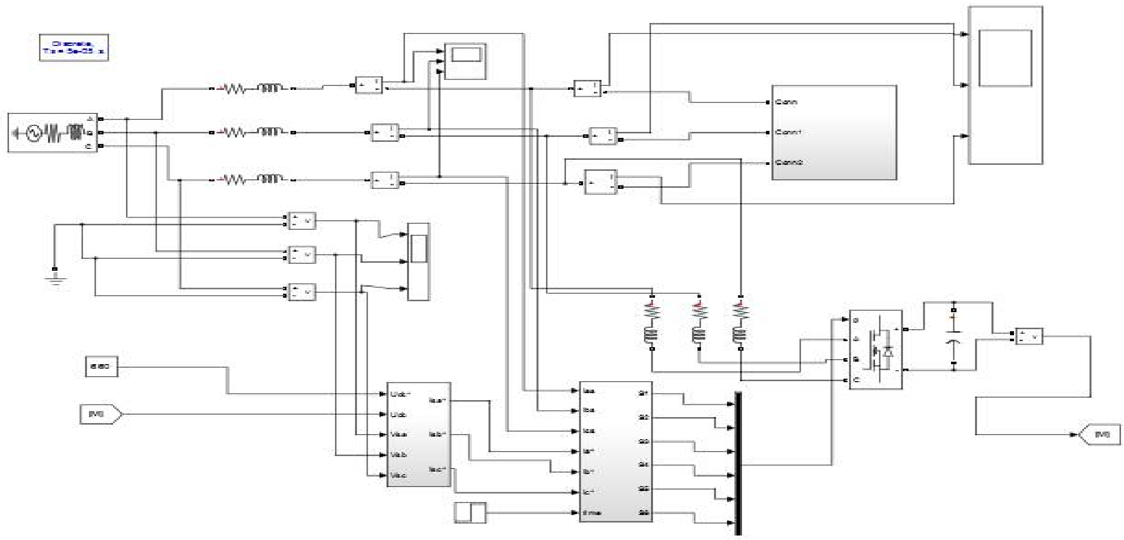

Figure 8: MATLAB/SIMULINK model of EAF with APF using sliding mode controller

V. SIMULATION RESULTS

The EAF model with APF using two different controllers is simulated using MATLAB/SIMULINK. From the results the THD of hysteresis controller is found to be more compared to the sliding mode controller. Figure 9 shows the THD of the EAF model without any filter. Figure 10 and 11 gives the THD of EAF model with APF using hysteresis controller and sliding mode controller respectively. It is found that without any filter the THD (i_s) is 34% and for hysteresis controller and sliding mode controller it is found to be 9% and 2% respectively.

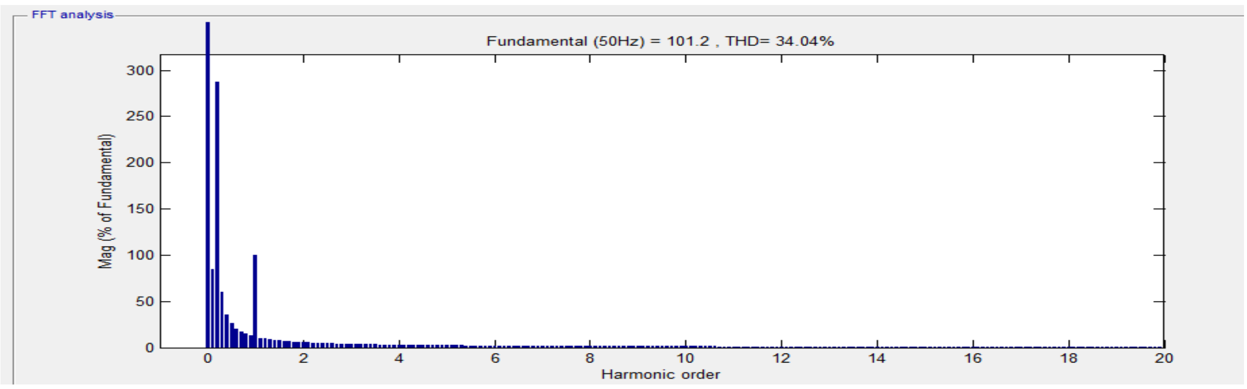

Figure 9: THD(i_s)of EAF model without filter

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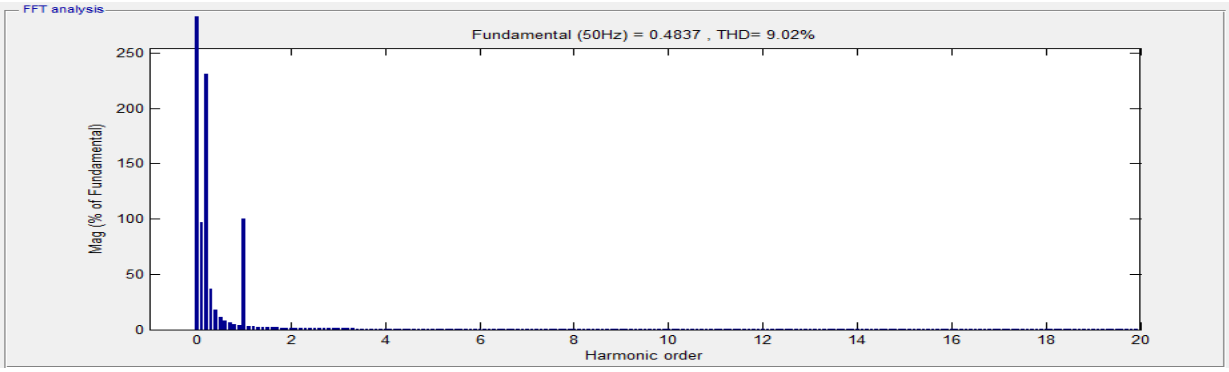

Figure 10: THD($\boldsymbol{i_s}$) of EAF model with APF using hysteresis controller

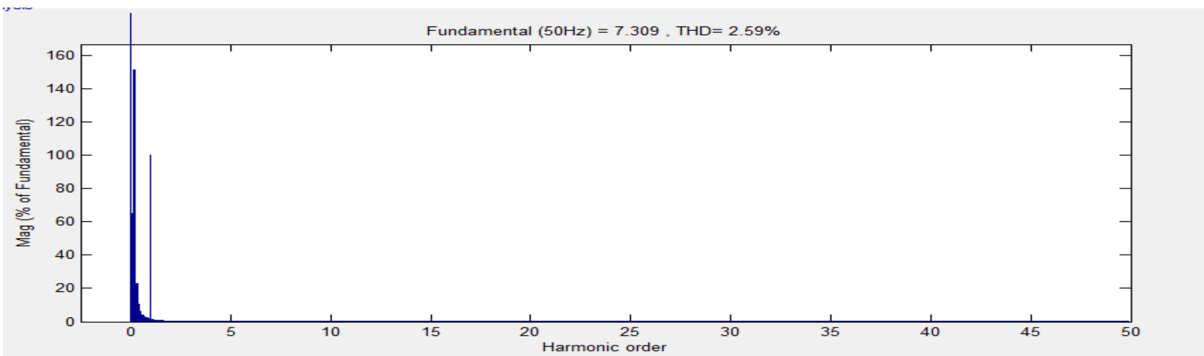

Figure 11: THD($\boldsymbol{i_s}$) of EAF with APF using sliding mode controller

The table 1 gives the comparison of THD (%) of source current on three-phase system having different controllers.

Table 1: Comparison of THD (%)

Comparative Study	(%)THD of source current Three-phase system with EAF load
Without filter	34
With filter using Hysteresis controller	9
With filter using Sliding Mode controller	2

VI. Conclusion and Future Work

In this paper, a three phase EAF model is designed and analysed using MATLAB simulation. With the proposed EAF model, it is found that the harmonic contents in the system consisting of EAF as non-linear load can be efficiently reduced. The comparison of EAF model without and with filter using different controllers is analysed using simulation studies. It is found that the system without any APF has considerable harmonics related to the model with APF. The THD performance of the system is found to be effectively improved using the sliding mode controller has compared to the hysteresis controller.

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