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Fuzzy Controlled Hybrid Active DC Filter (HADF) for Six Pulse HVDC Converter

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Abstract:-Power Converters occupy a special space in the power industry which are used for conversion of power from bi directional to unidirectional and vice versa. Converters are classified as six pulse, twelve pulse, twenty four pulse and so on based on number of switching devices used which require same number of gate pulses. These converters introduce harmonics into power system during the conversion process, which can be handled by filters. In the proposed work a fuzzy controlled Hybrid Active DC Filter (HADF) consisting of 80 MVAR shunt passive filters and shunt active dc power filter for six pulse High Voltage Direct Current (HVDC) converter is designed in MATLAB/Simulink environment, hybrid active dc filter mitigated the harmonic and compensated the required reactive power.

Keywords:- *High Voltage DC Transmission, Six Pulse Converter, Passive Filters, Shunt Active DC Power Filter, Fuzzy Logic Controller, MATLAB/Simulink.*

I. INTRODUCTION

Almost all the electronic devices operate on direct current supply, so converters like rectifiers are used for conversion of power from bidirectional to unidirectional. Based on the number gate pulses given to these converters they are classified as six, twelve pulse and so on. During power conversion these converters inject harmonics into the power system affecting its performance and power quality. Six Pulse and Twelve Pulse converters are used for HVDC transmission for converting three phase ac power to dc power. As HVDC transmission is more economical than High Voltage Alternating Current (HVAC) for distances above 500kM, HVDC is used for transmission of power because of its many advantages over HVAC [1]. For elimination of harmonics introduced by HVDC Converter a Hybrid Active DC Filter is proposed in this work [2]. Hybrid Active DC Filter can be connected in different topologies based on the requirement [3].

II. SIX PULSE RECTIFIER

A. Proposed System

In the proposed work a fuzzy controlled hybrid active dc filter consisting of 80 MVAR shunt passive filters and 136 MVAR shunt active dc power filter for a six pulse HVDC Converter is designed in MATLAB/Simulink as shown in Fig. 1.

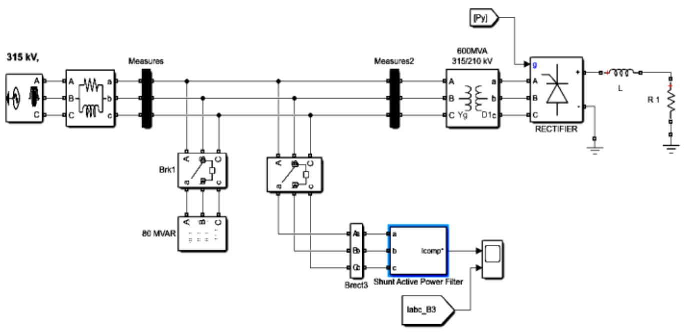

Fig. 1.MATLAB/Simulink Model of Proposed Fuzzy Controlled HADF for Six Pulse HVDC Converter

B. Shunt Passive Filters

The passive filters designed for the system are a Capacitor Bank, 5th Harmonic, 7th Harmonic and 11th Harmonic with total reactive power of 80 MVAR. Design of passive filters was carried out by using following equations [5] as shown in the Fig. 2.

$$X_c = \frac{kV^2}{Q_c} \quad (1)$$

where, X_c: Capacitive Reactance, kV: Voltage in kV
Q_c: Reactive Power

$$X_c = \frac{1}{2\pi fC} \quad (2)$$

$$X_L = \frac{X_C}{h_n^2} \quad (3)$$

$$X_L = 2\pi fL \quad (4)$$

$$X_n = \sqrt{X_L X_C} \quad (5)$$

$$R_n = \frac{X_n}{Q} \quad (6)$$

where,
X_c: Capacitive Reactance, X_L: Inductive Reactance,
C: Capacitance,
f: Frequency, h_n: Order of Harmonic,

L: Inductance, R_n: Resistance, Q: Quality Factor

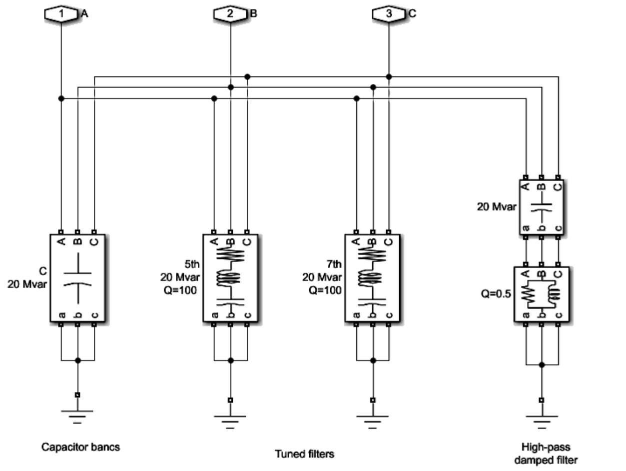

Fig. 2. MATLAB/Simulink Model of 80 MVAR Shunt Passive Filters

C. Shunt Active DC Power Filter

A Shunt Active DC Power is designed in MATLAB/Simulink capable of providing 136 MVAR reactive power with reference voltage of 600kV and dc link capacitance of 70µF which is controlled by the fuzzy logic assisted PI controller as shown in Fig. 3. Shunt Active DC Power Filter consists of a DC Capacitor, Bidirectional Converter and Harmonic Filter [4].

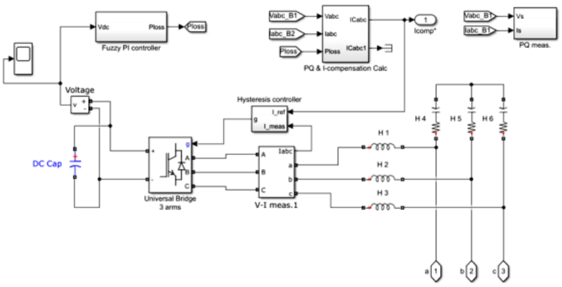

Fig. 3. MATLAB/Simulink Model of Shunt Active DC Power Filter

D. Fuzzy Logic Controller

Fuzzy Logic Controller is designed to assist the PI controller to control the variation between dc link voltage and the reference dc voltage. Fuzzy logic controllers for kp and ki are designed by using the membership functions shown in Fig. 5 and Fig. 7 using the fuzzy rule base shown in the Table 1 and Table 2.

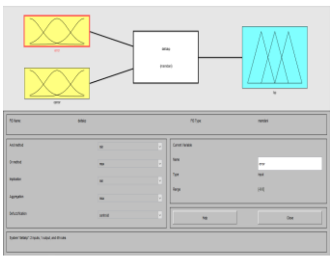

Fig. 4. MATLAB/Simulink Fuzzy Logic Designer of kp

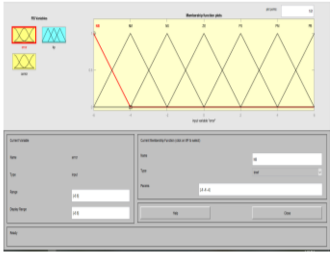

Fig. 5. MATLAB/Simulink Fuzzy Logic Membership Functions of kp

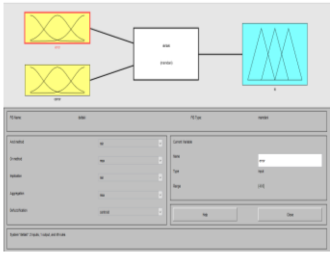

Fig. 6. MATLAB/Simulink Fuzzy Logic Designer of ki

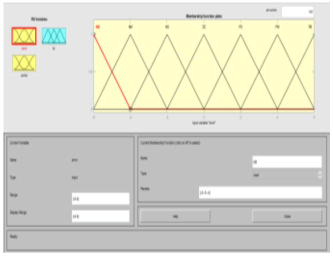

Fig. 7. MATLAB/Simulink Fuzzy Logic Membership Functions of ki

Error (e)	Change of Error (ce) for kp						
	NH	***NM***	***NL***	***ZE***	***PL***	***PM***	***PH***
NH	PH	NH	PH	NH	PH	NH	PH
NM	PH	NM	PH	NM	PH	NM	PH
NL	PM	NL	PM	NL	PM	NL	PM
ZE	PM	ZE	PM	ZE	PM	ZE	PM
PL	PL	PL	PL	PL	PL	PL	PL
PM	ZE	PM	ZE	PM	ZE	PM	ZE
PH	ZE	PH	ZE	PH	ZE	PH	ZE

Table 1:- MATLAB/Simulink Fuzzy Rule Base for Kp

Error (e)	Change of Error (ce) for ki						
	NH	***NM***	***NL***	***ZE***	***PL***	***PM***	***PH***
NH	ZE	ZE	NH	NM	NM	ZE	ZE
NM	ZE	ZE	NM	NM	NL	ZE	ZE
NL	ZE	ZE	NL	NL	ZE	ZE	ZE
ZE	ZE	ZE	NL	NM	PL	ZE	ZE
PL	ZE	ZE	ZE	PL	PL	ZE	ZE
PM	ZE	ZE	NL	PM	PH	ZE	ZE
PH	ZE	ZE	NL	PM	PH	ZE	ZE

Table 2:- MATLAB/Simulink Fuzzy Rule Base for ki

III. SIMULATION

Fuzzy Logic controlled HADF for Six Pulse HVDC Converter designed in MATLAB/Simulink is simulated with the sampling time of 43.4µ Seconds with the system parameters shown in the Table 3

Parameters	Values
Source Voltage (ph-ph)(rms)	315 kV
Frequency	50 Hz
Sampling Time	43.4 µSecs
Source Inductance	62.23 mH
Resistance	13.79 Ω
Transformer	600MVA (315kV/210kV)
Inductance	31.02 mH
DC Link Capacitance	70 µF
DC Voltage	600 kV
Smoothing Inductance	0.5 H
Load Resistance	125 Ω

Table 3:- Design Parameters of Proposed System

The parameters of Shunt Passive Filters designed were shown in the Table 4.

Passive Filters 80 MVAR for Six Pulse Rectifier 315kV, 50Hz				
	Capacitor Bank (20MVAR)	***5th Harmonic (20MVAR)***	***7th Harmonic (20MVAR)***	***11th Harmonic (20MVAR)***
C	641.9 nF	641.9 nF	641.9 nF	641.9 nF
L		631.9 mH	322.43 mH	159.23 mH
R		9.92 Ohms	7.08 Ohms	902 Ohm s

Table 4:- Design Parameters of Shunt Passive Filters

IV. RESULTS AND DISCUSSIONS

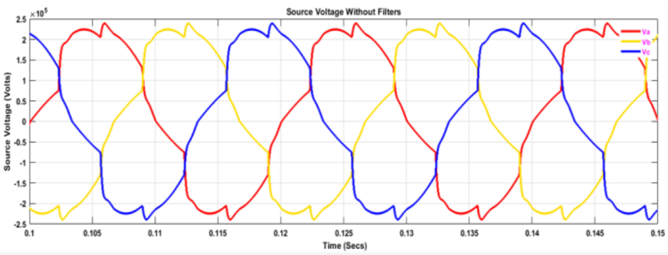

Fig. 8. Source Voltage Without Filters

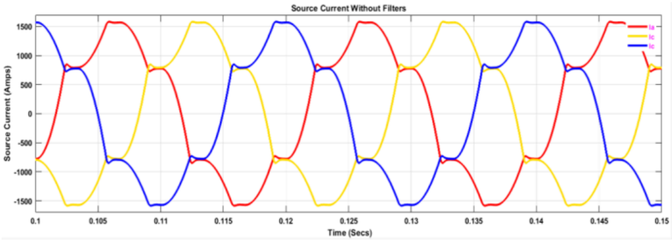

Fig. 9. Source Current Without Filters

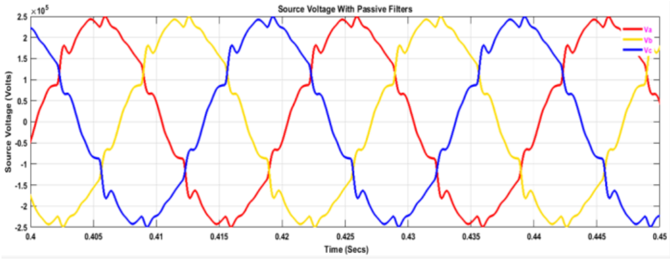

Fig. 10. Source Voltage With Passive Filters

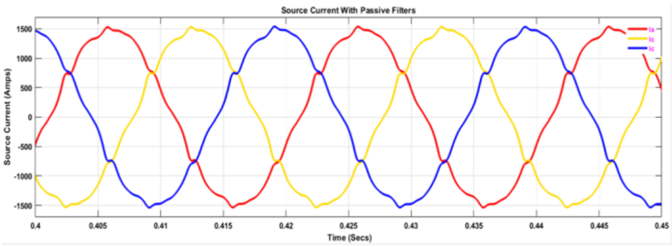

Fig. 11. Source Current With Passive Filters

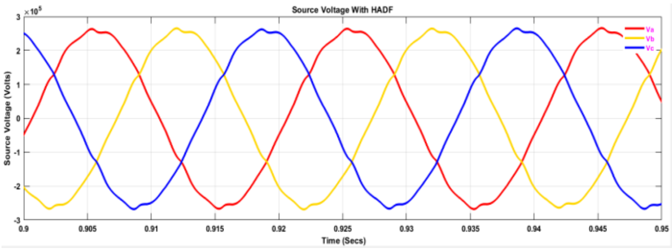

Fig. 12. Source Voltage With HADF

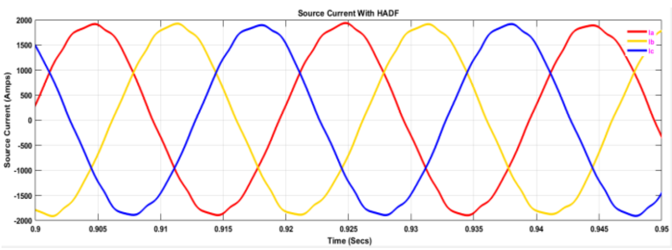

Fig. 13. Source Current With HADF

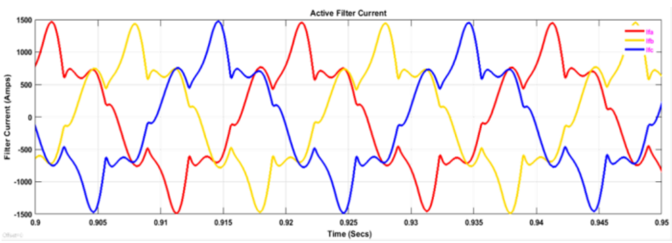

Fig. 14. Active Filter Current

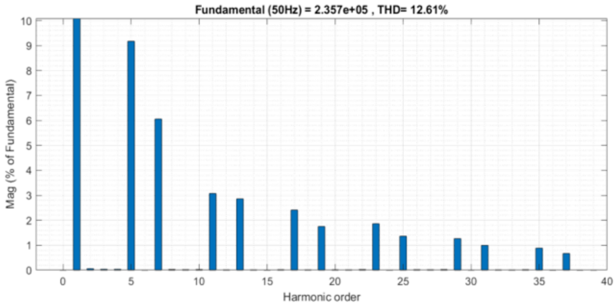

Fig. 15. THD of Source Voltage Without Filters

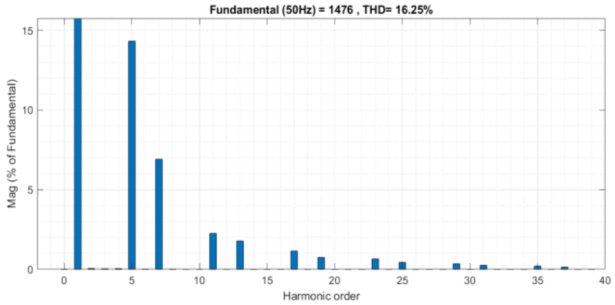

Fig. 16. THD of Source Current Without Filters

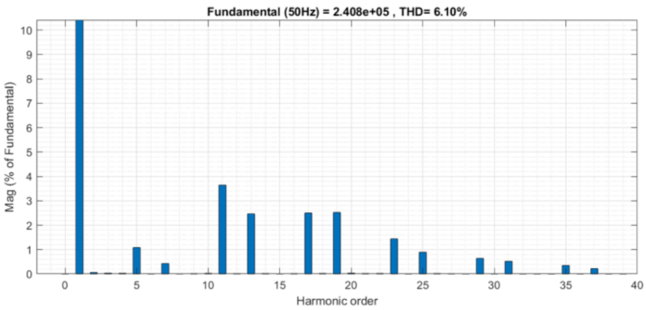

Fig. 17. THD of Source Voltage With Passive Filters

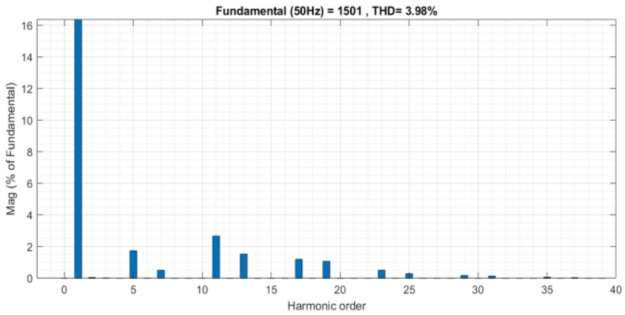

Fig. 18. THD of Source Current With Passive Filters

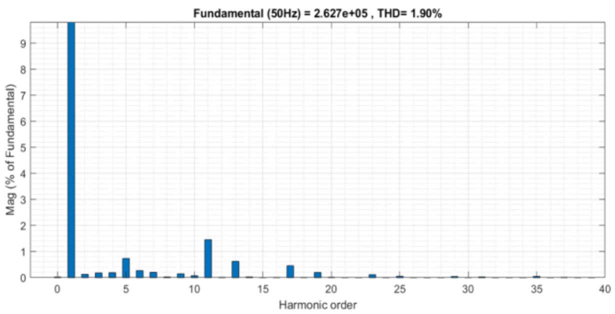

Fig. 19. THD of Source Voltage With HADF

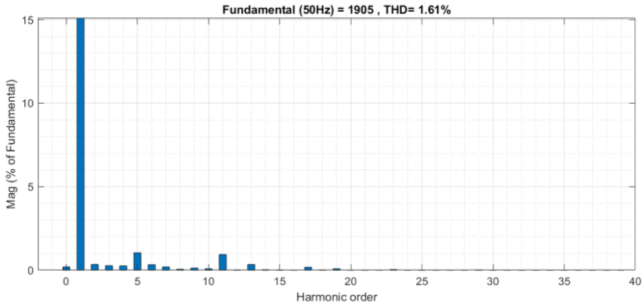

Fig. 20. THD of Source Current With HADF

Total Harmonic Distortion of Source Voltage and Source Current of Six Pulse Rectifier (in %)			
Signal	***Without Filters***	***With 80 MVAR Filters***	***With HADF***
Va	12.61	6.10	1.90
Vb	12.60	6.10	1.83
Vc	12.60	6.10	1.89
Ia	16.25	3.98	1.61
Ib	16.25	3.96	1.56
Ic	16.23	3.96	1.61

Table 5:- THD of Source Voltage and Current Without and With Filters

DC Voltage and Current			
Signal	***Without Filters***	***With 100 MVAR Filters***	***With HADF***
Voltage (kV)	246.7	256.8	278.5
Current (kA)	1.974	2.055	2.228

Table 6:- THD of Source Voltage and Current Without and With Filters

The waveforms of Source Voltage and Source Current and their Total Harmonic Distortions were observed and analyzed without and with connecting shunt passive filter and shunt active dc power filter.

Results of above analysis are summarized in the following way,

- Without connecting the filters, the source voltage and source current are containing dominant 5th and 7th harmonics and some higher order harmonics. So the waveforms are non sinusoidal as shown in the Fig. 8 and Fig. 9, The THD of source voltage and source current are 12.61% and 16.25% as shown in the Fig. 15 and Fig. 16.
- Once the 80 MVAR Shunt Passive Filter is connected, dominant 5th and 7th in the source voltage and source current are reduced but they contain higher order harmonics. So distortions in those waveforms were reduced to some extent still they are non sinusoidal as shown in Fig. 10 and Fig. 11. The THD of source voltage and source current are 6.10% and 3.98% as shown in Fig.17 and Fig. 18.

- Soon after connecting Shunt Active DC Power Filter, the higher order harmonics in the source voltage and source current are also eliminated and the source voltage and source current waveforms became sinusoidal as shown in Fig. 12 and Fig.13. . The THD of source voltage and source current are 1.90% and 1.61% as shown in Fig.19 and Fig. 20.

Furthermore with connecting the shunt passive and shunt active dc power filters the dc voltage and dc current at the output of six pulse HVDC converter were also increased. The THD of Source Voltage and Source Current without and with filters are shown in Table 5. The DC Voltage and DC Current without and with filters is shown in Table 6

V. CONCLUSIONS

Hybrid Active DC Filter consisting of shunt passive and shunt active filters in the proposed work mitigated the harmonics generated by the Six Pulse HVDC Converter. The lower order harmonics were eliminated by 80 MVAR shunt passive filter and the higher order harmonics were eliminated by 136 MVAR shunt active dc power filter. Since passive filters provide fixed compensation, the reactive power capacity of passive filters can be reduced by selecting appropriate shunt active filter as these filters provide variable reactive power. Hybrid Active DC Filter also boosted the DC Voltage and DC Current.

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