Optimized weight point ADF using SOS algorithm

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ABSTRACT

Active dc filter (ADF) has become the most viable alternatives for the compensation of the harmonics in the power system analysis. These filters are capable enough to minimize the total harmonic distortion (THD) and provide compensation towards the power quality issues appearing in the transmission system. A simulated model of a HVDC system is designed in MATLAB and the disturbance is injected in the form of load change and the controller efficacy is checked. This paper basically deals with the operational characteristics of the active filter for specific voltage rating irrespective of load and used to reduce harmonics present in the output voltage of the HVDC converter when cascaded with the inverter. The gains of the ADF are optimized with Symbiotic Organism Search Optimization (SOS) with THD as a constraint.

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1. INTRODUCTION

In the field of power system, the losses generated because of long line transmission has been a serious issue. This can be overcome by the use of HVDC transmission. The High Voltage Direct Current transmission network is a combination of filters (both AC and DC), a set of capacitor bank, VAR compensators, Y-Y-Δ transformers, reactors, DC cables any many more equipment. This type of transmitting system is preferable because of the advantages of loss less transmission. [1]. The VSC-HVDC has the ability to mitigate the power system harmonics and thereby improving the power quality in an interconnected system. [3-5].The limitation of HVDC leads to the generation of harmonics both in the AC as well as DC side due to addition of increased number of switches. Harmonics can be caused by any electrical equipment that uses switched mode power supply. It can also be due to improper switching of the converter switches, non linear loads and faults. Harmonic current can cause overheating of the distribution system .It will cause voltage distortion reducing the amount of voltage to the load circuit. [6] It will add to the loss component of the system and also Interference in telephone lines. Converters are basically the devices which converts AC to DC and vice versa. Normally power electronics switches are connected in a combined fashion whose turn on and off made the total thing possible. The valves can be made to turn on by applying proper gate pulses to the gate cathode terminal which are the pulses for short duration. In order to commutate a negative voltage is being developed across the conducting switches or a negative current is being applied to flow by turning on the other pair of switches in the bridge circuit.[10]

A close investigation through the literature as explained below helps in finding out the objective of the paper. A novel technique to tune the PI controllers of a bidirectional HVDC light system byembedding particle swarm optimization is explained in [1]. Analytical design techniques to evaluate the steady-state and transient interconnections between the converters, smoothing reactor, dc filter are given in [2] . A high-power LC hybrid active power filter (HAPF), which can meet the requirements of filtering and dynamic reactive power compensation is explained in [3].

A new extraction method to improve the performance of the conventional indirect extraction method is explained in [4]. A novel static var compensator with series AF is given in [5]. A hardware implemented FLC, SAPF for compensation to a nonlinear load is explained in [6]. The DFT is used to minimize the generated disturbances by nonlinear load in [7]. Component selection in electronic circuit design for analog active filter design is given in [8]. The paper [9] presents the total least mean squares (TLMS) algorithm is designed by recursively computing an optimal solution of adaptive TLS problem by minimizing instantaneous value of weighted cost function. A technique to adjust the CCSC gains to prevent from the possible internal harmonic instability of MMC stations is described in [10]. A review on different types HVDC system is explained in [11]. A proposed FOPID controlled has advantages like low settling time, less peak over shoot and reduced steady state error in load voltage [12]. The performance of the Shunt active filter depends upon the design of the filter components and control algorithm is verified in [13]. This paper [14] explains the design parameters of three phases shunt active filter based on PQ theory. The article [15] help to select the key parameters of a shunt active filter in the conditions of centralized and distributed power supply systems. The paper [16] presents a battery integrated photovoltaic (PV) system, which provides reliable power to local loads, by operating in either islanded or grid connected modes, depending on the grid conditions. The reduce harmonics based SAPF in the Matlab/ simpower environment is explained in [17]. An inverter feedback control using multilevel inverter is done in [18]. A reference current estimation using hysteresis current control is explained in [19, 20].

Current harmonics compensation of PV grid connected system using PI controller based active filter in [21] A study the mean-square performance of a convex combination of two transversal filters is described in [22] .Emerging techniques on the active filters are explained in [23].AC filtering design that make the arrangement for decoupling reactive power supply is explained in [24, 25]. A comparision of the mitigation techniques of both 6-pulse and 12-pulse HVDC systems using passive and shunt active power filters to eliminate line current harmonics and to compensate reactive power by increasing the power factor in [25].A comparision between different new techniques of elimination of harmonics by APF with the help of TMS320C32 is experimented in [26]. Different types of installed filters, as well as the aspect of control interactions among active filter is discussed in [27]. An auto corrected filter with regulated LC-circuit with different controlling methods is proposed in [28]. The paper [29] details the principle of active DC filter applied in the HVDC system. To meet the issues raised because of the instability of Grid generated problems and their control is discussed in [29 and 30].

This article is organized by arranging research method in section 2 , system converter investigation in section 3 , design of active DC filter is done in 4. System investigation in section 5, SOS algorithim is in section 6 and the result and analysis in 7. Conclusion is in section 8 and followed with Appendix.

2. RESEARCH METHOD

MATLAB (R2016a) software is used to simulate the model of the modelled power system. The modelled system comprises of a twelve-pulse converter, multilevel inverter controller and AC grid, which are modelled by using MATLAB software having 4 GB computer. The programming code for employed SOS algorithm is written in m. file which is subjected to tune the constraints of ADF and controllers by introducing disturbances and random loading. The number of population and iteration for the SOS algorithm has been considered as 100 and 100 respectively. The best suitable optimal gains of the controllers have been taken by doing 20 independent repetition of optimization. In this paper,

- A twelve pulse converter is designed with proper passive and active filter to deliver three phase AC output using a multilevel inverter.
- The optimised weight point active filter is evaluated using SOS algorithim.
- The transmission line with T and π network is extended for the same approach.
- The performances evaluation of the controllers in the scale of Fast Fourier Transform (FFT) is analyzed.

3. SYSTEM CONVERTER INVESTIGATION

The generated system is designed using different important components which are important for the point of view of the line. The desired system components are explained below.

3.1. Twelve pulse converter

A twelve pulse converter is basically consisting of two six pulse converters. The increase in the number of pulse in the AC-DC converter minimizes the harmonics. The converter generates unregulated power supply which can be intensified by the filter circuits. These regulators generate line current in the form of when feeding constant current loads. To minimize the harmonic content of the above said converter and improves the swell content, a 12-pulse AC-DC converter is configured. A schematic diagram of a twelve pulse converter is given in Fig. 1.The equation of a twelve pulse converter is given in Eqn. (1).[10]

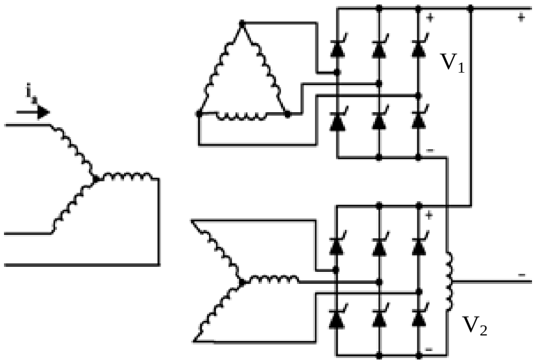

Figure 1. The diagram of a twelve pulse converter

$$V_1(\theta)=\sqrt{3}V_m\cos(\theta-\frac{\pi}{6}),\ V_2(\theta)=\sqrt{3}V_m\cos(\theta-\frac{\pi}{3}),\ V(\theta)=V_1(\theta)+V_2(\theta) \tag{1}$$

$$V(\theta)=\sqrt{3}V_m\cos(\theta-\frac{\pi}{6})+\sqrt{3}V_m\cos(\theta-\frac{\pi}{3}),\ V(\theta)=1.9319x\sqrt{3}V_m\cos(\theta-\frac{\pi}{4})....(\frac{\pi}{6}\leq\theta\leq\frac{\pi}{3})$$

Where

V_1	Output voltage of the upper converter	θ	Angle of firing
V_2	Output voltage of the lower converter	V_m	Maximum voltage

3.2. Multilevel Inverter

The increased number of steps in the output voltage of generated AC signal leads to reduced harmonics as it is more similar approaching the pure AC signal. This concept is greatly obeyed in multilevel inverter .The used set of IGBTs and capacitors for a precalculated output potential is explained in Fig .2. The switching pattern helps in changing the final output potential at the load point. The CHB helps in reducing the stress on each switch and advantageous and cost effective due to its reduced switch count. [1, 2]. The per phase voltage is given in Eqn (2) [18].

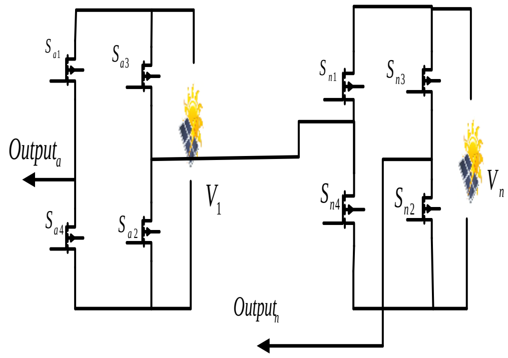

Figure 2. The generalized schematic of the cascaded H bridge inverter

$$U_{an}(wt)=\sum_{x=1,3,5}^{\infty}\frac{4U_{dc}}{x\pi}\begin{bmatrix}\cos ine(h\beta_1)\\+..........+\cos ine(h\beta_s)\end{bmatrix}\sin(hwt) \tag{2}$$

Where

U_{an}	The Inverter phase voltage	β	Optimal angle of switching
U_{dc}	Voltage of the dc capacitor	h	The number of order of harmonic

3.3. Filters

To reduce the harmonic content, several filters are used which are of two types such as Passive filter and Active filters. Passive filters are defined as the set of passive components arranged together to bypass the harmonic current. The characteristics equations of different passive filters are given in Eqn (3) [25]. The active filters consist of any active parameters like OPAMPs or transformer in the system to compensate the sag as well.

3.3.1. Passive filter

Passive filters can be formed by the combination of any of the passive elements in suitable arrangement to minimize the harmonics designed for. Selection of passive filter is a trivial task for any system. The method involves the percentage of harmonics in the signal without the filter and the required value with the filter. Normally a HVDC system has smoothening reactor on both side (rectifier and the inverter side). The calculation of the filter impedance can be given as in Eqn. (4) [4]. The two different type of passive filters available in the transmission line are given in Fig.3.

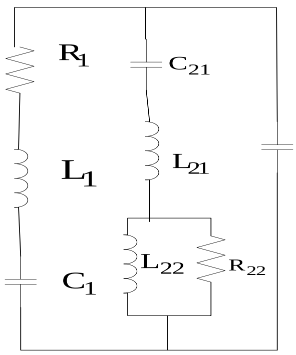

Figure. 3-a. Passive filter for T network.

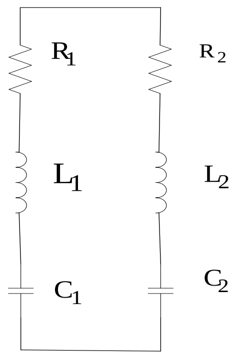

Figure. 3-b. Passive filter for π network.

$$H(s)=\frac{sCR}{(1+sCR)};H(s)=\frac{Ks}{(s^2+Ks+w^2)} \quad (3)$$

$$Z_f=V_o\times\frac{Z_s}{(V_s-V_o)} \quad (4)$$

where

Z_f	filter impedance	Vo	output voltage
Zs	impedance of the smoothing reactor	Vs	input/supply voltage
K	Gain factor of the filter	w	Frequency of oscillation

The suitable compensation of the passive filter depends on the source impedance. At a particular frequency there is always anti-resonance between the source impedance and the passive filter, called load harmonics amplifying phenomenon. Also designing is a difficult task so that sometimes it became so problematic that the practical meaning of using it will be lost. Some constraints are on the free choice of the values of the filter component, thereby making the design complex. Deviation of the natural frequency leads to the considerable mistuning of the filter circuit. [5]

3.3.2. Active filter

Active filter is the extension of the passive filter where an active element is inserted to enhance the compensation as well as restore the sag. This can be of series or shunt depending on the position in the circuit. The regulators employed in Active DC Filters evaluate the compensating the current reference and drag the power converter to synthesize it accurately. A shunt active filter can compensate the selective harmonics current of the system with linear and nonlinear loads and also can chase the changes in the harmonic content. [6] It is a tedious task to design a high VA-PWM converter with rapidly changing current behaviour as well as loss less system. The initial running cost is high as compared to the passive filters. An APF generally has three distinct blocks:

a) The PWM based converter
b) The active filter power controller
c) Gain compensator block

The PWM converter is the one which is responsible for power modulation for synthesization of the compensator current. The active filter controller takes care of the signal processing and determines the updated current reference that continuously allowed regulating the PWM. The controller works in a closed loop and aims in continuously sending the load current by updating the compensating current reference. In ideal case the PWM converter may considered as a linear power amplifier where the compensating current track correctly its reference. The PWM converter should have high switching frequency (f_s) in order to produce accurately the compensating current [7]. The load current is taken as a feedback to a bank of selective band pass filter in which the specific harmonics those have to be eliminated is selected within the band. Then the signal is fed to the amplifier there by given to the pulse generator which will give corresponding triggering pulses to a single or multi-phase inverter depending upon the application required. The inverter is giving supply to the transformer which will be in series with the passive part supplying a negative value of the same current flowing in the shunt branch, there by nullifying the effect of harmonics. [9] The actual load current as mentioned in Fig. 4 (a) force the ADF to generate a proportional inverted (negative) filter current as in Fig 4 (b) so that the harmonic value will get cancel out as represented in Fig. 4 (c).

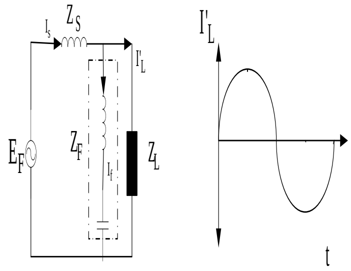

Figure 4. (a) The actual load current

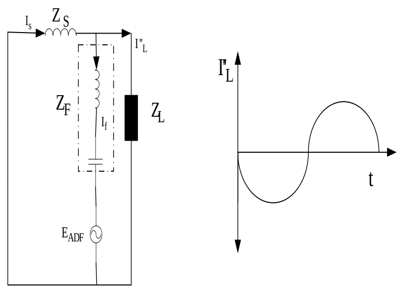

Figure 4. (b) The ADF to generate a proportional inverted (negative) filter current

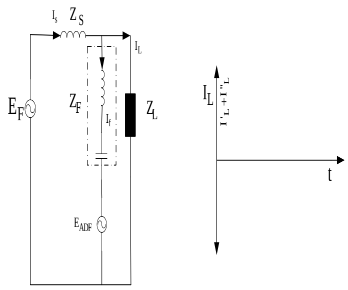

Figure 4. (c). The harmonic value getting cancel out

4. DESIGN OF ACTIVE DC FILTER

A Matlab model is developed for the design of the active DC filter is given in the block diagram and shown in Fig. 5. The ADF is a simple voltage converter with controlled switch, supply, coupling transformer and passive filters (PF). The inductive reactance of the HVDC is less than the filtering reactor LS and it is negligible so the shunt ADF injects the compensating current IF into the point of common coupling (PCC) to eliminate the harmonics contained in the output current of the converter station Ls. [1].

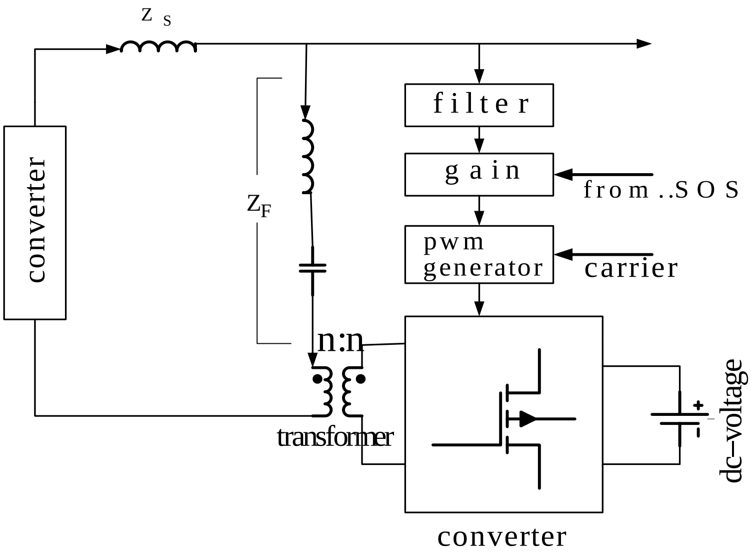

Figure 5. Block Diagram of the Active filter

4.1. Design of F(s)

The required equations obtained to find the desired values of Filter components can be calculated from Eqn (5-7). With proper values of F(s) using Eqn (8) the desired response can be obtained.[5]

$$I_h(t)=I_{load}(t)-I_d(t) \tag{5}$$

$$F(s)=\sum\left(K_i \times H_{fi}(s)\right) \tag{6}$$

$$H(fi)=\frac{2\xi\omega_i s}{\left(s^2+2\xi\omega_i s+\omega_i{}^2\right)} \tag{7}$$

$$F(s)=\frac{125.10s}{s^2+113.10s+(1.4212x10^7)}+\frac{135.86s}{s^2+150.8s+(5.6849x10^7)}+\frac{69.549s}{s^2+113.10s+(1.2791x10^8)}+\frac{77.699s}{s^2+150.8s+(2.2740x10^8)}+\frac{0.000785s}{0.0089s+1} \tag{8}$$

$$F(s)=\frac{0.000785s^9+4.047s^8+3.366x10^5s^7+1.359x10^9s^6+4.376x10^{13}s^5+1.246x10^{17}s^4+1.876x10^{21}s^3+2.752x10^{24}s^2+1.873x10^{28}}{0.0089s^9+5.697s^8+3.796x10^6s^7+1.905x10^9s^6+4.911x10^{14}s^5+1.81x10^{17}s^4+2.097x10^{22}s^3+4.898x10^{24}s^2+2.094x10^{29}s+2.35x10^{31}}$$

F(s) is the main component of the active filter which modulates the current whose harmonic content needs to be regulated. The proper design of F(s) helps the current to change the shape so that the net current after passing through the filter has negligible harmonic part.The selection of F(s) is validated using the Bodeplot as given in Fig.6.Bode plot helps in realizing the stability of the system performance by achieving required gain margin and phase margin.

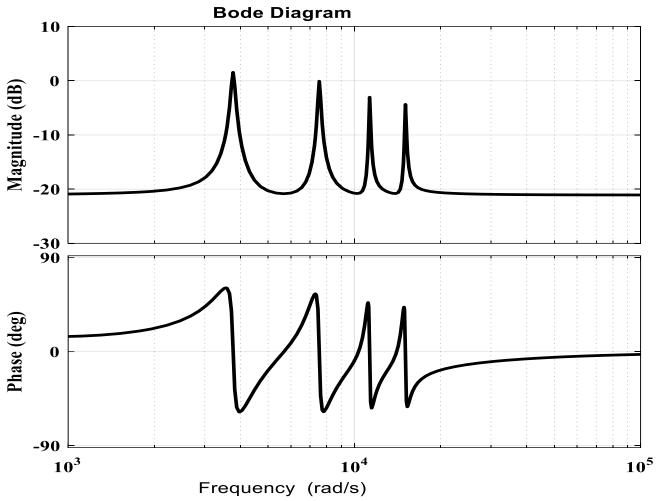

Figure 6. The Bode plot diagram of the F(s)

4.2. Calculation of DC voltage

To cancel all the harmonics the Dc voltage requirement can be given by the Eqn (9).[3]

$$U_{dc} = -(I_h \times Z_{fh}), U_{adf} = -\left(\sum_{i=1}^{h} Z_f\left(\frac{j\times 2\pi f_i}{j\times 2\pi f_i L_s}\right) U_{si}(s)\right) \tag{9}$$

Where

I_h	harmonic current of the order h induced by the converter	$U_{adf}(s)$	voltage output of ADF
Z_{fh}	impedance of the associated passive filter	Z_s	impedance of the passive filter
U_{si}	the harmonic voltage output of the converter	L_s	impedance of the smoothing reactor
K_i	control co efficient of each harmonic term	U_d	ADF dc voltage supply
ω_i	passband center angular frequency	n : 1	transformer ratio of the coupling transformer (n can be any number including fraction)
ξ_i	parameter to adjust the pass band width	G	Gain
I_s	harmonic current output of the converter circuit	I_f	harmonic current output of the transmission line
I_h	harmonic current output of the filtering branch	U(s)	harmonic output voltage of the converter

4.3. Calculation of the gain

The gain of the ADF is calculated using SOS method. The objective function for the calculation of the gain can be considered as the total Harmonic distortion. The detail circuit diagram can be given in Fig.7. Initially the weights of the gains are adjusted with small random values. The SHO adjusts the THD to the minimum set value and deliver the gains for the filter current. The source current has optimized gains in the form of weighted function, which is updated in every iteration, that can be obtained as per Eqn (10). [22, 9]

$$w_n^{k+1} = w_n^k + \delta w_n, \frac{\delta \sum_{iter=1}^{iter^{max}} \Sigma\, e_n^2}{e_{nmin}^2} \tag{10}$$

Where

$W_1(k)$	Weight gain adjustment towards filter current components
$W_2(k)$	Weight gain adjustment towards source current components
δ	Compensating gain multiplier
w_n^k	Weight gain for k^{th} component for n^{th} gain
w_n^{k+1}	Weight gain for $(k+1)^{th}$ component for $(n+1)^{th}$ gain
I_{ref}	Reference current
I_{act}	Actual current

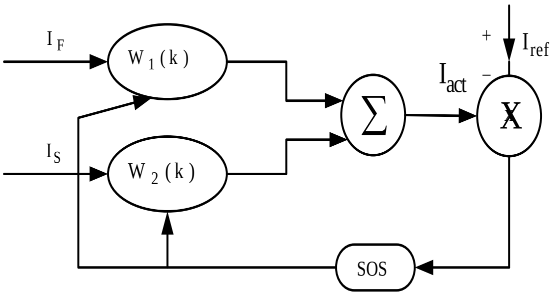

Figure 7. The Gain factor selection block diagram

5. SYSTEM INVESTIGATED

The system shown below comprises of a twelve pulse generator with two transformer coupled with each other with Y-Y-Δ configuration. The total length of the transmission line is 300km with smoothening reactor connected. The transformer tap changers are not simulated and fixed taps are assumed. The reactive power required by the converters is provided by a set of capacitor banks for a total of 600 MVAR on each side. The detailed system investigated is shown in Fig. 8.

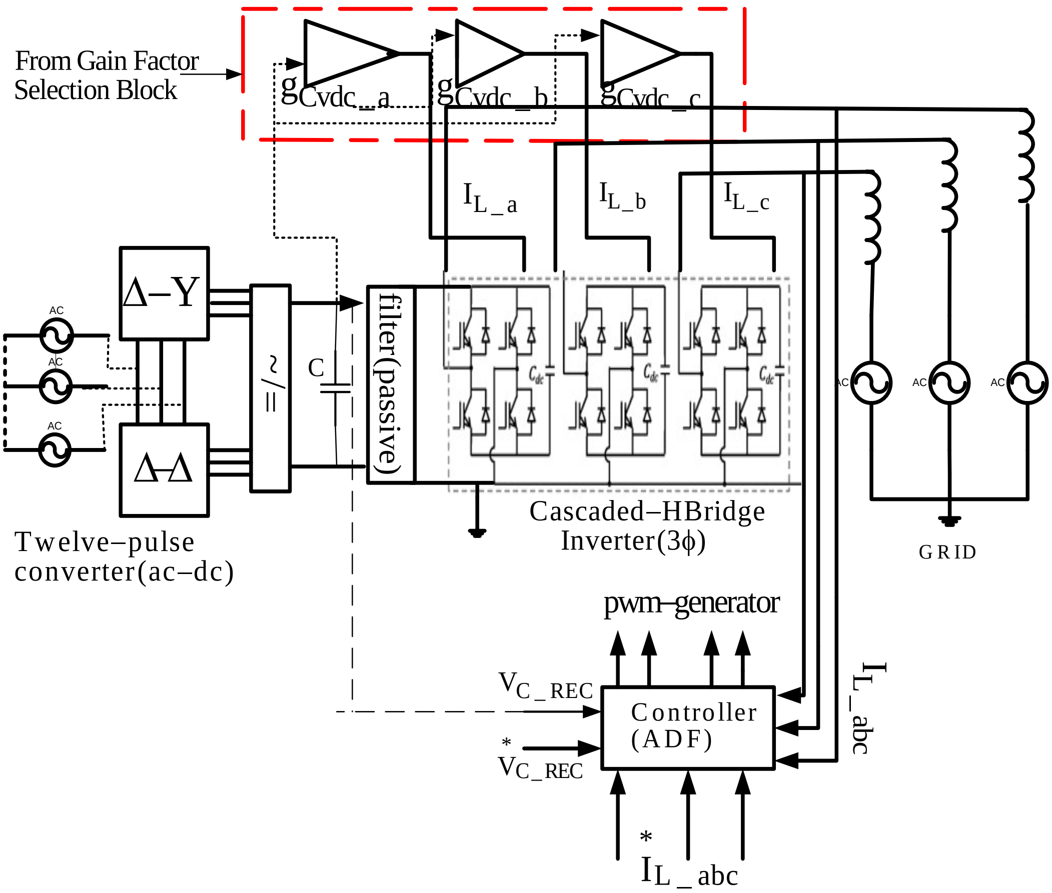

Figure 8. The detailed description about the system under study

6. SYMBIOTIC ORGANISMS OPTIMIZATION METHOD (SOS)

Symbiotic Organisms Optimizatin is used to solve non-linear optimization numerical problems based on. Mutualism, commensalism and parasitism phases. The complete block diagram is given in Fig 9.

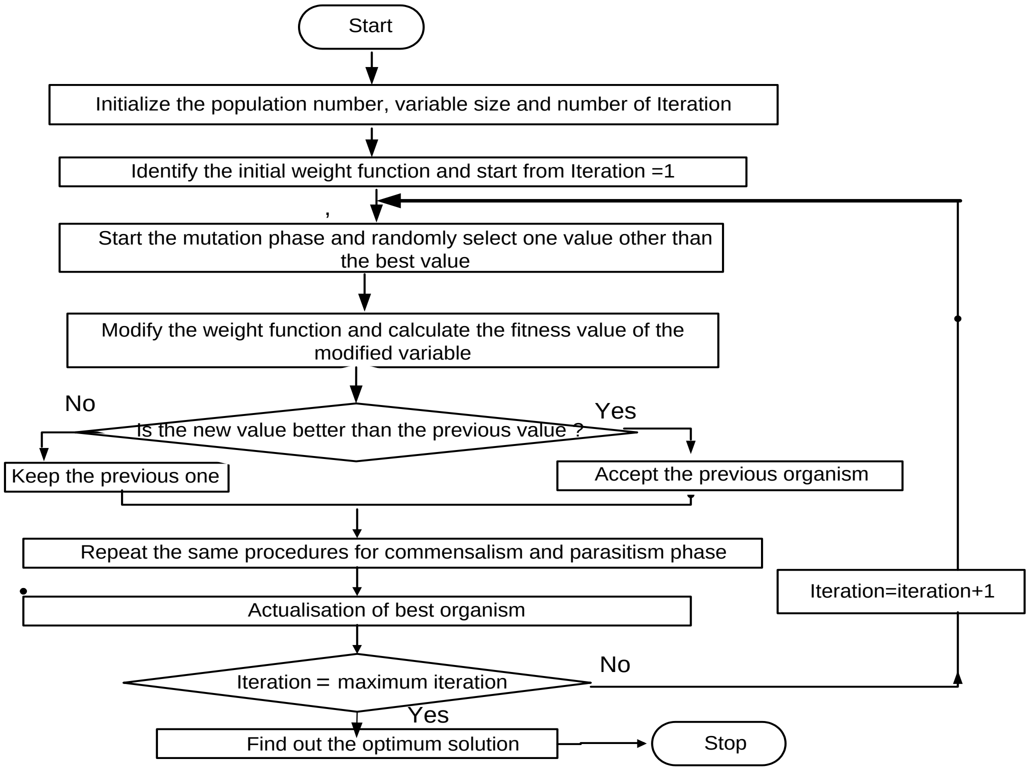

Figure 9. The flowchart for SOS.

7. RESULT AND ANALYSIS

The analysis has been carried forward in MatLab and Simulink for DC line generated from a 150KV,3φ,50Hz AC system having the line impedance of 0.01Ω and 1mH. The 12-pulse converter system is used to find out the DC output for 45 degree firing angle. The 300km transmission line has been done for both T and π network having 0.0015Ω line resistance, 0.0752H line inductance and 1.42µF capacitance per km for T network and 0.0258Ω line resistance, 0.0752H line inductance and 0.0123µF line capacitance per km.

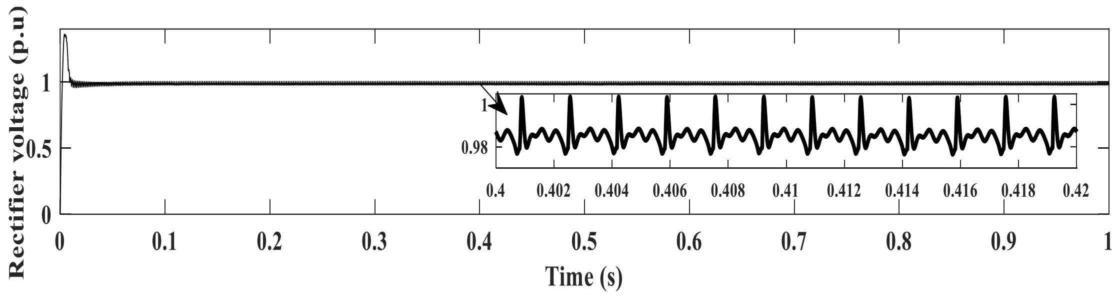

Figure 10. The 12-pulse converter waveform

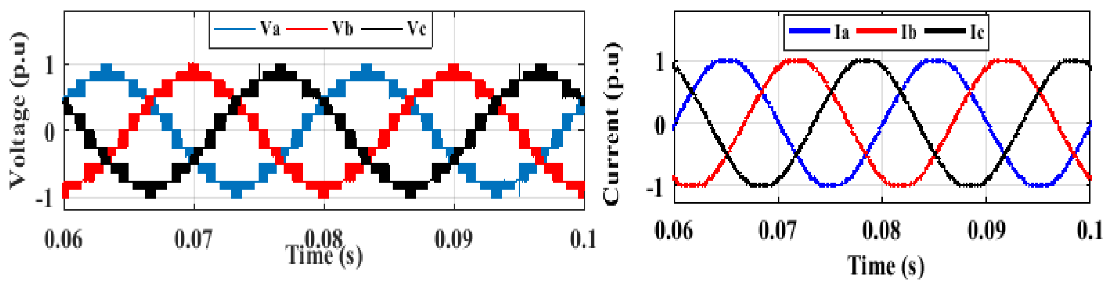

Figure 11. The three phase inverter voltage and current

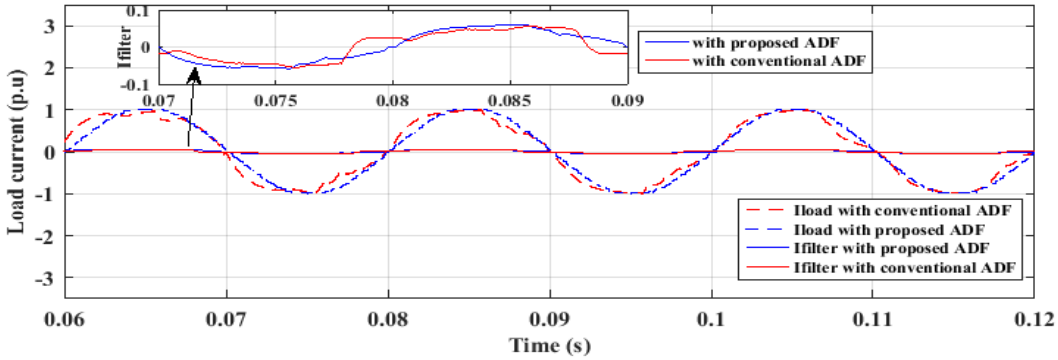

Figure 12. The comparision of output load current and filter current

Fig (10) shows the rectifier voltage of DC-transmission line in HVDC without ADF. Fig (11) gives the three phase inverter voltage and current in p.u of the multilevel inverter. The output load current and filter current is given in Fig (12).For transient analysis, the load resistance has been changed and consequently, the response obtainted is given Fig (13) and Fig (14). The ADF with adaptive neural filtering has good performance compared with conventional filtering.

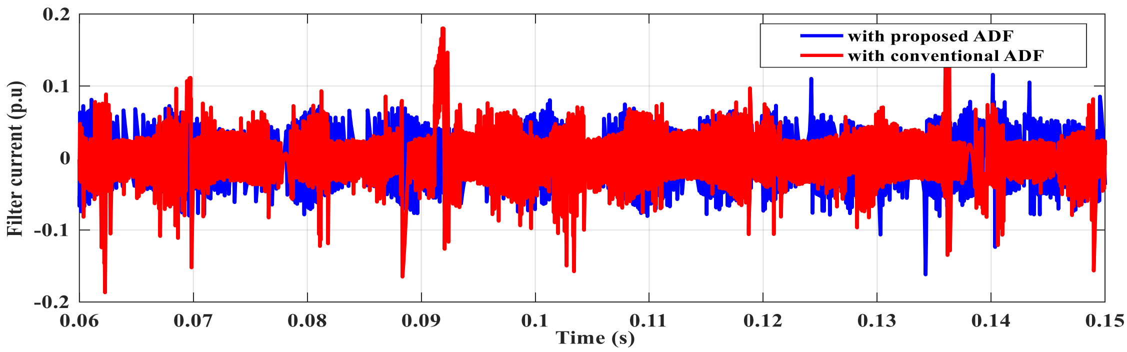

Figure 13. The transient response of filter current

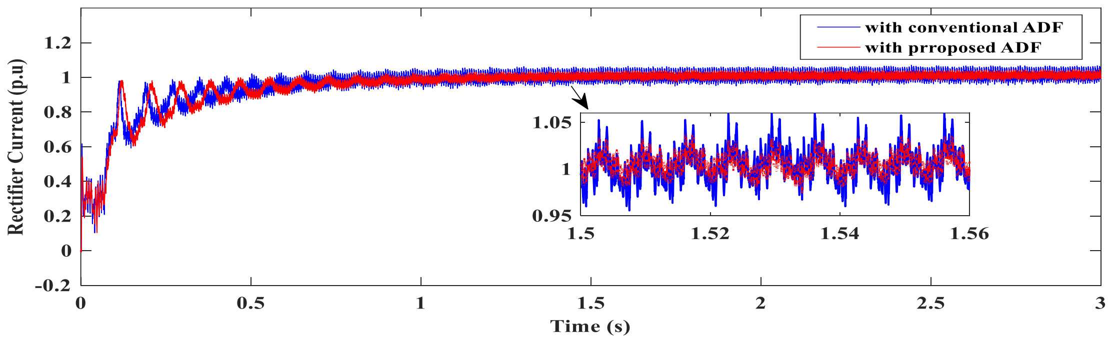

Figure 14. The transient response of rectifier current

The T and π model is developed in Matlab Simulink for the block diagram as in Fig (8) and the result is extracted in the form of FFT analysis for output voltage without filter. Harmonic analysis is done w.r.t the fundamental component because

- The modulation and the demodulation of the same value has to be done in the conversion and the inversion process.
- As Vh is represented in percentage of the fundamental component as (we are considering the harmonics in the multiples of fundamental) hence it will get cancelled out in the THD calculation.
- The average value of the fundamental component is zero for a full cycle. (as the average value of the fundamental component is zero for a full cycle hence the fundamental component is not considered for the harmonic analysis of the signal)

The result is also compared for passive and active filter and the reduction of the magnitude of the harmonic is given in Table 1.The comparision of both T and π network is observed.The THD comparision is given in Fig (15) and (16) for T and π network respectively. The FFT method reduces the duplicate terms in the mathematical algorithm to reduce the mathematical operation required and the computation factor thereby saving the time and more accurate. [2] The THD is always calculated taking reference to the fundamental component for ac as well as dc [8].This can be given as in Eqn (11). [13]

$$I_{load}(t) = I_d(t) + \sum_{n=1}^{\infty} I_d \, sin(nwt + \varphi), THD = \frac{\left(\sqrt{\sum_{n=2}^{\infty} V_h}\,(n)^2\right)}{V_1} \tag{11}$$

where

Id(t)	dc component of the signal selected	V_h	harmonic voltage other than fundamental
Iload(t)	load component of the signal	V_1	fundamental component of the voltage
Ih(t)	harmonic component of the signal		

Table 1. Comparision of the amplitude of harmonic order w.r.t fundamental

				T NETWORK				
HARMONICS	**12TH**	**24TH**	**36TH**	**48TH**	**60th**	**72th**	**84th**	**96th**
With ADF	7.69	5.48	1.07	-2.23	1.44	-0.5	-0.82	0.69
With proposed ADF	0.02	0.24	0.23	0.02	0.1	0.03	0.03	-0.07
				π NETWORK				
HARMONICS	**12TH**	**24TH**	**36TH**	**48TH**	**60th**	**72th**	**84th**	**96th**
With ADF	50.17	12.11	1.24	-0.25	0.7	-0.46	-0.81	1.16
With proposed ADF	-0.6	-0.02	0.61	-0.21	0.4	-0.77	0.16	-0.18

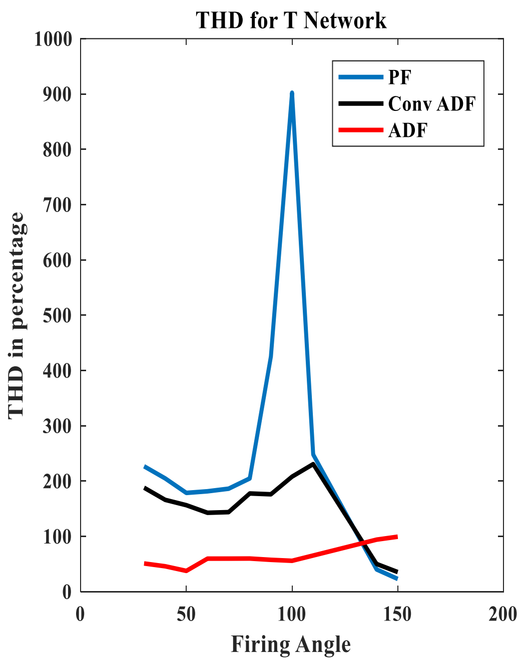

Figure 17. Comparision of the THD for T network

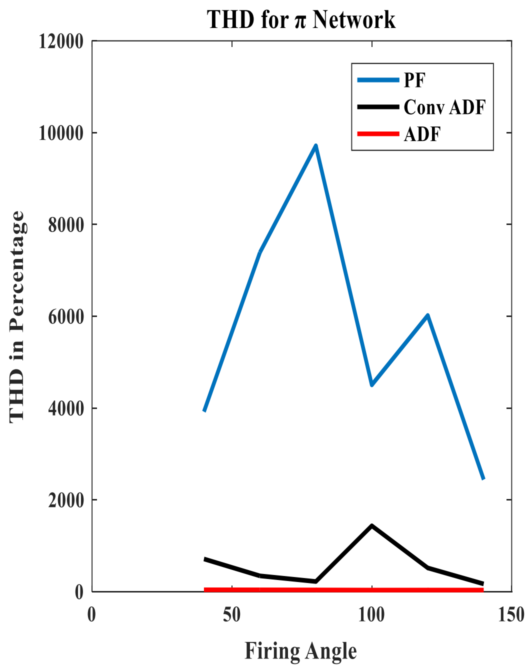

Figure 18. Comparision of the THD for π network

The comparision Table as shown in Table 1 depicts that the proposed ADF is able to give better result as compared to conventional ADF.The adaptive nature of the proposed ADF is also an additional advantage to the network.

8. CONCLUSION

As per the analysis given we can see that the active filter is able to reduce the THD of the output waveform appreciably than the normal passive filter used. The passive filter used in series with the active filter with a switch to isolate the active part in case of any short circuit due to fault. Some design parameters values are choosen on the basis of setting a trade off of different constraints. The Active filter has minimum limitation other than the initial installation cost. The proposed method is having an additional benefit of eighted functional gain thus improving the performance. The future analysis can be done by analyzing the behavior of the circuit with different type of loading as well as power flow in the HVDC line.

APPENDIX

T Network

Supply voltage(Vs)=150KV,3φ, 50Hz, line impedance=0.01Ω,1mH,Ls=0.02H R1=3.4Ω, n=2.8
L1=0.025H, C1=2.81μF L21=2.5mH, C21=1.75μF, L22=1mH, R22=5KΩ, C3=1.87μF Transmission Line=300KM

***π* Network**

Supply voltage(Vs)=150KV,3φ, 50Hz Line impedance=0.01Ω,1mH, Ls=0.02H R1=0.034 Ω, n=1.2
L1=0.03H, C1=2.35μF, L2=0.04H ,C2=0.109μF, R2=0.024Ω Transmission Line=300KM

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