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Analysis of Hybrid Filter for Harmonic Mitigation and Reactive Power Support

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Abstract:
Harmonic distortion is mainly due to the tuned passive filter and line inductance which produces resonances in the industrial system. To suppress this above problem hybrid active filter is used. The proposed hybrid filter is operated as variable conductance according to the total harmonic distortion in voltage and current. Thus harmonic distortion can be reduced to an acceptable level in the power system. The hybrid active filter is a combination of seventh tuned passive filter and an active filter in series connection so that the VA rating of the active filter and the dc voltage of the active filter are reduced to acceptable levels and in addition to that hybrid active filter is used because of its filtering capability and the cost. A Design consideration is presented and experimental results are provided to validate the effectiveness of the proposed method.

I. INTRODUCTION:

The extensive usage of nonlinear loads such as adjustable speed drives, uninterruptable power supply and battery charging system increases the harmonic pollution. The diodes or rectifiers are used to realize the power conversion because of lower component cost and its simplicity. Moreover rectifiers allow a large amount of harmonic current flow in the system. This excessive power flow produces harmonic distortion which may give rise to malfunction of sensitive equipment. Normally tuned passive filter are located at the secondary side of the distribution transformer to provide low impedance for controlling harmonic current and to correct the power factor for harmonic load. To provide the parametric changes in the passive filters, results in unintended series or parallel resonances that may occur between the passive filter and the line inductance. The functionality of passive filter may become progressively worse and extra calibrating work is needed to maintain the filtering capability. Various active filtering techniques have been presented to indicate the harmonic issues in the power system. The active filter is used for compensating harmonic currents of non-linear loads, but this may not be effective. To improve the performance of the passive filter "active inductance" hybrid filter was introduced. The fifth harmonic resonance is present between the power system and the capacitor bank. In order to suppress that fifth harmonic resonance a hybrid shunt active filter with filter – current detecting capability was used. The combination of both the active and the passive filter in series with the capacitor bank by coupling a transformer was used to reduce the harmonic resonance and to balance the harmonic current. This method needs extra transformers or tuned passive filter to maintain the filtering capability. An anti-resonance hybrid filter for delta-connected capacitor bank of power-factor correction applications is presented. This circuit was limited to three single-phase inverters, and the filtering performance was not considered. In addition, the hybrid active filter was proposed for the unified Power Quality (PQ) conditioner to address PQ issues in the power distribution system.

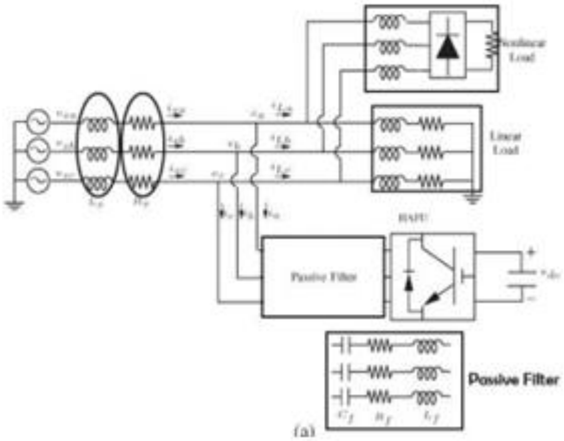


Figure. 1.(a): Proposed System

Operating principle:

Fig 1(a) shows a simplified circuit diagram considered in this paper, where Ls represents the line inductance plus the leakage inductance of the transformer. The Hybrid Active Filter Unit (HAFU) is constructed by a seventh-tuned passive filter and a three-phase voltage source inverter connected in series connection. The passive filter is intended for compensating harmonic current and reactive power. The inverter is designed to suppress harmonic resonances and to improve the filtering performances of the passive filter.

Harmonic Loop

To suppress harmonic resonances, the HAFU was proposed to operate as variable conductance at Harmonic frequencies as follows:

$$L^*_h = S^* \cdot eh \qquad (1)$$

Where L^*_h represents the current harmonic command. The conductance command S* is a variable gain to provide damping for all harmonic frequencies. Harmonic voltage component eh is obtained by using the SRF transformation, where a Phase-Locked Loop (PLL) is realized to determine the fundamental frequency of the power system. In the SRF, the fundamental component becomes a dc value, and other harmonic components are still ac values. Therefore, harmonic voltage component $e^e_{qd,h}$ can be extracted from e^e_{qd} using high pass filters.

Fundamental Loop

In the paper, the q-axis is aligned to A-phase voltage. Since the passive filter is capacitive at the fundamental frequency, the passive filter draws leading current from the grid, which is located on the d-axis. The proposed inverter produces the low voltage on the d-axis, which is in phase with the leading current. Therefore, the control of dc bus voltage can be accomplished by exchanging real power with the grid. Thus, the current command $i_d{}^*{}_f$ is obtained by a proportional–integral (PI) controller. The fundamental current command i*f in the three-phase system is generated by applying the inverse SRF transformation The harmonic voltage drop on the passive filter due to the compensating current of the HAFU, where I represents the maximum harmonic current of the active filter, and the voltage drop on filter resistance R_f can be neglected. As can be seen, a large filter capacitor results in the reduction of the required dc voltage. The filter capacitor determines reactive power compensation of the passive filter at the fundamental frequency. Thus, the dc voltage v*dc can be determined based on this compromise. Note that the compensating current should be limited to ensure that the hybrid filter operates without undergoing saturation,

i.e., $v_{dc}>2$

Current Regulator

The current command i*consist of i^*_h and i^*_f Based on the current command $i^*$and the measured current i, the voltage command v*can be derived by using a proportional controller as follows:

$v^*=K_C.(I^*-i)$ (2)

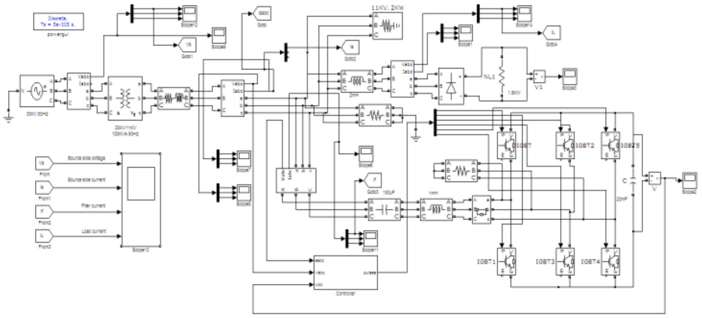
Where Kc is a proportional gain. According to the voltage command v∗, space vector pulse width modulation (PWM) is employed to synthesize the required output voltage of the inverter. The computational delay of digital signal processing is equal to one sampling delay T, and PWM delay approximates to half the sampling delay T/2. Hence, the proportional gain K_c can be simply evaluated from both open loop and closed-loop gains for suitable stability margin and current tracking capability.

Reactive Power Compensation with Hybrid filters:

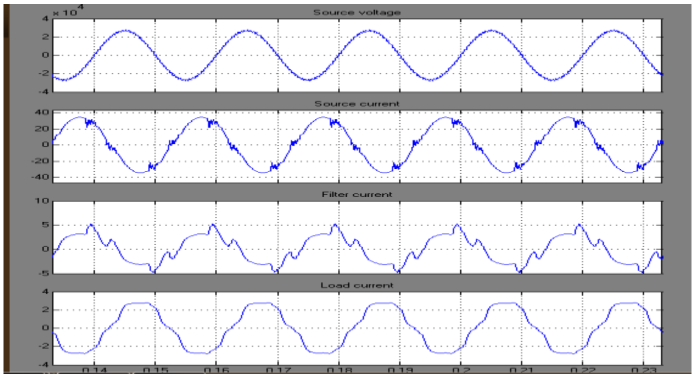
The process is explained in detailed as follows previously we have considered only the harmonic and fundamental currents for generating the required reference current. Now in addition to these currents another current i.e., quadrature component of the load current (iq) is also taken as feedback to the PI controller. So, those now the error input signal to the PI controller consists of three currents those are harmonic current, fundamental current and quadrature component of the load current. Thus required references current get generated and this obtained reference current is multiplied with gain to obtain the current in terms of voltage signal. The obtained voltage signal (carrier signal) is taken as one of the input to the comparator and the other input signal is reference signal thus the output is obtained in the form of pulses these obtained pulse signals are given to Hybrid active filter unit thus the Hybrid active filter unit operates depending upon the output obtained using PWM technique. Therefore the filter can compensate the required amount of current with a phase shift. In this way we can compensate the reactive power. With reactive power compensation there will be improvement in load power factor, voltage at load.

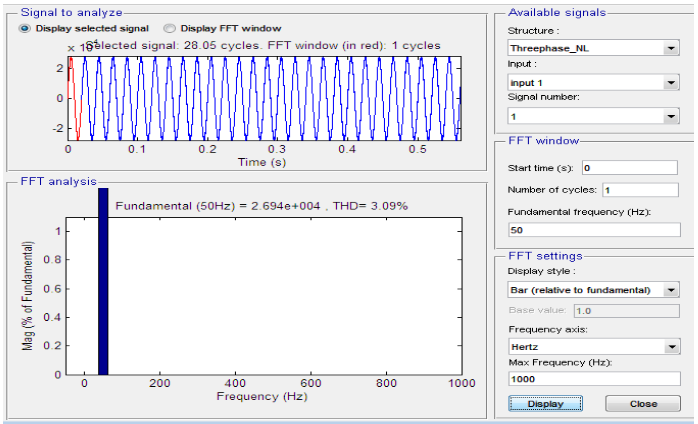
II. SIMULATION REULTS

Simulink Circuit without Hybrid Filter



Without Hybrid filter:



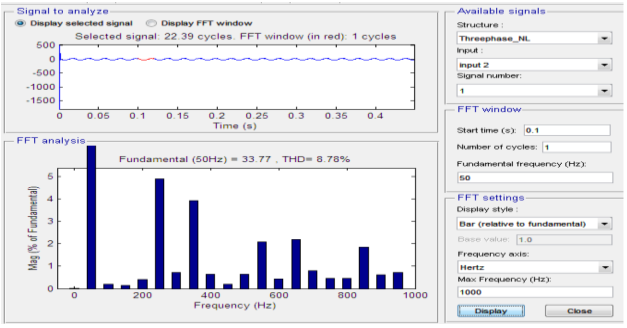


● Display selected signal ○ Display FFT window

Selected signal: 28.05 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 2.694e+004 , THD= 3.09%

Structure : Threephase_NL
Input : input 1
Signal number: 1
Start time (s): 0
Number of cycles: 1
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000


Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 22.39 cycles. FFT window (in red): 1 cycles

FFT analysis

Fundamental (50Hz) = 33.77 , THD= 8.78%

Available signals

Structure : Threephase_NL

Input : input 2

Signal number: 1

FFT window

Start time (s): 0.1

Number of cycles: 1

Fundamental frequency (Hz): 50

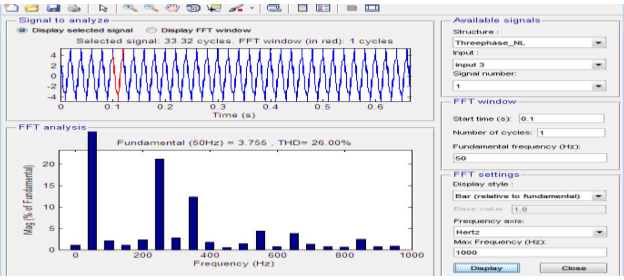
FFT settings

Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000


Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 33.32 cycles. FFT window (in red): 1 cycles

FFT analysis

Fundamental (50Hz) = 3.755 , THD= 26.00%

Available signals

Structure : Threephase_NL

Input : input 3

Signal number: 1

FFT window

Start time (s): 0.1

Number of cycles: 1

Fundamental frequency (Hz): 50

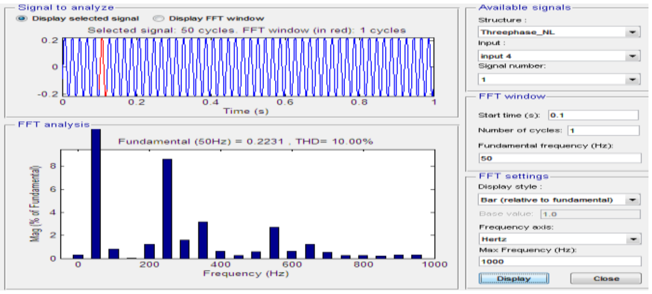
FFT settings

Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000


Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 50 cycles. FFT window (in red): 1 cycles

FFT analysis

Fundamental (50Hz) = 0.2231 , THD= 10.00%

Available signals

Structure : Threephase_NL

Input : input 4

Signal number: 1

FFT window

Start time (s): 0.1

Number of cycles: 1

Fundamental frequency (Hz): 50

FFT settings

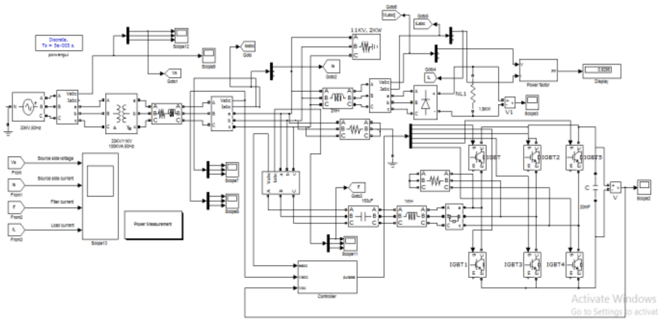
Display style : Bar (relative to fundamental)

Base value: 1.0

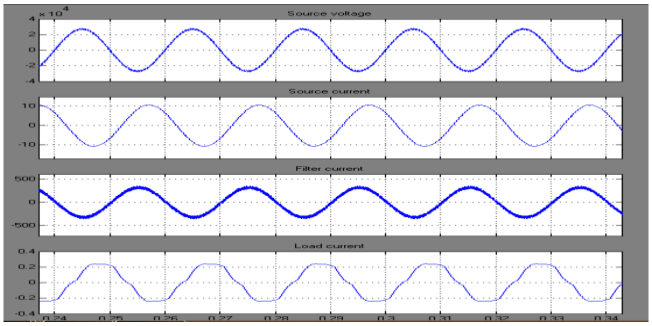
Frequency axis: Hertz

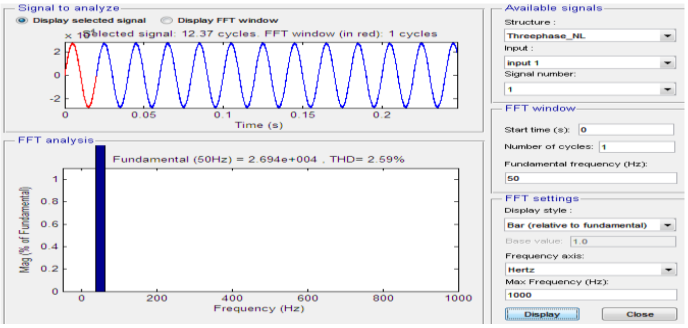
Max Frequency (Hz): 1000

Simulink Circuit with Hybrid Filter Before Compensation



Hybrid Filter Before Compensation:




Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 12.37 cycles. FFT window (in red): 1 cycles

FFT analysis

Fundamental (50Hz) = 2.694e+004 , THD= 2.59%

Available signals

Structure : Threephase_NL

Input : input 1

Signal number: 1

FFT window

Start time (s): 0

Number of cycles: 1

Fundamental frequency (Hz): 50

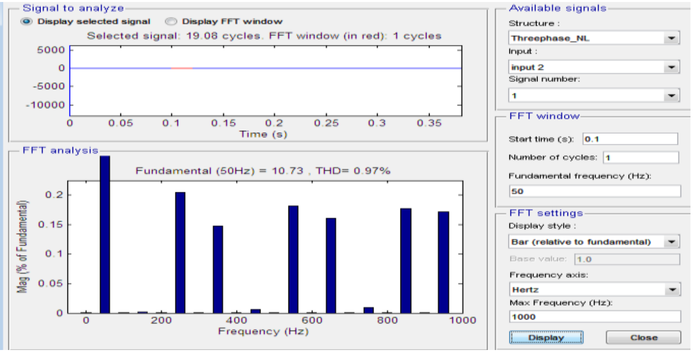
FFT settings

Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000


Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 19.08 cycles. FFT window (in red): 1 cycles

FFT analysis

Fundamental (50Hz) = 10.73 , THD= 0.97%

Available signals

Structure : Threephase_NL

Input : input 2

Signal number: 1

FFT window

Start time (s): 0.1

Number of cycles: 1

Fundamental frequency (Hz): 50

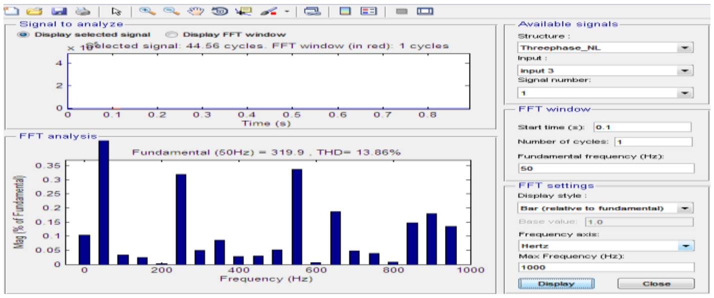
FFT settings

Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000


Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 44.56 cycles. FFT window (in red): 1 cycles

FFT analysis

Fundamental (50Hz) = 319.9 , THD= 13.86%

Available signals

Structure : Threephase_NL

Input : input 3

Signal number: 1

FFT window

Start time (s): 0.1

Number of cycles: 1

Fundamental frequency (Hz): 50

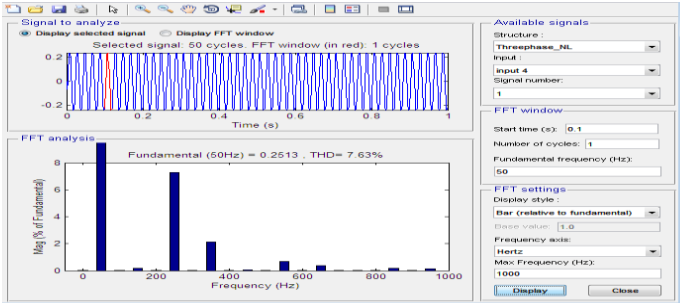
FFT settings

Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Max Frequency (Hz): 1000


Signal to analyze

● Display selected signal ○ Display FFT window

Selected signal: 50 cycles. FFT window (in red): 1 cycles

FFT analysis

Fundamental (50Hz) = 0.2513 , THD= 7.63%

Available signals

Structure : Threephase_NL

Input : input 4

Signal number: 1

FFT window

Start time (s): 0.1

Number of cycles: 1

Fundamental frequency (Hz): 50

FFT settings

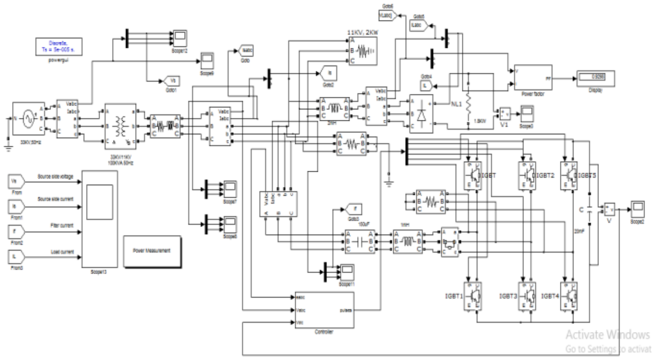
Display style : Bar (relative to fundamental)

Base value: 1.0

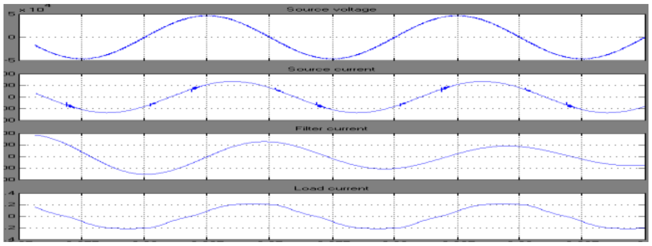
Frequency axis: Hertz

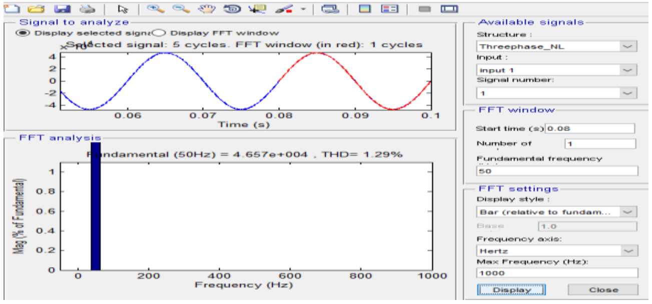
Max Frequency (Hz): 1000

Simulink Circuit For Hybrid Filter After Reactive Power Compensation



Hybrid Filter After Compensation



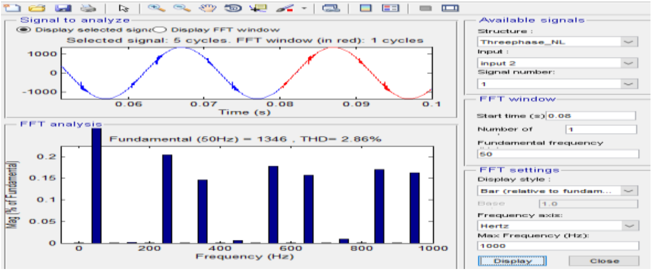

Signal to analyze
● Display selected signal ○ Display FFT window
Selected signal: 5 cycles. FFT window (in red): 1 cycles

FFT analysis
Fundamental (50Hz) = 4.657e+004 , THD= 1.29%

Available signals
Structure : Threephase_NL
Input : input 1
Signal number: 1

FFT window
Start time (s) 0.08
Number of 1
Fundamental frequency 50

FFT settings
Display style : Bar (relative to fundam...
Base 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

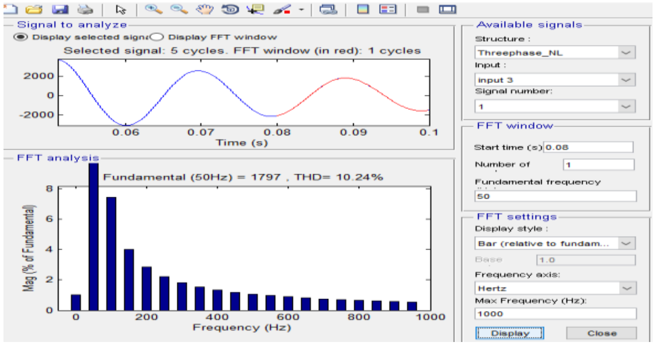

Signal to analyze
● Display selected signal ○ Display FFT window
Selected signal: 5 cycles. FFT window (in red): 1 cycles

FFT analysis
Fundamental (50Hz) = 1346 , THD= 2.86%

Available signals
Structure : Threephase_NL
Input : input 2
Signal number: 1

FFT window
Start time (s) 0.08
Number of 1
Fundamental frequency 50

FFT settings
Display style : Bar (relative to fundam...
Base 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

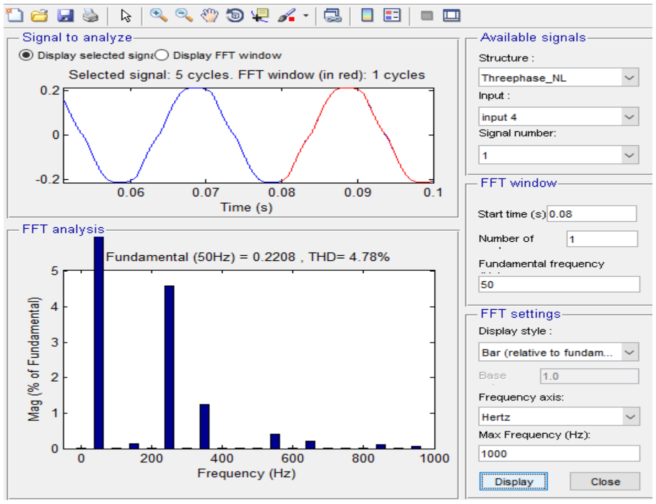

Signal to analyze
● Display selected signal ○ Display FFT window
Selected signal: 5 cycles. FFT window (in red): 1 cycles

FFT analysis
Fundamental (50Hz) = 1797 , THD= 10.24%

Available signals
Structure : Threephase_NL
Input : input 3
Signal number: 1

FFT window
Start time (s) 0.08
Number of 1
Fundamental frequency 50

FFT settings
Display style : Bar (relative to fundam...
Base 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000


Signal to analyze
● Display selected signal ○ Display FFT window
Selected signal: 5 cycles. FFT window (in red): 1 cycles

FFT analysis
Fundamental (50Hz) = 0.2208 , THD= 4.78%

Available signals
Structure : Threephase_NL
Input : input 4
Signal number: 1

FFT window
Start time (s) 0.08
Number of 1
Fundamental frequency 50

FFT settings
Display style : Bar (relative to fundam...
Base 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

III. SUMMARY OF THE RESULTS:

3-Φ loads	**HAFU OFF STATE**	**HAFU ON STATE**
Source Voltage (eab)	3.09 %	2.58 %
Source Current (is)	7.16 %	4.81 %
Filter Current (if)	25.99 %	13.64 %
Load Current (iL)	9.99 %	7.63 %

TOTAL HARMONIC DISTORTIONS	**HYBRID FILTER BEFORE COMPENSATION**	**HYBRID FILTER AFTER COMPENSATION**
Source Voltage (eab)	2.58 %	1.29 %
Source Current (is)	4.81 %	2.86 %
Filter Current (if)	13.94 %	10.25 %
Load Current (iL)	7.63 %	4.78 %

PARAMETERS	**HYBRID FILTER BEFORE COMPENSATION**	**HYBRID FILTER AFTER COMPENSATION**
Load Voltage	10.3 KV	11KV
Power Factor	0.894	0.929
Active Power	2844 W	3153 W
Reactive Power	1451 VAR	1213 VAR

IV. CONCLUSION:

In this paper the role of Hybrid Active Filter unit to suppress the harmonic distortion is discussed. The hybrid active filter is composed of the seventh harmonic tuned passive filter and an active filter in series connection and with the active filter operating as the variable harmonic conductance, the filtering performances of the passive filter can be significantly improved. Simulation results verify the effectiveness of the proposed system.

- The voltage distortion due to non- linearity can be reduced by increasing the conductance.

- Decrease in conductance leads to reduction in voltage distortion.
- High frequency resonance due to capacitive filter can be reduced by this method.

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