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# Harmonic Reduction Using Seven-Level Shunt Active Power Filter For High-Power Non-Linear Load System

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**Abstract: This Paper proposes the high-power non-linear loads, such as mainly used in electric novel ships, the shunt active power filter is proposed here to reduce the harmonic contents in source voltage and source currents of harmonic polluted three phase system supplying a Non-linear load. The Shunt active filter is designed with Sevenlevel cascaded H-bridge inverter. To handle the large compensation currents and provide better thermal management, two or more paralleled semiconductor switching devices can be used. In this paper two active filter inverters are connected with tapped reactors to share the compensation currents. The active filter topology can produce seven voltage levels. The harmonic filter reduces the harmonic contents in source currents as well as the source voltage multilevel shunt active filter does not require an interfacing transformer to connect it with the high power system. This is shown through simulation that the proposed active filter can achieve high overall system performance.**

**Key words: Shunt Active power filters, Total harmonic distortion, Power conversion.**

## 1. INRODUCTION

In Modern power quality electrical system, the power quality expressed as quality of voltage and quality of current are defines as “The measure, analysis and improvement of the bus voltage with sinusoidal wave form at rated voltage and constant freaquency”. There has been a sudden increase of non-linear loads, such as power supplies, adjustable speed drives etc. These non-linear loads draw non-sinusoidal currents from supply and causes distortion called harmonics. These Harmonics further causes problems such as voltage distortion, over heating of equipment, excessive neutral current, poor power factor etc. These voltage and current harmonics might affect the operation of devices in AC system. Conventionally, passive LC filters are used to reduce or eliminate harmonics related problems. However due to their inflexibility and large size, passive filters are replaced by active filters. In that various active filter configurations, the shunt active filter system have number of advantages and constitute the optimal harmonic filtering solution. Generally, the ratings of shunt active filters are based on the rms compensating current and the rms terminal voltage for High-power applications such as ship propulsion systems. The large compensation current often requires parallel operation of two or more switching devices or active filters.

In the years of recent, multilevel converters have shown some significant advantages over traditional two-level converters. Espicially for high-power and high-voltage applications. In addition to their superior output voltage quality, they can also reduce voltage stress across switching devices. Since the output voltages have multilevels, lower dv/dt is achieved.

Which is greatly alleviates electromagnetic interference problems due to high frequency switching. Over the years, most research work has focused on converters with three to five voltage levels, although topologies with very high number of voltage levels were also presented. Generally, the more voltage levels converter has the less harmonic and better power quality it provides. However, the increase in converter complexity and number of switching devices is a major concern for a multilevel converter. More voltage levels shown generally mean lower total harmonic distortion, the gain in THD is marginal for converters with more than seven levels.

This Paper presents a shunt active filter configuration that uses tapped reactors for harmonic current sharing. It reduces switching devices current stress by distributing the compensation current between two parallel legs of an H-bridge topology. Shunt active filter also reduces voltage stress across the switches by utilizing a conventional three-level flying capacitor topology. Overall, the configuration is capable of producing seven distinct voltage levels, and greatly reduces switching ripple in the compensating currents.

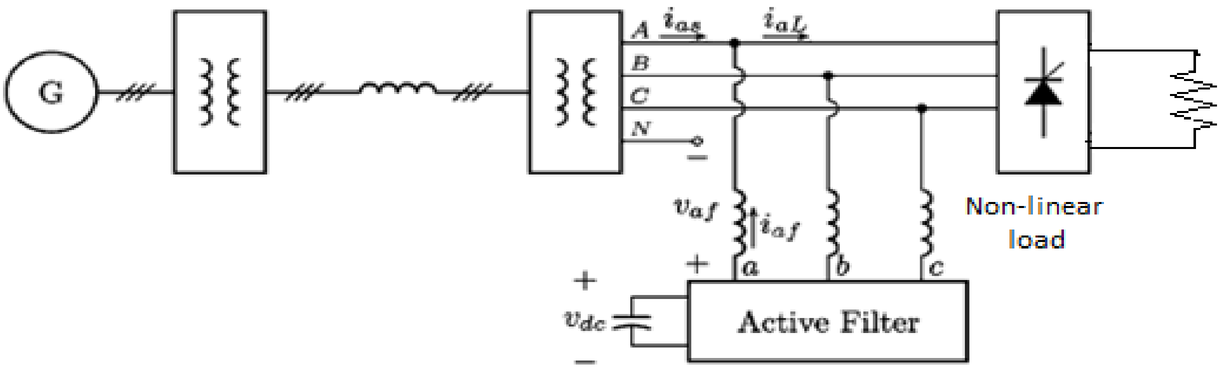


Fig.1 Active filter connection to a shipboard power system

## 2. SHUNT ACTIVE POWER FILTER

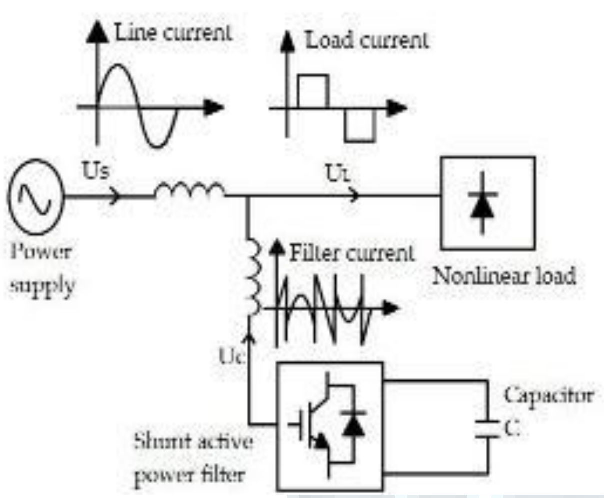


Fig.2 Schematic of Shunt active power filter

The Shunt topology is most popular as compared to others due to its performance and easy implementation. Active power filters has an alternate solution to passive filters. Active power filters are workable alternative for traditional passive filters to improve power factor and reduce harmonics in power system. The active power filter topology selection depends upon total harmonic distortion, power rating and cost of passive filter components, power factor, filter losses, switching losses, capability to provide harmonic isolation between load and supply, control complexity.

The Active filter topology consists of an H-bridge configuration made from three-level flying capacitor branches. It is essentially a voltage source inverter with capacitive energy storage (Cdc) shared by all three-phase. A total of eight switching devices are used in each phase. A tapped reactor is used to connect the two legs of the H-bridge. The reactor is Tipically wound to be center tapped, making the output line-to-ground voltages (for example Vag) the average of the voltages from each side of the H-bridge. Then, the line-to-ground voltages will have five distinct voltage levels. However, with this topology the tap is set at 1/3 position. This results in seven distinct output voltages, and improves the power quality.

### A. Active Filter Control:

Compensate the load harmonic currents to effectively, the active filter should be designed to meet these three goals. They are

(1) Extract and inject load harmonic currents.
(2) Maintain a constant DC capacitor voltage.
(3) Avoid generating or absorbing reactive power with fundamental frequency components.

## 3. TOTAL HARMONIC DISTORTION

Most of the common harmonic currents for diode or thyristor rectifier loads are of the $5^{th}$,$7^{th}$,$11^{th}$ and $13^{th}$ order. Although a high-pass filter can be used to extract these components directly from the line currents, it is not feasible to obtain high attenuation at the fundamental frequency due to the high current amplitude. Generally, the more voltage levels converter has the less harmonic and better power quality it provides. However, the increase in converter complexity and number of switching devices is a major concern for a multilevel converter. The more voltage levels mean it shown less total harmonic distortion. In this paper, a predictive current regulator is implemented to track the harmonic currents, which has the advantages of simple structure and less computational requirement.

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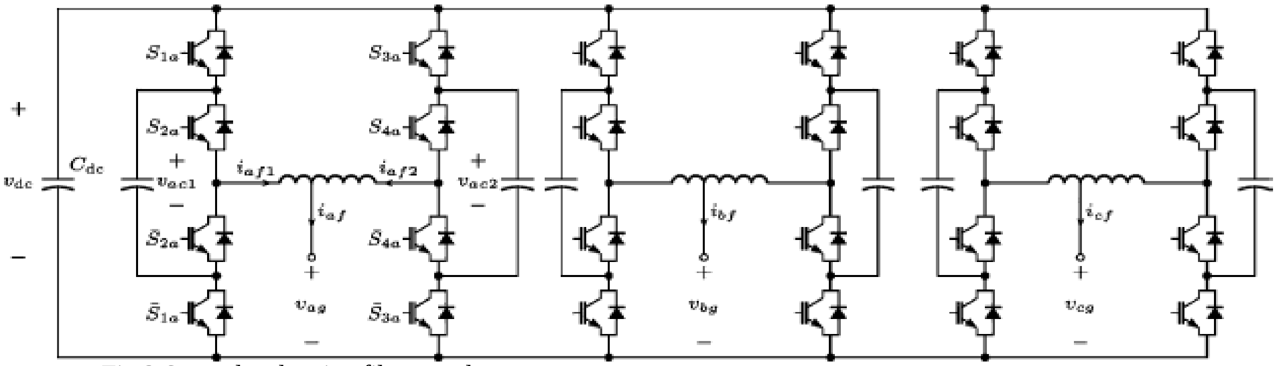

Fig.3 Seven-level active filter topology

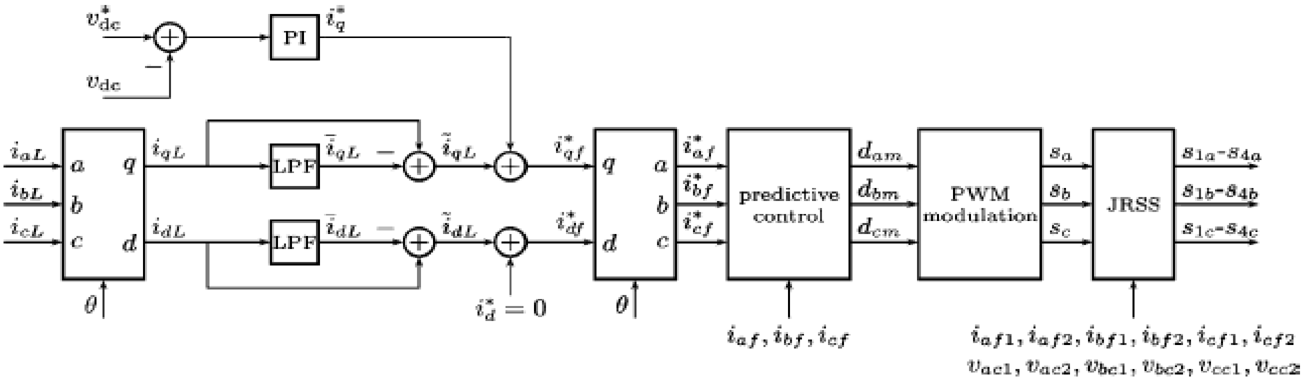

Fig.4 Active filter control diagram

## 4. MULTILEVEL INVERTER TOPOLOGY

A cascaded multilevel inverter made up of from series connected full bridge inverter, each with their own isolated dc bus. The seven level voltage source modulation is accomplished by comparing the duty cycles with a set of six carrier waveforms. This is illustrated for phase ‘a’ shown in fig.5 .

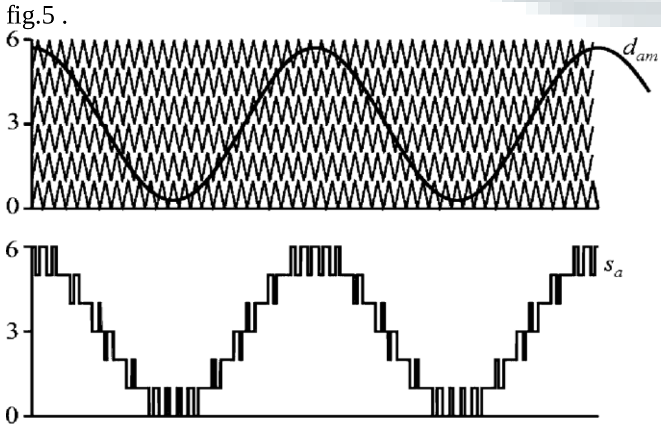

Fig.5 seven-level voltage source modulation

The resulting switching state $s_a$ is the number of triangle waveforms that the duty cycle is greater. Therefore the switching state has a range of 0-6. And this will appear in tabular form (Table I)

TABLE I
ACTIVE FILTER LINE-TO-GROUND VOLTAGES

| $s_a$ | $v_{a1}$ | $v_{a2}$ | $v_{ag}$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 1 | 0 | $v_{dc}/2$ | $v_{dc}/6$ |
| 2 | $v_{dc}/2$ | 0 | $v_{dc}/3$ |
| 2' | 0 | $v_{dc}$ | $v_{dc}/3$ |
| 3 | $v_{dc}/2$ | $v_{dc}/2$ | $v_{dc}/2$ |
| 4 | $v_{dc}/2$ | $v_{dc}$ | $2v_{dc}/3$ |
| 4' | $v_{dc}$ | 0 | $2v_{dc}/3$ |
| 5 | $v_{dc}$ | $v_{dc}/2$ | $5v_{dc}/6$ |
| 6 | $v_{dc}$ | $v_{dc}$ | $v_{dc}$ |

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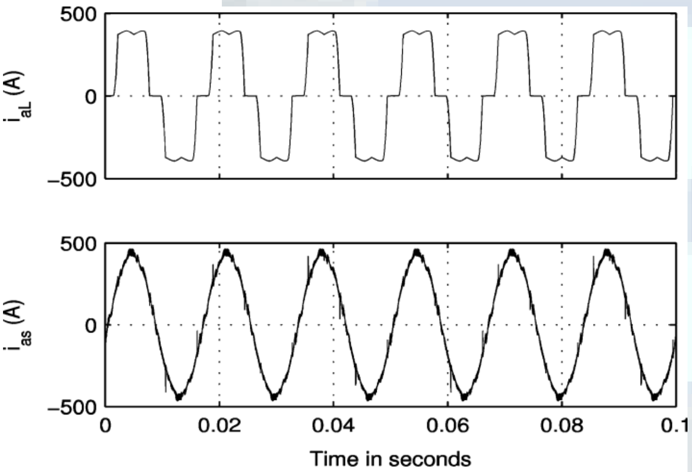
## A. Non-linear loads:

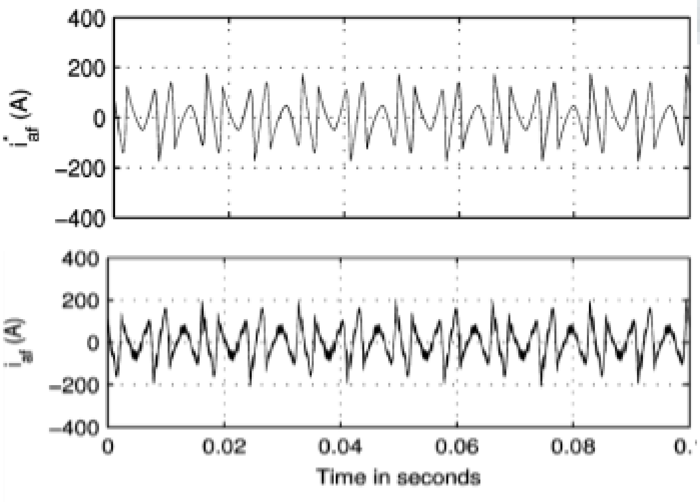
The non-linear loads are plays an important role in this paper. The loads are apply to the system in non-linear mode the harmonics are present in the system. For compensating the harmonics the shunt active filter topology is used. The voltage levels are increased the total harmonic distorsion is less and power quality is improved. So, that's why the seven level active filter is used.

## 5. SIMULATION RESULTS

The simulation results have been conducted in the advanced continuous simulation language (ACSL) to validate the proposed topology. The example naval ship power has a rated line-to-line voltage of 4.16kv and a three-phase six-pulse diode rectifier. The rated dc capacitor voltage of the active filter is 6800v. The three-phase tapped reactor has leakage inductance of $L_{l\ =\ 50}$ μH, winding resistance r = 0.1Ω, and mutual inductance $L_M$ = 1H. The active filter interface inductance is $L_f$ = 0.1mH.




(a)

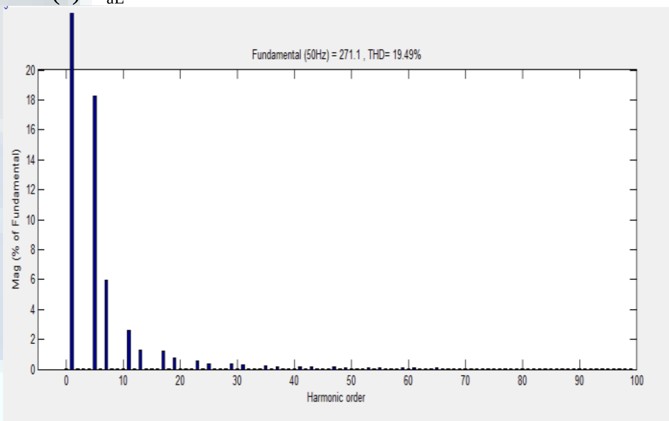



(b)

Fig.6 Active filter detailed simulation results

In Fig.6 shows the phase 'a' operation of the active filter with a rectifier load. As can be seen, the load current $i_{al}$ contains a significant amount of harmonics. The active filter produces multilevel voltages that generate a current $i_{af}$ to cancel the harmonic contents. The compensated source current $i_{as}$ contains much less harmonics than $i_{aL}$. The magnitudes of the harmonic spectrum of the load and source currents are shown in fig.7.

(a) $i_{aL}$ : load current




(b) $i_{as}$ :source current

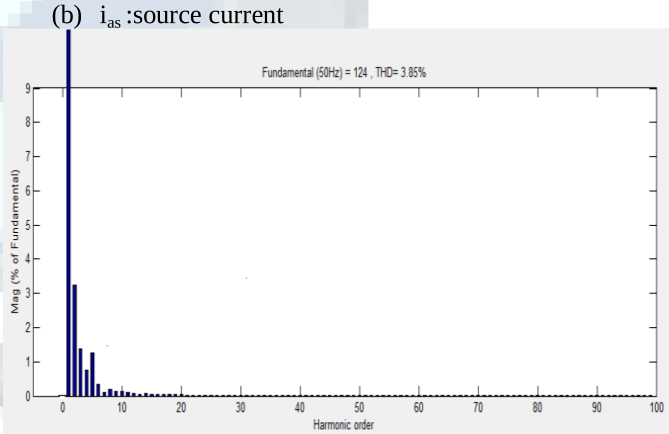



Fig.7 Harmonic magnitude in load and source currents

The total harmonic distortion of the load current is 19.49%, which is reduced to about 3.85% in the compensated source current. The source current still contains a certain amount of higher frequency components. However they are generally not a concern and can easily be removed by passive filters.

To illustrate the generation of seven voltage levels, fig.8(a) shows the phase 'a' line-to-dc-ground voltages applied at each end of the tapped reactor.

These voltage is produced by the flying capacitor legs and have three-levels. The phase 'a' converter-side line-to-neutral output voltage $V_{af}$ from the ACSL simulation is shown in fig.8(b). In this the multiple voltage levels give the voltage a smooth shape that reduces injection current ripple.

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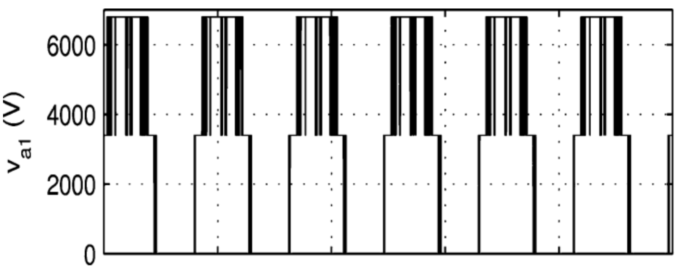
(a) $V_{a1}$




(b) $V_{af}$

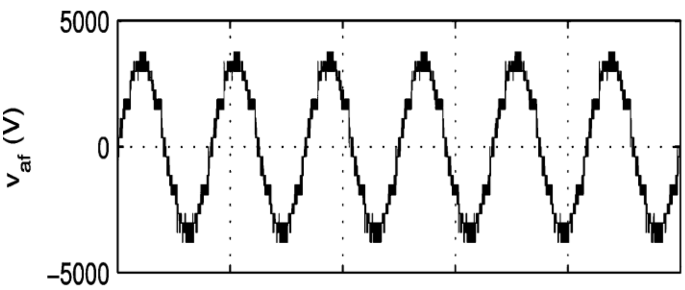



Fig.8 Reactor terminal and output voltages

## 6. CONCLUSION

This paper is the new model of power converter, the converter is based on parallel connection of phase legs through an interconnection reactor. However, this reactor has an off-center tap at one-third position resulting in an increased number of voltage levels. Specially, the flying capacitor phase legs are paralleled in this way to form a seven-level voltage converter. The converter is used an active filter control application. By used this active filter the details of the high-level control as well as the switching control have been presented. The control way is by using the reactors share the compensation currents as well as flying capacitor voltage balance. This technology mainly useful in a naval ship board system.

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