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Ripple Reduction Using Seven-Level Shunt Active Power Filter for High-Power Drives and Non-Linear Load System

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ABSTRACT: This Paper proposes the high-power non-linear loads and high-power adjustable-speed motor drives, 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 and drives. The Shunt active filter is designed with Seven level 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. Based on the joint redundant state selection strategy, a current balancing algorithm is proposed to keep the reactor magnetizing current to a minimum. 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.

KEYWORDS: Shunt Active power filters, Total harmonic distortion, Power conversion, Power Drives.

I. INRODUCTION

ADJUSTABLE-SPEED motor drives (ASDs) have found extensive application in a variety of high-power systems. One example is the electric propulsion system used in modern naval ships, the power ratings of which can be tens of megawatts. Typically, the front-ends of such ASDs employ a diode or a thyristor rectifier. In spite of their simple control and robust operation, these devices can generate voltage and current harmonics that might affect the operation of other devices in the same ac system. Conventionally, passive LC filters are used to mitigate harmonic-related problems. However, due to their large size and inflexibility, passive filters are gradually being replaced by active filters that utilize power electronic inverters to provide compensation for harmonics [1]

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 frequency”. 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.

The schematic diagrams of shunt active filters with nonlinear load and High power drive (Shipboard power system) have shown in fig 1 & fig 2. Especially 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 multilevel, 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.

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 current

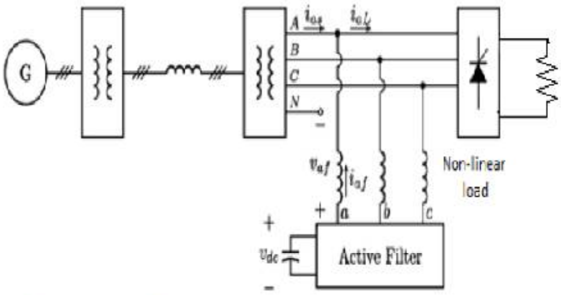

Fig.1 Active filter connection to a Nonlinear power system

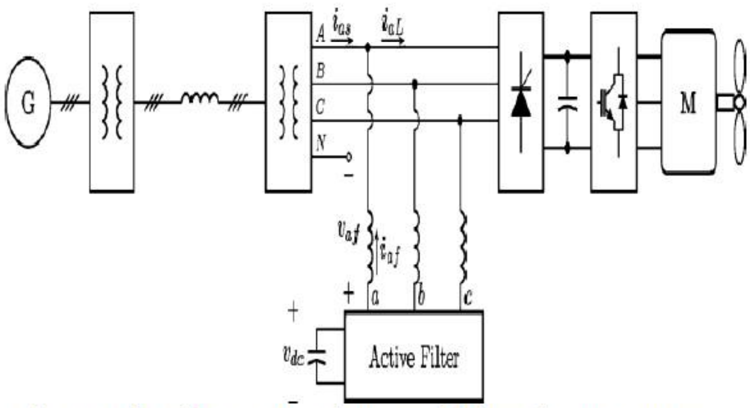

Fig.2. Active filter connection to a shipboard power system

II. 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. The schematic diagram of shunt active filter shown in fig. 3.

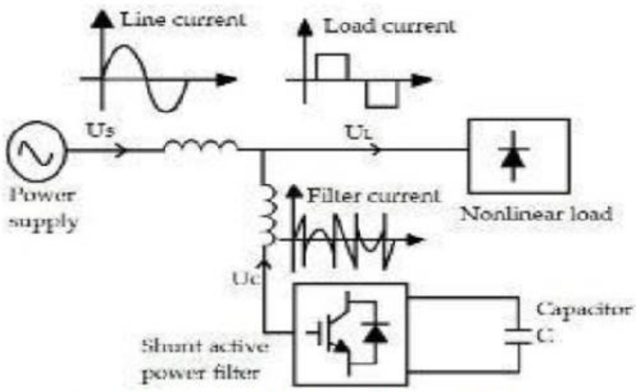

Fig.3 Schematic of Shunt active power filter

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 typically 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.

III. ACTIVE FILTER CONTROL

To effectively compensate the load harmonic currents, the active filter controller should be designed to meet the following three goals: 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.

A. Total harmonic distortion

Most of the common harmonic currents for diode or thyristor rectifier loads are of the 5th, 7th, 11th and 13th 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 the more voltage levels mean it shown less total harmonic distortion. However, the increase in converter complexity and number of switching devices is a major concern for a multilevel converter.

Low-pass filters are then used to extract the dc components, which correspond to the fundamental frequency components of the load currents.

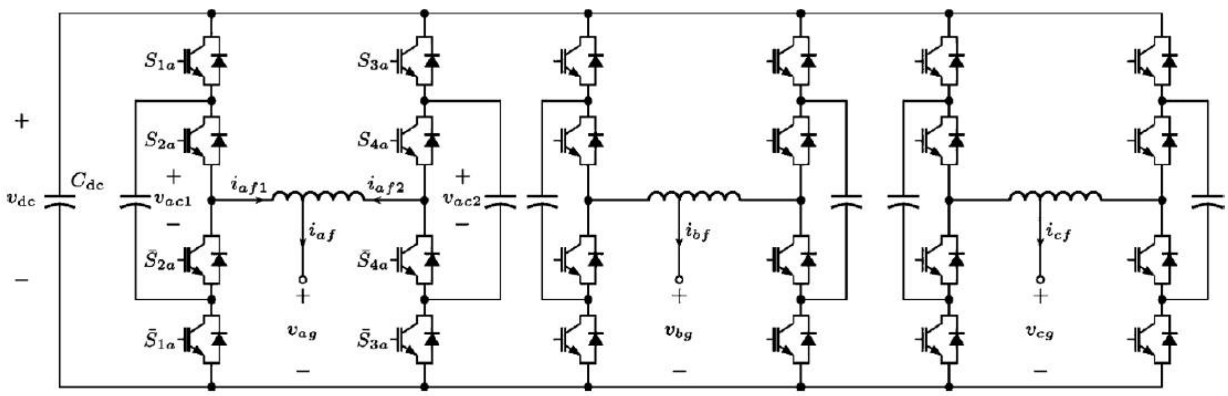

Fig.5 Proposed seven-level active filter topology.

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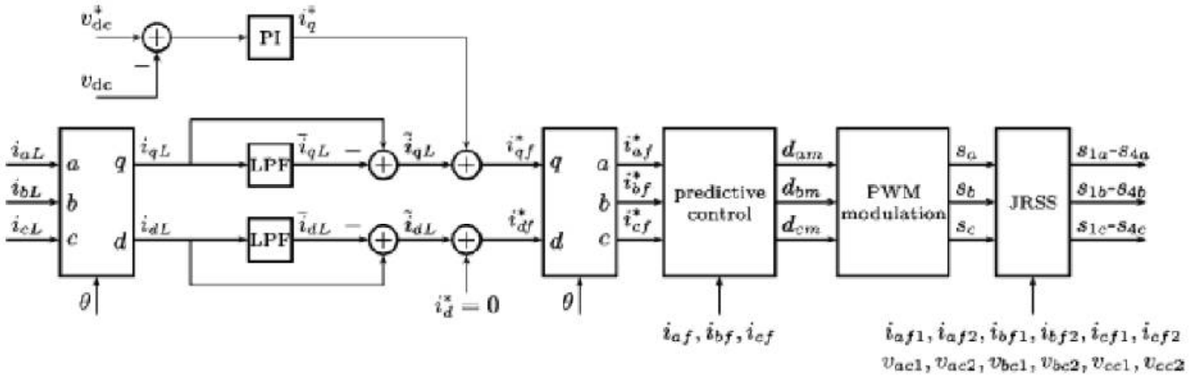

Fig.6 Active filter control diagram

B. DC Capacitor Voltage Control For the active filter to operate effectively, it is important to maintain the dc capacitor voltage at a constant value. Since the active filter topology is essentially identical to that of an active rectifier, similar control strategies for the active rectifier are applicable. The dc capacitor voltage is directly affected by the real power transferred across the active filter. To keep the voltage constant, ideally, no real power should be transferred. However, due to losses in switching devices and other components, a small amount of real power is needed. In the synchronous reference frame with the *q*-axis aligned with the voltage at the point of common coupling, the real power transferred can be expressed as

$$P = \frac{3}{2} v_{qs} i_{qf}$$

which means that by adjusting the q-axis filter current, the real power can be effectively controlled. The capacitor voltage regulation is then handled by a simple proportional-integral (PI) control adding to the q-axis filter current, shown in Fig 6.

IV. MULTILEVEL INVERTER TOPOLOGY

A cascade multilevel inverter made up of from series connected full bridge inverter, each with their own isolated dc bus. The seven level voltage source modulations are able to comparing the duty cycles with a set of six carrier waveforms. This is illustrated for phase “a‟ shown in fig 7.

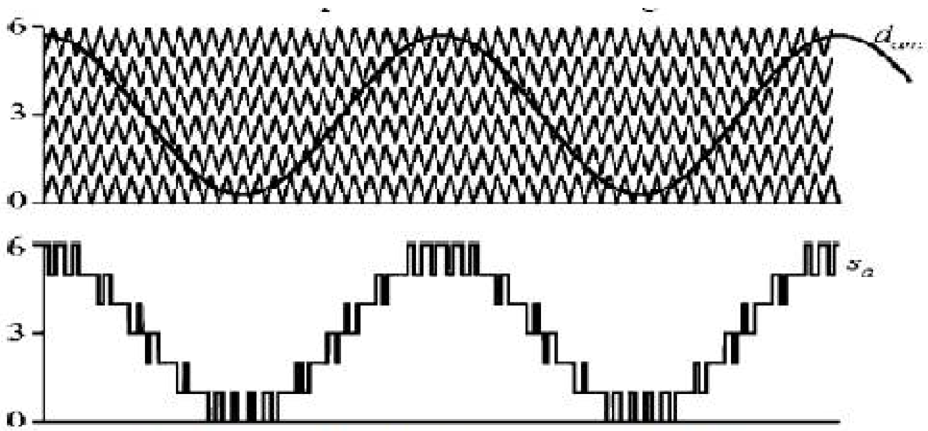

Fig.7 seven-level voltage source modulation

A. Multilevel Voltage-Source Modulation

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 in Fig 7. The resulting switching state is the number of triangle waveforms that the duty cycle is greater than. Therefore, the switching state has a range of 0–6, and this is in agreement with Table I.

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B. Capacitor Voltage Balancing

After carrying out the modulation, the switching states for each phase need to be broken out into transistor signals.

In order to have the correct voltage levels, the flying capacitors must remain charged at exactly **v**dc/2. The resulting switching state sa 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

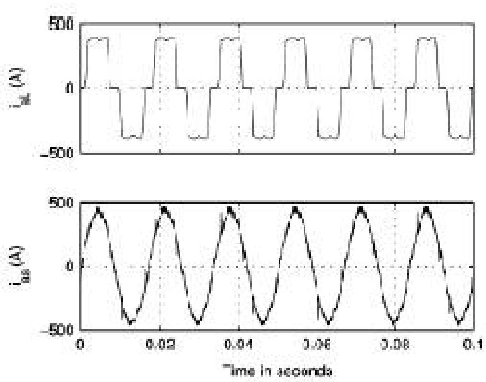
s_{1a}	s_{2a}	v_{a1}	i_{af1}	Charging
0	0	0	+	0
0	0	0	–	0
1	1	v_{dc}	+	0
1	1	v_{dc}	+	0
0	1	$v_{dc}/2$	+	–
0	1	$v_{dc}/2$	–	+
1	0	$v_{dc}/2$	+	+
1	0	$v_{dc}/2$	–	–

C. 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 distortion is less and power quality is improved. So, that's why the seven level active filter is used.

V. SIMULATION RESULTS

Numerical simulations have been conducted in the Advanced Continuous Simulation Language (ACSL) to validate the proposed topology. The example naval ship power system has a rated line-to-line voltage of 4.16 kV and a three-phase six-pulse diode rectifier. A three-phase PWM inverter is connected to the rectifier dc bus, and supplies power to a permanent-magnet synchronous motor load. The rated dc capacitor voltage of the active filter is 6800 V. The three-phase tapped reactor has a leakage inductance of Ll = 50 μH, winding resistance r = 0.1 Ω, and mutual inductance LM = 1 H. The active filter interface inductance is Lf = 0.1 mH.

In Fig.8 shows the phase „a" operation of the active filter with a rectifier load. As can be seen, the load current ial 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.9 and fig 10.



(a)

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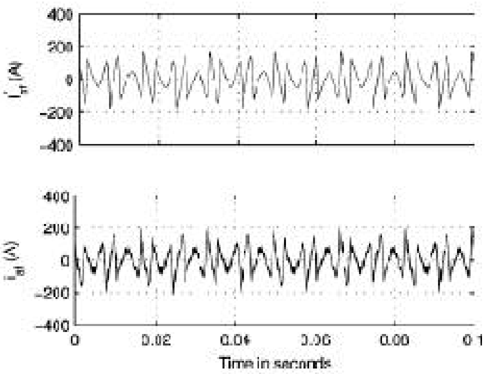

(b)

Fig. 8. Active filter detailed simulation results

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.

(a) ial : load current

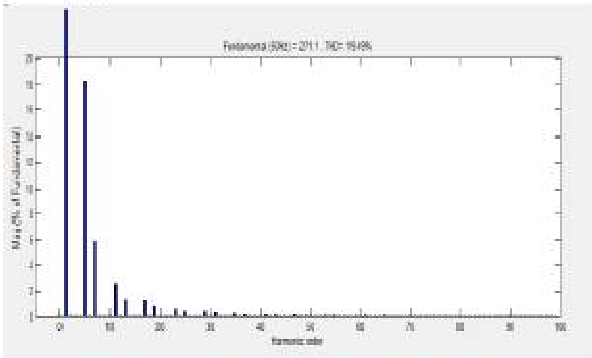

Fig. 9. Harmonic magnitude in load current

To illustrate the generation of seven voltage levels, fig.11(a) shows the phase „a" line-to-dc-ground voltages applied at each end of the tapped reactor.

(b) ias: source current

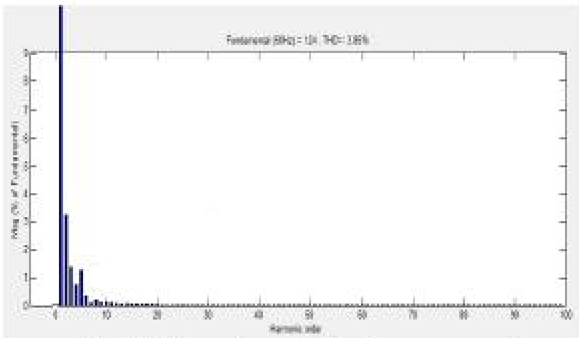

Fig. 10. Harmonic magnitude in source current

The voltage is produced by the flying capacitor legs and has three-levels. The phase „a" converter-side line-to-neutral output voltage **v**af from the ACSL simulation is shown in fig.11(b). In this the multiple voltage levels give the voltage a smooth shape that reduces injection current ripple.

VI. CONCLUSION

A new type of power converter has been introduced in this paper. The converter is based on parallel connection of phase legs through an inter phase reactor. However, the reactor has an off-center tap at one-third resulting in an increased number of voltage levels. Specifically, two three-level flying capacitor phase legs are paralleled in this way to form a seven-level power converter. The converter is utilized in an active filter application. The details of the high-level control as well as the switching control have been presented. The control ensures reactor current sharing a swell as flying capacitor voltage balance. The proposed active filter has been validated for a naval ship board power system.

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