Efficient Harmonic Reduction in MLI Based Three Phase System using Seven Level SAPF

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Abstract* - *In high-power controlled-speed motor drives, such as those used in electric ship propulsion systems, active filters provide a viable solution to mitigating harmonic related issues caused by diode or thyristor rectifier front-ends. To handle the large compensation currents and provide better thermal management, two or more paralleled semiconductor switching devices can be used. In this work, a novel topology is proposed where two active filter inverters are connected with tapped reactors to share the compensation currents. The proposed active filter topology can also produce seven voltage levels, which significantly reduces the switching current ripple and the size of passive components. Based on the joint redundant state selection strategy, a current balancing algorithm is proposed to keep the reactor magnetizing current to a minimum. It is shown through simulation that the proposed active filter can achieve high overall system performance. The system is also implemented on a real-time digital simulator to further verify its effectiveness.

IndexTerms—Active filters, harmonic analysis, power conversion, power electronics.

I. INTRODUCTION

The power demand always exceeds the available power generation in any developing country. Hence, renewable power generating systems such as PV and wind energy conversion systems are used to supplement the fossil fuel based power generation. But due to the non-linearity of the load that is diode bridge rectifier with RL- load, there is harmonics in the load currents. Hence, harmonics reduction and reactive power compensation simultaneously can be done by using a voltage source inverter connected in parallel with the system which acts as a shunt APF for reducing the distortions produced due to non-linear load in the load current. This active filter generates a compensating current which is of equal in magnitude as harmonic current and opposite in phase with it to reduce the harmonics present in the load current.APF is classified as series, shunt or combination both series and shunt but shunt APF is preferred here as the principle of the shunt APF is to produce compensating currents of equal in magnitude but opposite in-phase to those harmonics that are present due to non-linear loads. Multilevel inverters have been under research and development for more than three decades and have found successful industrial applications. However, this is still a technology under development, and many new contributions and new commercial topologies have been reported in the last few years. The aim of this work is to group and review recent contributions, in order to establish the current state of the art and trends of the technology to provide readers with a comprehensive and insightful review of where multilevel converter technology stands and is heading. This chapter first presents a brief overview of well- established multilevel inverters strongly oriented to their current state in industrial applications and then centers the discussion on the new multilevel inverters that have made their way into the industry. Multilevel inverters have been attracting increasing interest recently the main reasons are; increased power ratings, improved harmonic performance, and reduced electromagnetic interference (EMI) emission that can be archived with multiple dc levels that are synthesis of the output voltage waveform. In particular multilevel inverters have abundant demand in applications such as medium voltage industrial drives, electric vehicles, and grid connected photovoltaic systems. The present work provides a solution to design an efficient multilevel topology which is suited for medium and high power applications. In the subsequent sections the research background is discussed in detailed. Motivation and objectives are clearly outlined.

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II. HARMONIC EXTRACTION SYSTEM MODEL

In recent years both power engineers and consumers have been giving focus on the “electrical power quality” i.e. degradation of voltage and current due to harmonics, low power factor etc. Nearly two decades ago majority loads used by the consumers are passive and linear in nature, with a few non-linear loads thus having less impact on the power system. However, due to technical advancement in semiconductor devices and easy controllability of electrical power, non-linear loads such as SMPS, rectifier, chopper etc. are more used. The power handling capacity of modern power electronics devices such as power diode, silicon controlled rectifier (SCR), Insulated gate bipolar transistor (IGBT), Metal oxide semiconductor field effect transistor (MOSFET) are very large, so the application of such semiconductor devices is very popular in industry as well as in domestic purpose. Whilst these advantages are certainly good but there lies of such excessive use of power electronic devices a great problem, i.e. generation of current harmonics and reactive power in the power system network. As a result, the voltage at different buses of power system network is getting distorted and the utilities connected to these buses are not operated as designed. The harmonic current pollute the power system causing problems such as transformer overheating, voltage quality degradation, rotary machine vibration, destruction of electric power components and malfunctioning of medical facilities etc.

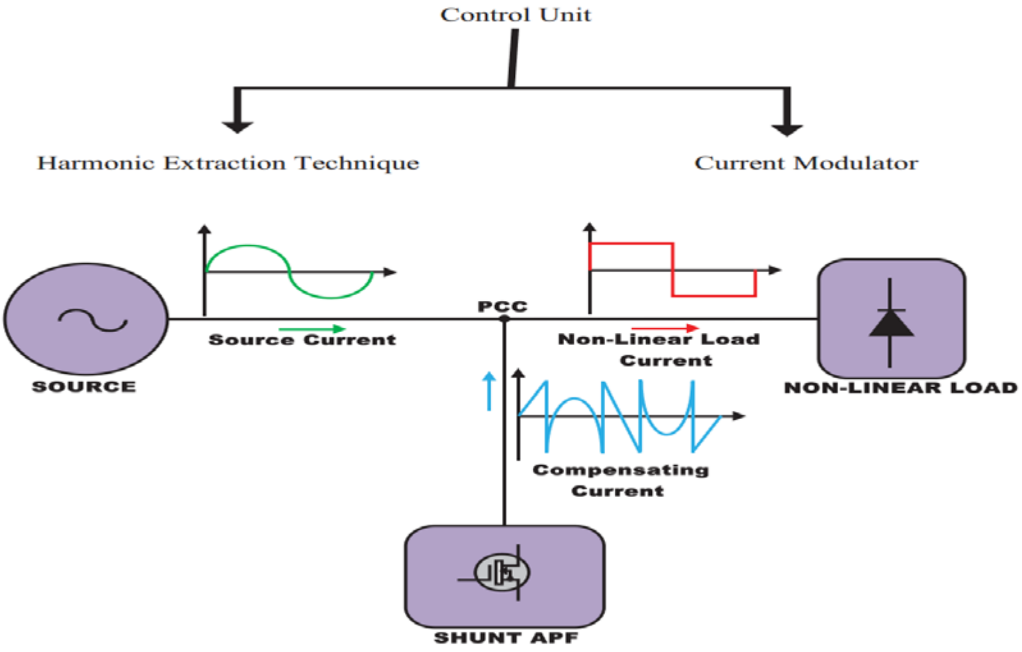

Figure 2.1 Shunt Active power filter.

Harmonic extraction is the process in which, reference current is generated by using the distorted waveform. Many theories have been developed such as p-q theory (instantaneous reactive power theory), d-q theory, frieze controller, PLL with fuzzy logic controller, neural network etc.. Out of these theories, more than 60% research works consider using p-q theory and d-q theory due to their accuracy, robustness and easy calculation.

III. PROPOSED SYSTEM ARCHITECTURE

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. Harmonic Current Extraction

For diode or thyristor rectifier loads, the most common harmonic currents 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. The synchronous q-d reference frame controller developed for shunt active filter systems is used to generate the reference compensating current. As shown in Fig. 3.1, the measured load phase currents (i_{aL} ,i_{bL}, and i_{cL}) are first transformed into the synchronous reference frame to obtain i_{qL} and i_{dL}. The synchronous reference frame phase angle can be obtained by processing the measured system voltage with a phase-locked loop circuit or algorithm. Low-pass filters are then used to extract the dc components, which correspond to the fundamental frequency components of the load currents. The dc component is removed by a simple subtraction of the filtered components (i_{qL} and i_{dL}) and the transformed components (i_{qL} and i_{dL}).

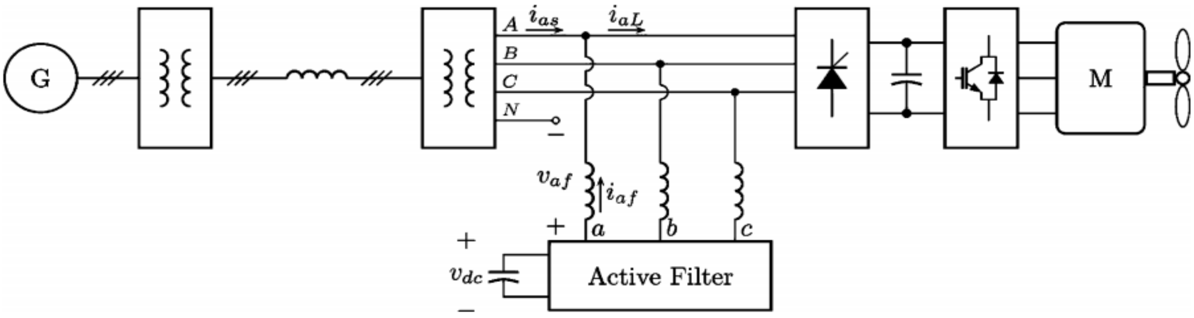

Figure 3.1 1Active filter connections to a shipboard power system.

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.

C. Reactive Power Control

In most cases, a unity power factor for fundamental frequency components is required at the active filter terminals. This goal can be achieved by keeping the average d-axis current at zero, as shown in Fig. 3.2 The combined control of dc capacitor voltage and reactive power uniquely determines the fundamental frequency component of the active filter output current.

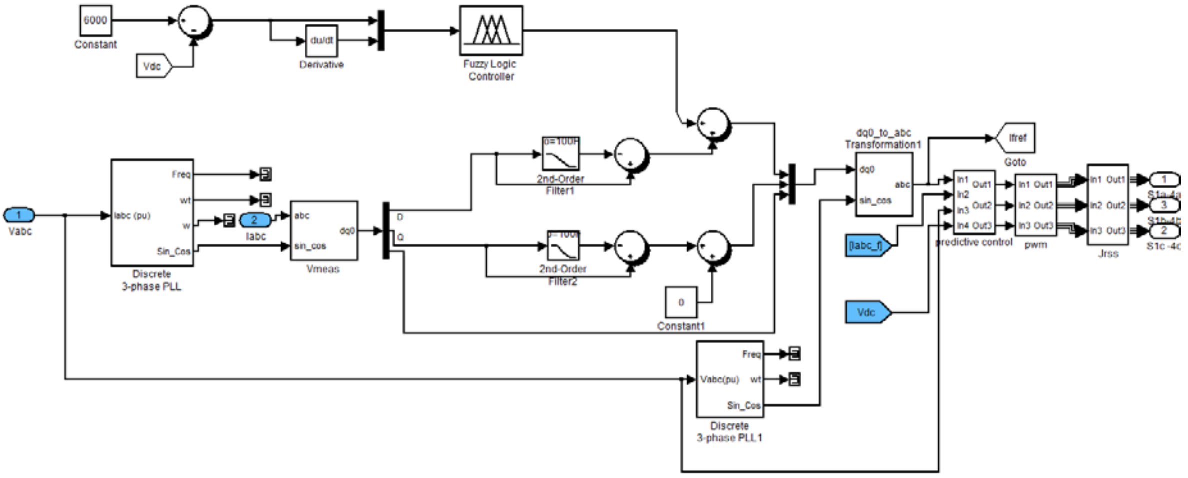

Figure 3.2 Active filter control diagram.

D. Harmonic Current Regulator

A current regulator is needed to generate the commanded compensation current. Generally, a hysteresis control provides fast response and is suitable for non sinusoidal current tracking. However, it suffers from some serious disadvantages such as variable switching frequency and phase interaction problems [1].

IV. SYNTHESIS OUTCOME

Numerical simulations have been conducted in the Matlab simulator Simulink to validate the proposed topology. The outcome of the proposed work has demonstrated in Figure 4.1 to 4.6 below.

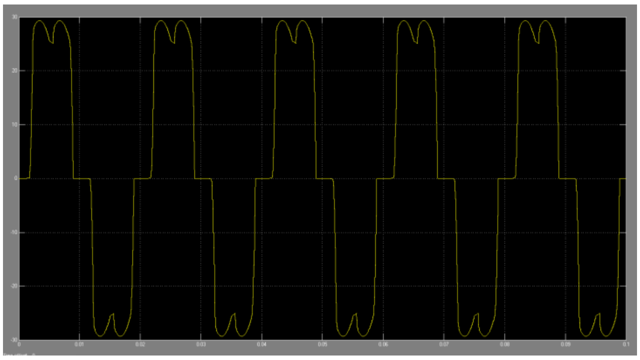

Fig. 4.1 Source current before Compensation

Fig. 4.2 Source current after compensation with fuzzy controller

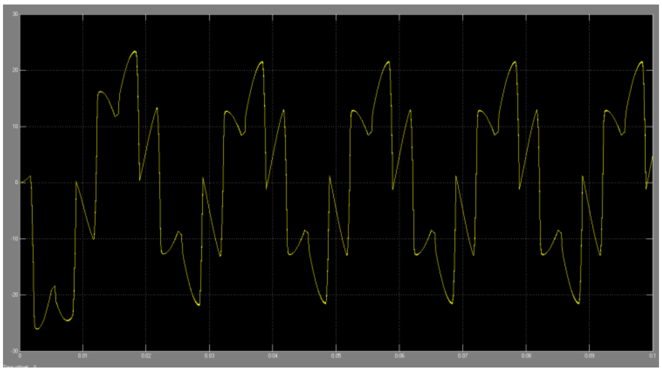

Fig. 4.3 Injected current from multi level SAPF with fuzzy controller

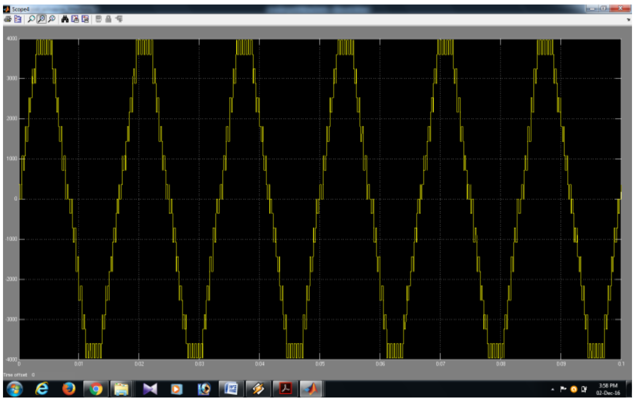

Fig. 4.4 7 levels after compensation with fuzzy controller

Table 1: THD Comparison

Phases	Previous System With SAPF and PI Controller	Proposed System With 7 Level MLI and Fuzzy Logic
Phase A	4.43%	1.41%
Phase B	4.43%	1.39%
Phase C	4.43%	2.42%

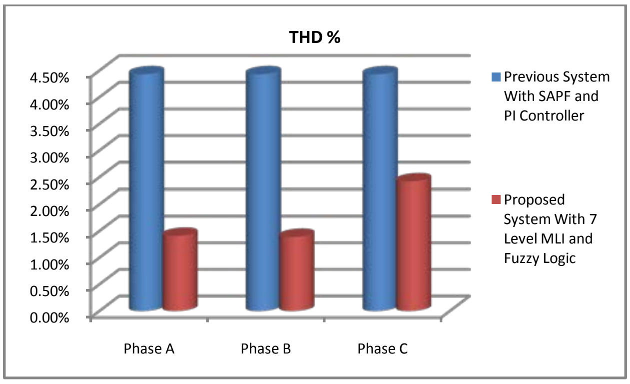

Fig. 4.6 THD Comparison with Previous Work

V. CONCLUSION AND FUTURE SCOPE

A new sort of power converter has been presented in this work. The converter is based on parallel association 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 used in an active filter application. The points of interest of the abnormal state control and the exchanging control have been introduced. The control guarantees reactor current sharing and in addition flying capacitor voltage adjusts. The proposed active filter has been approved for an efficient power system utilizing detailed simulation on MATLAB Simulink and waveform analysis.

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