MODULAR STURUCTURED MULTILEVEL INVERTER AS A THREE-PHASE SHUNT ACTIVE POWER FILTER WITH UNIFIED CONSTANT FREQUENCY INTEGRATION CONTROL

ALI IBRAHIM ISMAAIL

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Specially Dedicated To

My Beloved Mother, Father, Brothers and Sisters

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In the name of Allah, Most Gracious, and Most Merciful

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ABSTRACT

In recent years, the usage of power electronics equipments continues to increase, due to the increased usage of nonlinear loads and distributed power sources. These nonlinear loads generate harmonics and reactive currents, which lead to low power factor, low energy efficiency, low power capacity, and harmful disturbance to other appliances. These reactive currents will distort the voltage at the point of common coupling, reducing the quality of power delivered to other consumers on the network. Nowadays shunt active power filters (APFs), due to their flexibility and reliability are one of the most versatile and efficient solutions in the compensation of the load power factor and current harmonics. APFs provide only the harmonic and reactive power to cancel the one generated by the nonlinear loads or sources. This project presents a Modular Structured Multilevel Inverter (MSMI) as a three-phase shunt active power filter with Unified Constant Frequency Integration (UCI) control. Using MSMI APF with a unified constant-frequency integration controller, a unity power factor and low total harmonic distortion can be realized in all three phases. The proposed control approach employs one integrator with reset, along with several logic and linear components such as flip-flops, comparators, and clock. There are several important features of this implementation, it does not require three-phase load current and phase voltage sensing, also the nontrivial task of calculating harmonics and reactive current component is not required, and finally, it does not use any multipliers. These features make the proposed control approach simple, robust and reliable. The proposed three-phase MSMI APF with UCI control was simulated using MATLAB/Simulink. Simulation results have demonstrated a good suppression in harmonic distortion and improvement in the power factor of the power system.

ABSTRAK

Dalam beberapa tahun kebelakangan ini, penggunaan peralatan elektronik kuasa semakin meninggkat disebabkan oleh peningkatan penggunaan beban tidak lurus dan pengagihan sumber kuasa. Beban tidak lurus mengeluarkan harmonik dan arus re-aktif yang akan mengurangkan faktor kuasa, kecekapan kuasa, kapasiti kuasa dan gangguan berbahaya kepada alatan yang lain. Arus re-aktif akan mengganggu voltan pada titik penyambungan biasa yang mana akan mengurangkan kualiti kuasa yang dihantar kepada pengguna di talian. Sekarang ini, ‘shunt active power filter (APFs)’ banyak digunakan kerana fleksibiliti dan keboleharapan yang sungguh serba boleh dan penyelesain yang cekap dalam menimbal-balik faktor kuasa beban dan harmonik arus. APFs menyediakan harmonik dan kuasa re-aktif untuk membatalkan harmonik dan kuasa re-aktif yang dihasilkan oleh beban tidak lurus atau sumber. Projek ini mempersembahkan ‘Modular Structured Multilevel Inverter (MSMI)’ sebagai tiga fasa ‘shunt active power filter (APFs)’ bersama dengan ‘Unified Constant Frequency Integration (UCI) control’. Dengan menggunakan MSMI APF bersama ‘Unified Control Frequency Integration Control’, faktor kuasa sepadu dan jumlah gangguan harmonik yang rendah boleh direalisasikan pada semua sistem tiga fasa. Kawalan yang telah dicadangkan menggunakan satu pengamilan bersama reset, beberapa logik serta komponen lurus seperti flip-flop, pembanding dan jam. Ada beberapa keutamaan dalam perlaksanaan projek ini, di mana ia tidak menggunakan arus beban tiga fasa dan pengesan voltan fasa. Ia juga tidak menggunakan tugas yang tidak remeh untuk mengira harmonik dan arus re-aktif. Akhir sekali ia juga tidak menggunakan pendarab. Keutamaan ini menghasilkan cadangan kawalan yang mudah, tahan lasak dan boleh diharap. Cadangan menggunakan tiga fasa MSMI APF bersama kawalan UCI telah disimulasi menggunakan MATLAB/Simulink. Keputusan simulasi telah menunjukkan penumpasan gangguan harmonik yang baik dan membaikkan faktor kuasa dalam sistem kuasa.

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CHAPTER 1

INTRODUCTION

The increasing use of power electronic devices to provide more precise control of electrical power has brought about an increase in the distortion of voltage and current waveforms. Modern electrical distribution systems typically supply a high percentage of nonlinear loads. Due to the increased use of nonlinear industrial loads and power electronics, the currents and voltages present on the system can no longer be deemed as pure sinusoidal. These nonlinear loads generate poor power quality. However, the power quality problem has become a great concern due to the rapidly increasing use of nonlinear loads and power electronic equipment. Harmonic distortion is a key phrase used today when talking about power quality. Harmonic distortion is the production of harmonic frequencies by an electronic system when a signal is applied at the input, and it is measured in terms of percent total harmonic distortion of the fundamental frequency [24]. Additional losses in the electrical distribution systems are caused by the harmonic currents. The losses lead to low power factor which yields as overheating in apparatus, higher air-conditioning costs and higher power costs. Furthermore, harmonic will lead to lower reliability.

In the present era of utility deregulation and competition, many utility and industrial customers are concerned about reliability of electrical supply and quality of power. They are also anxious over the truth that harmonic can lead to computer network failure, humming in telecommunication lines and transformer overheating. The effects of harmonic distortion are hard to measure while the end results are easy to understand in terms of higher operating costs and lower reliability.

The total harmonic distortion problem are well understood and directly related to the proliferation of loads consuming non-sinusoidal current, referred to as "nonlinear loads". These types of loads are used for the conversion, variation and regulation of electric power in commercial, industrial and residential installations. There are many equipment (loads) with feed power from AC power supply such as computers, printers, power equipment, television sets, microwave ovens, fluorescent lightings and motors, as well as heating and air-conditioning equipment. These represent a mixture of linear and non-linear loads, all powered from the same AC source. If the content of non-linear loads becomes too large, it could reason significant distortion to the AC voltage. When this distortion is taken to extremes, it can result in malfunction or damage to other equipment sharing that source.

Nowadays, a variety of approaches are used to minimize and control harmonic distortion, but all present disadvantages. All solutions demonstrate higher utility costs because of continued poor power factors. However, to reduce harmonic contamination in the power lines, active power filters (APF) are viable solutions to eliminate the harmonics and improve the power factor. There are many configurations of active filters, such as the series active filter, shunt active filter, and combination of shunt and series active filter. Shunt APF is considered to be the most basic configuration for active power filter. An APF is a device that is connected in parallel with the AC line as shown in Figure 1.1. It needs to be sized only for the harmonic current drawn by the non-linear loads and function as a current source to cancel the reactive and harmonic currents generated from a group of nonlinear loads, so that the resulting total current drawn from the AC main is sinusoidal [8]. The performance of an APF largely depends on the inverter topologies and the pulse width modulation (PWM) control method.

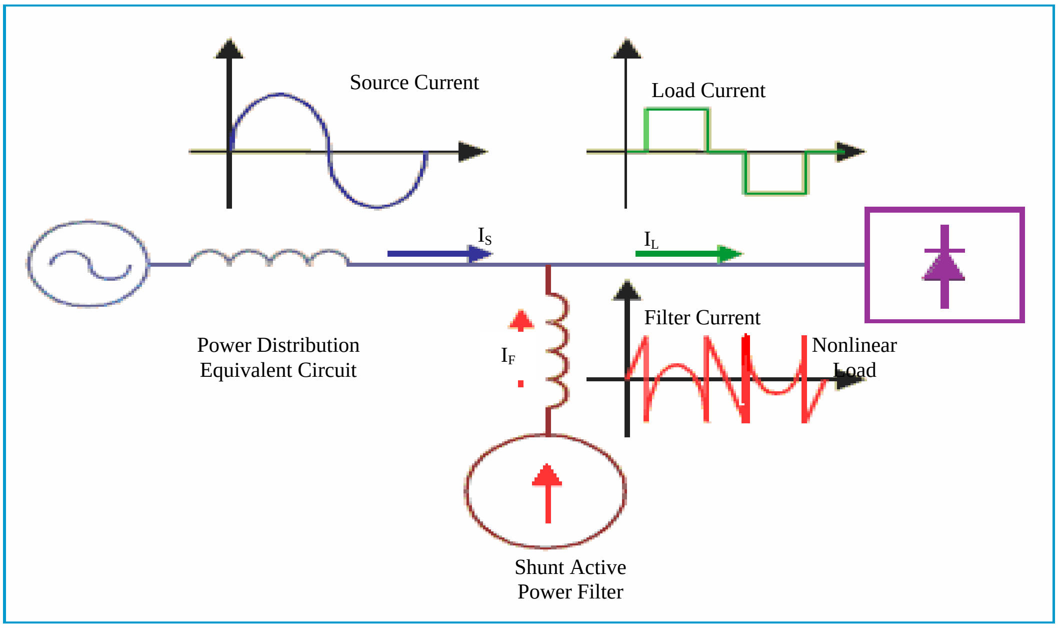

Figure 1.1: Shunt APF connected to the nonlinear load.

Active power filters are becoming a viable alternative to passive filters and are gaining market share speedily as their cost becomes competitive with the passive variety [8]. Also APF has some advantages such as the size of APF depend on the harmonic current drawn by the nonlinear loads and that need to be compensated, simplicity, reliability, efficiency, respond to changing load and harmonic conditions. However, passive power filter have many disadvantages, such as large size, resonance, and fixed in their harmonic response.

Numerous types of shunt active power filters have been proposed in many papers. Most of these papers discuss the standard and function for controlling different topologies of APFs. Meanwhile, little of them talk about the voltage range application of APFs. This project is concerned on a new topology of three-phase APF based on Modular Structure Multilevel Inverter (MSMI), which is generally for high voltage/high power applications. The MSMI has many distinct features in terms of its structure, which is simple, modular and also requires the least number of components. These features provide the flexibility in extending the MSMI to higher number of levels without undue increase in circuit complexity as well as facilitate packaging [7].

1.1 Project overview

The issue of active filters started in 1971. Shunt APF has been explored by many researchers. The shunt APF is considered to be the most basic configuration for APF [12]. In order to control the produced current that is equal in amplitude and opposite in direction of the reactive current of the nonlinear load, different control strategies have been presented to improve the dynamic and steady-state performance of the APF (such as proportional-integral (PI), variable-structure control, fuzzy logic, and neural nets) [1]. Most of these control approaches need to sense the three-phase line voltage, three-phase load current and then calculate its harmonics and reactive components in order to generate the reference for controlling the current of a bridge converter. Those control methods require fast and real-time calculation; therefore, a high-speed digital microprocessor and high-performance A/D converters are necessary, which yields complexity, high cost and low stability [3].

Another simple method of control scheme for three-phase APF is known as Unified Constant-Frequency Integration Control (UCI) based on one cycle control was introduced by Dr. Smedly from California Institute of Technology in 1991 [9]. The controller is designed to vary the duty cycle of the inverter switches such that compensation of the harmonics can be done in cycle. This control method eliminates the need of calculating the current reference as well as the use of multipliers and voltage sensors in the control loop [3].

UCI control becomes a focus control strategy and the development of the control techniques applied to APFs meet a new high tide in the last years [5]. UCI control method employs an integrator to control the pulse width of an AC-DC converter so its current draw is precisely opposite to the reactive and harmonic current draw of the nonlinear loads. The control method features are carrier free, constant switching frequency operation, minimum reactive and harmonic current generation and simple analog circuitry. It provides a low cost and high performance solution for power quality control. This control method is generalized to control a family of converters that are suitable for APF applications.

Due to the widespread use of modern electronic equipment and the natural limitation to the appliance of active filters at high power levels, it is difficult to realize high power rated filters with the required bandwidth for compensating the typical harmonic currents. The inverter topology that seems to be gaining interest lately is the multilevel inverter. Multilevel inverter was initiated by A. Nabae in 1981 who introduced a basic three level inverter, also known as the Neutral Point Clamped (NPC) inverter [15]. The main feature of a multilevel inverter is its ability to reduce the voltage stress on each power device due to the utilization of multiple levels on the DC bus.

This project suggests a three-phase MSMI APF for high power application that utilizes the UCI control scheme. Three-phase MSMI APF consists of cascade of full-bridge inverters with separate DC sources (SDCS) and this cascade full-bridge inverter can be connected in star connection as shown in Figure 1.2. The output phase voltage is the sum of inverter units' output [10]. A UCI control method is based on one-cycle control that employs an integrator with reset as its core component along with a few logic and linear components to control the pulse width of a three-phase rectifier APF, so that all three phase currents drawn form or the current output to the utility line is sinusoidal. With one-cycle control, the multipliers and three-phase load current sensors in the control loop are eliminated and the control circuitry is simple and robust. The overall circuitry is reduced. Active power filters with UCI controller provide a cost effective and flexible solution for power quality control.

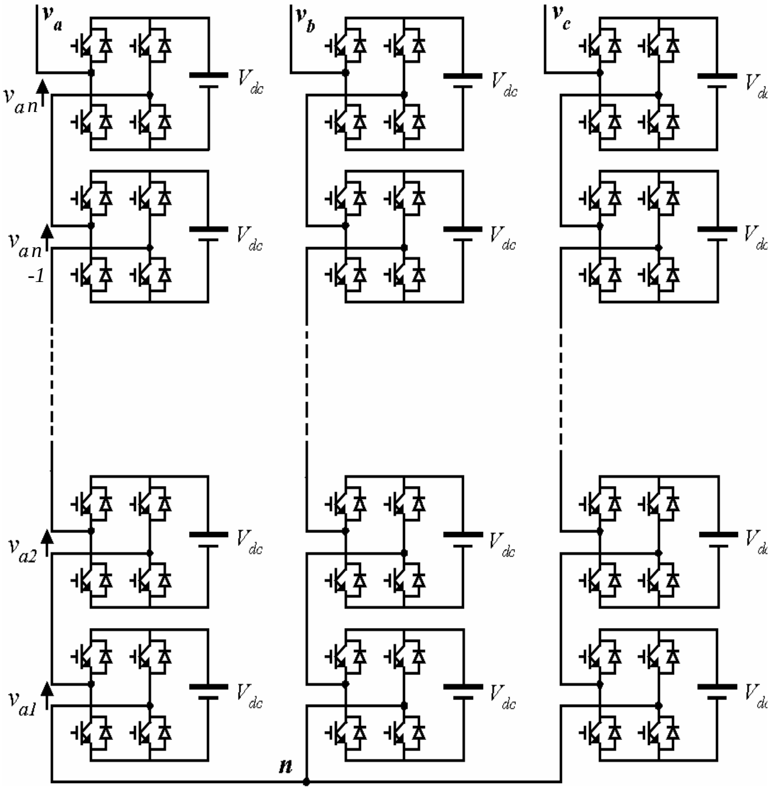

Figure 1.2: Three-phase Wye connection of n level cascade inverter

The proposed configuration of a three-phase MSMI APF with UCI control obtains low total harmonic distortion (THD) and enforces the three-phase load current to follow the three-phase line voltage, which results in a three-phase unity power factor. The MSMI APF is suitable for high power application and has the ability to reduce the voltage stress on the semiconductor components.

This project is an extension to a previous project which has been completed for a single-phase MSMI APF with UCI. A three-phase simulation of an MSMI APF system is presented for the purpose of demonstration in this project and acceptable result has been obtained from the simulation.

1.2 Objective

The objectives of this project can be summarized as follows:

- To extend the use of a single-phase MSMI in an APF system with UCI control, to three-phase application.

- To achieve low supply current total harmonic distortion (THD) in the power system.

- To achieve three-phase unity power factor on the supply side.

1.3 Scope of project

This project introduces three phase MSMI shunt APFs with UCI control. The scope of the project can be summarized as follows:

- Represent the nonlinear load with a diode rectifier with RC load, and analysis as the distorted source current waveform drawn by the nonlinear load.

- A simulation study on the operation and performance of a three-phase MSMI with UCI control as an active power filter.

- Using MATLAB Simulink to simulate both single-phase and three-phase MSMI APFs.

- Testing the simulation to evaluate the performance of the three-phase APF.

- Comparing the performance of the APF systems (both single phase and three-phase).

1.4 Thesis Outline

This thesis is organized into five chapters, which are summarized as follows:

Chapter 1 gives an introduction and short peep on the fundamental aspects of the project, such as: overview, project background, objectives and scope of the project.

Chapter 2 describes the full bridge inverter topology and its control scheme, the schematic of three-phase MSMI APF as well as the control diagram.

Chapter 3 demonstrates the development of the simulation blocks of the proposed three-phase MSMI APF configuration with selected control scheme.

Chapter 4 displays the simulation results and discusses the compensation performance of the single phase and three-phase MSMI APF subject to a typical nonlinear load.

Chapter 5 presents conclusions and recommendations for future researchers.