MODULAR STRUCTURED MULTILEVEL INVERTER AS ACTIVE POWER FILTER WITH UNIFIED CONSTANT-FREQUENCY INTEGRATION CONTROL

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Specially dedicated to my beloved mum and dad,
Sisters and Mr. Chin Kian Joan for their love, care and support.

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ABSTRACT

The usage of power electronics-based loads is increasing rapidly in recent years. The harmonic and reactive current produced by these nonlinear loads to the common coupling point at where they are connected have caused low power factor, low efficiency and harmful electromagnetic interference to neighborhood appliances. The shunt active power filter (APF) is the most common method being employed to produce harmonic current component that cancel the harmonic current from nonlinear load so that the AC main current is sinusoidal. This project presents a Modular Structured Multilevel Inverter (MSMI) as APF with Unified Constant Frequency Integration (UCI) control scheme. This scheme employs an integrator with reset as its core component to generate triangular carrier waveform. Some logical devices such as flip flop and comparators are utilized to produce switching signal to the multilevel inverter. The proposed configuration of MSMI APF with UCI control will be able to achieve unity power factor correction and low Total Harmonic Distortion (THD). Meanwhile, no sensor is required to detect the load and APF current for reference current generation as other previously proposed control method, so that the complicated digital computation can be avoided. MSMI was selected as the power converter because modularized circuit layout is possible for MSMI, which brings the convenience for future expansion in order to achieve higher power ratings for the APF system. Generally, the entire system is simple, robust and reliable. Proposed APF configuration will be compared with the conventional APF for justification of its performance.

ABSTRAK

Penggunaan beban yang berdasarkan elektronik kuasa semakin meningkat sejak kebelakangan ini. Harmonik dan arus reaktif yang dihasilkan oleh beban tak linear ke atas titik gandingan sepunya di mana ianya disambung telah menyebabkan faktor kuasa dan kecekapan litar berkurang serta mewujudkan kesan elektromagnetik yang memberi kesan buruk kepada alat-alat lain yang disambung berdekatan dengannya. Penapis Kuasa Aktif (PKA) selari merupakan kaedah yang paling biasa digunakan untuk menghasilkan komponen arus harmonik yang dapat menghapuskan arus harmonik daripada beban tak linear supaya gelombang arus bekalan Ulang-alik (UA) adalah sentiasa berbentuk sinus. Projek ini akan menunjukkan operasi Penyongsang Pelbagai Aras Struktur Bermodul (PPASB) sebagai PKA yang dikawal oleh kaedah kawalan Pengamilan Disatukan Berfrekuensi Tetap (PDBT). Kaedah ini menggunakan pengamil sebagai alat utama untuk menghasilkan gelombang pembawa berbentuk segitiga. Selain itu, alat-alat logik seperti flip flop dan pembanding juga digunakan untuk menghasilkan isyarat suis kepada penyongsang pelbagai aras. Konfigurasi PKA ini dengan kaedah PDBT berupaya untuk mencapai faktor kuasa uniti dan Jumlah Herotan Harmonik (JHH) yang rendah. Sementara itu, tiada pengesan berlebihan diperlukan untuk mengesan arus beban dan arus penapis kuasa aktif untuk penghasilan arus rujukan seperti mana kaedah kawalan yang lain, supaya pengiraan digital yang rumit dapat dielakkan. PPASB dipilih sebagai penukar kuasa kerana susun atur litarnya yang bermodul akan dapat memudahkan perkembangan akan datang bagi menghasilkan system PKA dengan kadar kuasa yang lebih tinggi. Secara umumnya, sistem keseluruhan adalah mudah, tahan lasak dan boleh diharapkan. PKA yang dicadangkan akan dibandingkan dengan PKA biasa untuk justifikasi terhadap operasinya.

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CHAPTER I

INTRODUCTION

The rapid developments of power electronics devices have considerably improved the quality of modern life by introducing sophisticated energy-efficient and controllable equipments to industries and homes. However, they also create power quality problems due to their non-linear characteristics. Therefore, power quality has become a major issue for both the electric utilities industries and their commercial and industrial customers. The electric utilities industries, also known as electricity power delivery industries are concerned very much with harmonic distortion being generated by nonlinear loads from the end user side. Utilities therefore advice their customers adhere to certain harmonic limitation requirement, such as the IEEE 519 in *Appendix A,* when installing loads to the common coupling point. These requirements have been established to ensure that excessive harmonic currents will not be injected into the AC lines, which would affect the quality of power to other users that are sharing the same power line. The utilities tend to bring the harmonic problems under control in order to reduce overstress at the utilities equipments. Noncompliance of harmonic limitations at the user end could lead to penalty charges, higher rate schedules, or even electric service cutoff.

In general, both the utilities and customers are concerned about harmonic distortion. For the power delivery industries, they are concerned about the ineffective utilization of power that is delivered and also the losses caused by poor power factor due to the customers' loads. Besides that, harmonic will lead to lower reliability, as the equipments on the generation side are required to meet greater power demand from customers that would result in extra heat being generated in the power plant equipments. As for the customers, they are worried with the fact that harmonics can lead to computer network failures, humming in telecommunication lines, motor burnouts and transformer overheating.

Disturbances encountered by the customers mentioned above are well understood and directly related to the proliferation of loads consuming nonsinusoidal current, or can be 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. Three categories of the nonlinear loads are listed in Table 1.1.

Table 1.1: Examples of nonlinear loads

Categories of nonlinear loads	Examples
i) Industrial equipments	Motor drives, solid-state rectifiers, uninterruptible power supplies, arc furnaces and welding equipments.
ii) Office equipments	Fax machines, air-conditioners, photocopiers, and computers.
iii) House-hold appliances	Television sets, microwave ovens, light dimmer, fluorescent lightings and washing machines.

Improvement in power electronic devices undeniably has caused harmonic problems in the power distribution networks, but at the same time, it also allows the possibility of designing self-adaptable harmonic suppressors, which are also known as Active Power Filters (APFs). The APF is actually an inverter that is connected at the common point of coupling to produce harmonic components which cancel the harmonic components from a group of nonlinear loads to ensure that the resulting total current drawn from the main incoming supply is sinusoidal. Shunt APFs are the most commonly used topology and they are connected in parallel with the AC line. Their sizes depend on the harmonic current drawn by the non-linear loads and compensations that need to be done. The APF configuration used in this project is a Pulse Width Modulation (PWM) voltage source inverter that is connected parallel to the system. The shunt APFs installation diagram is shown in Figure 1.1. [29]

APFs have certain advantages if compared to the passive power filters. They are known to be able to adapt concurrently to changing loads, can be expanded easily and will not affect neighborhood equipments. Generally the APFs are smaller and their prices are comparable or less than a passive solution. [28]

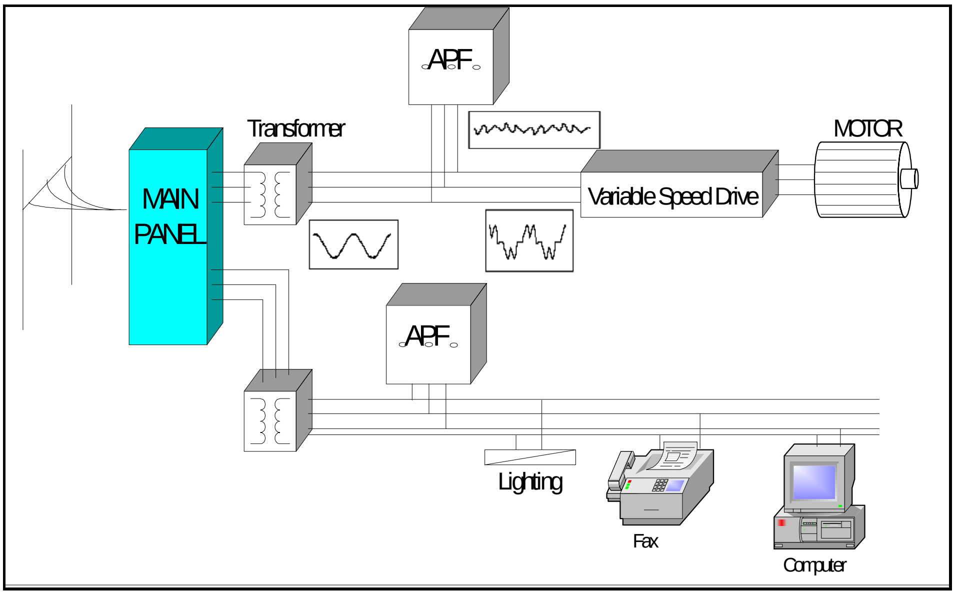

Figure 1.1: Harmonic compensation circuit with installation of shunt APFs

Although many technical papers related to APFs have been presented during the last decade, majority of them discuss the principles of operation and different schemes for controlling different topologies of APFs only. There is very little concern to the limitation of the APFs to the application voltage range. In fact, and most of the developed APFs are applicable for low power level only due to the semiconductor devices constraints. Considering the operational power rating for the APFs, this project proposes a new configuration of APF based on the Modular Structured Multilevel Inverter (MSMI) which is mainly for high power applications.

1.1 Project Overview

Vast varieties of APFs have been developed and each type has its own unique characteristic either at the power stage or at its control unit. Some of the developed control schemes require sensing of the input voltage and load current followed by calculation of the harmonic components in the load in order to generate the reference for controlling the voltage source inverter. Example of such control schemes are the PQ theory [12], linear current control, digital deadbeat control and hysterisis control [9]. These control schemes require fast and precise calculation of the current and voltage references. Thus, several high precision analog multipliers or a high speed DSP chip with fast A/D converter that yields high cost, complexity and low stability are normally required.

These constraints have inspired a group of power quality researchers to develop a simpler control scheme for APFs known as Unified Constant-Frequency Integration control (UCI) based on the One-Cycle Control theory [1] as presented in [4] and [6]. The One-Cycle Control is reliable and it has been proven applicable to all types of PWM, resonant-based, or soft-switched switching converters [1]. With the UCI control scheme, calculation and generation of the current references for the controller are not required. Thus, the number of multipliers and sensors to sense the APF current or the nonlinear load current are reduced. This has greatly simplified the control circuit. The UCI control scheme uses integration and reset method to force the switched variable at the switch output to be exactly equal to the control reference in each switching cycle, regardless of the power source ripple and changes of loads.

This project proposes on an APF system based on a non-conventional inverter configuration for high power application, namely the MSMI that employs the UCI control scheme. This APF system consists of cascaded H-bridge inverters as the power converter. In the controller, the core components are the integrators with reset that generate triangular carrier waveforms for the PWM operation. Logical devices such as flip flops and comparators are utilized to produce switching signals for the inverter switches. Meanwhile, only simple sensors are required for sensing of the input current of the nonlinear load and output voltage of the APF as the input parameters of the controller. Thus, avoiding complicated digital computation of the reference parameters as required by the other control scheme mentioned is possible. Generally, the entire APF system is simple, robust and reliable.

The proposed MSMI APF with UCI control is able to achieve unity power factor correction and low Total Harmonic Distortion (THD). The MSMI has the advantage of reducing the voltage stress on its switching devices compared to the standard H-bridge inverter. Furthermore, the modularized circuit layout of the MSMI allows easy expansion of the APF system.[10] This will be convenient if expansion of an APF is required to meet higher power level demand, such as in power transmission line. A single phase simulation of an MSMI APF system is presented for the purpose of demonstration in this project. Extension of this particular configuration to three phase in the future is possible.

1.2 Project Background

Multilevel inverter was initiated by A. Nabae in 1981 who introduced a basic 3 level inverter which is also known as the Neutral Point Clamped (NPC) inverter.[2] The output voltage of the NPC PWM inverter contains less harmonics than a conventional inverter, be it quasi-square wave or square-wave inverter. The multilevel inverter popularity grows rapidly due to its attractive features in increasing system efficiency. Its operation contributes in decreasing the harmonic distortion in output voltage waveform without decreasing the inverter output power.[3] Improvement has been done to the standard multilevel inverter configuration which brought about the emergence of the Diode-Clamped Multilevel Inverter (DCMI), Flying Capacitors Multilevel Inverter (FCMI) and Modular Structured Multilevel Inverter (MSMI).

An APF is configured from switching converters or better known as inverters that are based on pulsed operation and can be categorized as a nonlinear dynamic system. Conventional linear control technique is said to be not efficient in controlling such nonlinear dynamic system. A pulsed nonlinear control method known as "One-Cycle Control" was introduced by Dr. Smedley from California Institute of Technology in 1991. The controller is designed to vary the duty cycle of the inverter switches such that compensation of harmonic current can be done in one cycle. The One-cycle control method was later extended to APF application and better known with the term UCI control.

This project will take the advantage of the MSMI topology and the UCI control scheme in realizing its objectives.

1.3 Objectives

First of the project objective is to extend the use of the UCI control scheme for controlling the MSMI in an APF system, which will bring about the reduction of line current harmonic distortion.

The second objective is to achieve unity power factor by forcing the current to be in phase with the voltage at the AC mains based on the switching signals generated by the UCI controller.

The third objective is to prove that the performance of the MSMI APF is better than the APF based on the H-bridge inverter topology.

1.4 Scope of Project

The scope of the project can be summarized as follows:

- Analyzing the distorted source current waveform drawn by a typical nonlinear load which is represented by a diode rectifier with RC load.
- Developing the simulation blocks of the H-bridge inverter and MSMI APF system.
- Extending the UCI controller system design for the MSMI.
- Simulating both APF systems using MATLAB/Simulink.
- Comparing the performance of the APF systems.

1.5 Thesis Organization

Chapter 1 provides readers a first glimpse at the basic aspects of the project, such as overview, project background, objectives and scope.

Chapter 2 consists of literature review that gives an insight to the H-bridge inverter, MSMI, the operation of APFs based on different inverter topologies and the selected control scheme.

Chapter 3 elaborates on the development of simulation blocks of the conventional and proposed configuration of APF with selected control scheme.

Chapter 4 demonstrates the simulation results and discussion regarding the compensation performance of the H-bridge inverter and MSMI APF subject to a typical non-linear load.

Chapter 5 includes the project conclusion and a few suggestions for further expansion of the project.

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