Implementation of Multi-Stage Converter and Ultra-Capacitor DC Link-Based Voltage Source Active Power Filter

Lwin Mar Aung

Department of Electronic Engineering, Technological University (Maubin),
Ayeyawaddy Region, Republic of the Union of Myanmar

***Abstract*— A new topology for active power filters (APF) using an 27-level converter is analyzed. Each phase of the converter is composed of three three-state converters, all of them connected to the same capacitor dc link voltage and their output connected in series through output transformers. The power quality is improved by using active power filter. The different power quality problems in distribution systems and their solutions with power electronics based equipment. This power quality problem exists if any voltage, current or frequency deviation results in a failure or in a bad operation of customer's equipment. A multi-stage inverter using three-state converter is being analyzed for active filter and static var compensator applications. A 1F Ultracapacitor is used in the DC link, making it possible to obtain a very stable voltage at the DC bus, even with highly contaminated currents. This high capacity also makes it possible to continue feeding the contaminating load during a Voltage Dip. Simulation results for this application are based on PIC16F877A assembly language.**

***Keywords*— Active Power Filter, Multilevel System, ISIS Software.**

I. Introduction

The proliferation of microelectronics processors in a wide range of equipments has increased the vulnerability of such equipment to power quality problems [3]. These problems include a variety of electrical disturbances, which may originate is several ways and has different effects on various kinds of sensitive loads. Most of the more important international standards define power quality as the physical characteristics of the electrical supply provided under normal operating conditions that do not disrupt. A power quality problem exists if any voltage, current or frequency deviation results in a failure or in a bad operation of customer's equipment. Active power filters can perform one or more of the functions required to compensate power systems and improving power quality. Multi-stage converters [10-12] work more like amplitude modulation rather than pulse modulation, and this fact makes the outputs of the converter very much cleaner. The objective of this paper is to show the performance advantages of a multilevel converter used as an APF. The overall circuit of voltage source active power filter is used to automatic step-up voltage when the line voltage drop. In this circuit, PIC16F877A microcontroller is used to control the multi-stage converter. And then, the output voltage of the converter is step-up by using boost transformer. The operation of voltage source active power filter is shown in Fig.1.

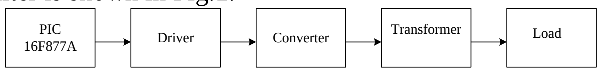

Fig.1 Block diagram of voltage source active power filter

II. Main Characteristic of Multi-stage Converter

The design of voltage source active power filter is based on multi-stage converter and ultracapacitor. The basic multi-stage converter is expressed as followed.

A. Basic Multi-stage Converter

The basic element of the converter is the full-bridge converter. Fig.2 shows the basic topology of one converter used for the implementation of multi-stage converters. It is based on the simple, four switches device used for single phase inverters. These converters are able to produce three levels of voltage in the load: +Vdc, -Vdc, and Zero.

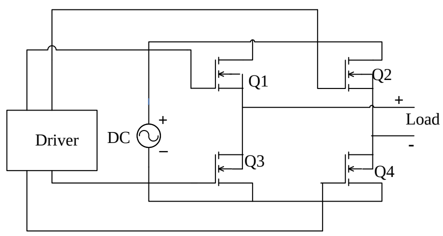

Fig.2 Three-level module for building multiconverters

References [7-9] have proposed a per phase power conversion scheme for synthesizing multilevel waveforms, connecting many converters like the one shown in Fig. 2 in series, but with all the dc voltages equal to "Vdc". Such a multilevel inverter with 'n' equal dc voltage levels can offer only 2^{n+1} distinct voltage levels at the phase output. The references go one step ahead with dc voltages varying in binary fashion, which gives an exponential increase in the number of levels. For 'n' such cascaded inverters, with dc voltage levels varying in binary fashion, one can achieve 2^{n+1} distinct voltage levels. In this paper, the outputs of the modules are connected thorough transformers whose voltage ratios are scaled in power of three, allowing 3n levels of voltage. Then, with only three converters (n=3), 27 different levels of voltage are obtained: 13 levels of positive values, 13 levels of negative values, and zero. As a comparison, the first topology only achieves 3 levels with four converters, and the second topology just 10 levels.

B. Power Distribution

One of the good advantages of the strategy described here for multi-stage converters is that most of the power delivered comes from the Master. The example of the power distribution in one phase of the three-stage converter, feeding a pure resistive load with sinusoidal voltage. A little more than 80% of the real power is delivered by the Master converter and only 20% for the Slaves. Even more, the second and third slave only deliver 5% of the total power. This means that the output transformers and the semiconductors needed by the Slave modules are small.

C. Ultracapacitor

Ultracapacitors are modern electric energy storage devices, designed similarly to conventional electrolytic capacitors. Ultracapacitors perform mid-way between conventional capacitors and electrochemical cells (batteries). Fast Charge and Fast Discharge Capability. Highly reversible process, 100,000’s of cycles. Lower energy than a battery 10% of battery energy. Greater energy than electrolytic capacitors. Excellent low temperature performance.

III. The Principle Of Active Power Filter

The operation principle of APFs is the proliferation of microelectronics processors in a wide range of equipments has increased power quality problems. Moreover, it is basically canceling the distorting harmonic currents by measuring them and generating a harmonic current spectrum in opposite phase to the measured current. Active power filters are also used for elimination of voltage harmonics, reactive power compensation and load balancing depending on the type of the APF. There exist several active power filter types in the literature in accordance with their converter types, circuit topologies and number of phases.

The basic principle of a shunt active power filter is shown in Fig.3 as

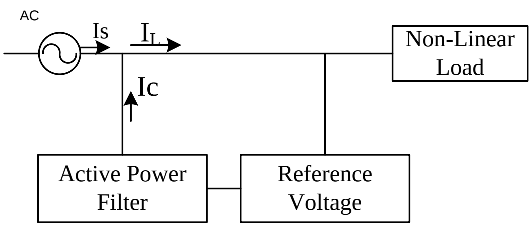

Fig.3 General block diagram of voltage source active power filter

$$I_c = I_s - I_l \qquad (1)$$

Where I_C is the compensation input current, I_S is the source current and I_L is the load current, respectively.

Active power filters are divided into two groups according to their converter types used in the development of the power circuit, as Current Source Converter (CSC) and Voltage Source Converter (VSC) type active power filters. The main difference between these two topologies is the energy storage element at the DC link side of the converter. In CSC type APF, the power circuit acts as a non sinusoidal current source with a DC link inductor (L_{dc}) as an energy storage element. In this circuit, Voltage Source Active Power filter is used.

IV. Design and Implementation of Voltage Source Active Power Filter

The circuit diagram of voltage source active power filter is based on multi-stage converter and ultracapacitor dc link. When the line voltage dip, PIC microcontroller is controlled drivers to start up the converters. Then, the output voltage of the converter is step-up transformer. Finally, the required voltage is received. This operation is illustrated as shown in Fig. 4.

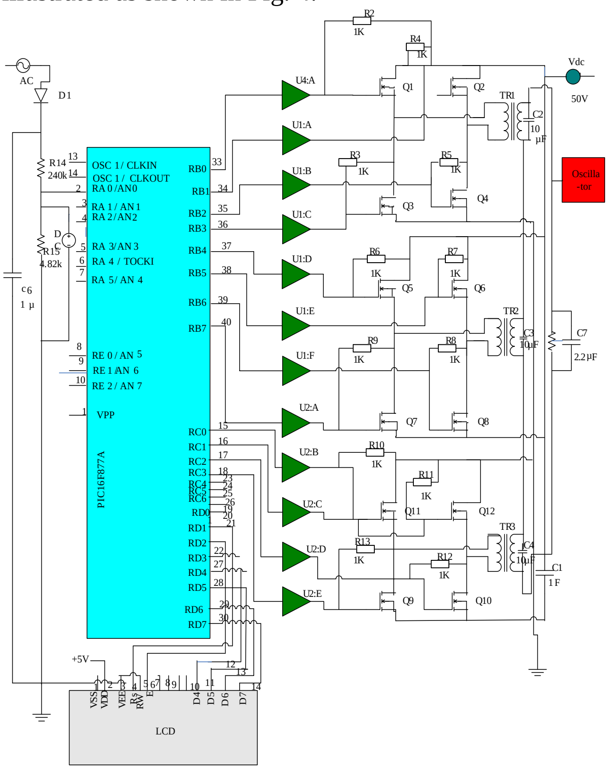

Fig.4 Overall circuit diagram of voltage source APF

A. DC power supply for LCD

The purpose of using input power is 1W and the supply voltage for LCD is 5V for calculation of the input capacitor. The filter capacitor is used to get the pure dc voltage for 7805 regulator IC. The value of input capacitor is calculated as shown in Fig.5.This section is one part of the overall circuit of voltage source active power filter.

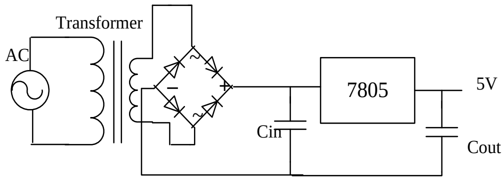

Fig.5 Circuit diagram of dc supply

Assume maximum rectifier input power, P_{in} = 1W

The electrical energy, $W_{in} = \frac{P_{in}}{f}$ (2)

$$= \frac{1}{50}$$

$$= 0.02\ J$$

For Bridge rectifier,

$$C_{in} = \frac{W_{in}}{V^2_{in(max)} - V^2_{in(min)}} \quad (3)$$

Transformer voltage ratio,
At maximum voltage state V_{pri} =220V, V_{sec} =9V
At minmum voltage state V_{pri} = 160, V_{sec} = 6.5V
Assume diode voltage drop = 1V

$$V_{rect(max)} = (9 \times \sqrt{2}) - 1$$

$$= 11.7\ V$$

$$V_{rect(min)} = (6.5 \times \sqrt{2}) - 1$$

$$= 8.2\ V$$

$$C_{in} = \frac{0.02}{(11.7)^2 - (8.2)^2}$$

C_{in} = 470μF

A. Calculation of Resistor for the circuit

The value of resistor R_1 and R_2 are calculated for the supply voltage of PIC16F877A microcontroller is achieved by using voltage divider. And then, the controller is calculated the input line voltage for displayed on LCD.

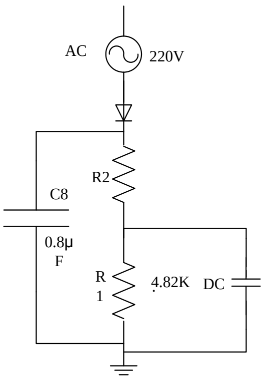

Fig5. The input section of the circuit

For $V_{in(peak)}$ =220V

$$V_{p(peak)} = 220 - 0.7$$

$$= 219.3V$$

Choose R_L= 245KΩ, C= 1μF

$V_{0ut(max)}$ = 5V

$$V_{dc} = (1 - \frac{1}{2fR_1C})V_{p(peak)} \quad (4)$$

$$V_{dc} = (1 - \frac{1}{2 \times 50 \times 245K \times 1 \times 10^{-6}})(219.3)$$

V_{dc} = 210V

$$V_2 = \frac{R_2}{R_L} \times V_{dc} \quad (5)$$

$$V_{dc} - V_{out} = \frac{R_2}{R_L} \times V_{dc}$$

$$210\text{-}5 = \frac{R_2}{245K} \times 210$$

R_2 = 240KΩ
R_L =R_1+R_2 (6)

R_1 = R_L − R_2
R_1 = 245 − 240
R_1 = 5KΩ

A. C. The operation of Boost transformer

The main function of active power filter is used step-up transformer. The transformer is operated step-up the required line voltage. Therefore, the ration number of coil is calculated as shown in Fig. 6 and the output watt power is defined 3KW.

- Input voltage = 50 V
- Output voltage = 220V
- Output power = 3000 W

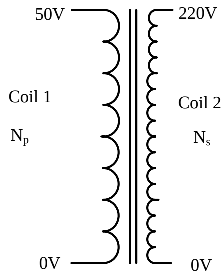

Fig6. Winding diagram of boost transformer

To calculate the cross section area of iron core (A),

$$A = \frac{\sqrt{P_{in}}}{5.58} \quad (7)$$

$$= \frac{\sqrt{3.3k}}{5.58}$$

$$= 10.35\ inches^2$$

To calculate the turn per volt,

$$N = \frac{E \times 10^8}{4.44BFA} \quad (8)$$

$$N = \frac{100000000}{4.44BFA}$$

Where
F = frequency
B = Magnetic flux density of iron core
A = cross section area of iron core

$$N = \frac{100000000}{4.44 \times 50 \times 60000 \times 10.35}$$

= 0.725 turns per volt

For number of turns in primary coil,
N_p = 0.725 x Vin (9)
= 0. 725 x 50 = 36.27 turns
For number of turns in secondary coil,

$N_{s1} = 0.725 \times V_{out}$ (10)

$= 0.725 \times 220 = 159.5$ turns

So that the primary winding of the 3kW transformer will have 37 turns and the secondary winding of transformer will be 160 turns.

D. Program Flow Chart for PIC Microcontroller

The main function of this circuit is applied proteus 7.8 software and one control program for microcontroller is written with one PIC assembly language. To get the required reference voltage, the PIC controller is controlled the other equipments such as multistage converters and transformers. The program is illustrated program flowchart as shown in Fig. 7.

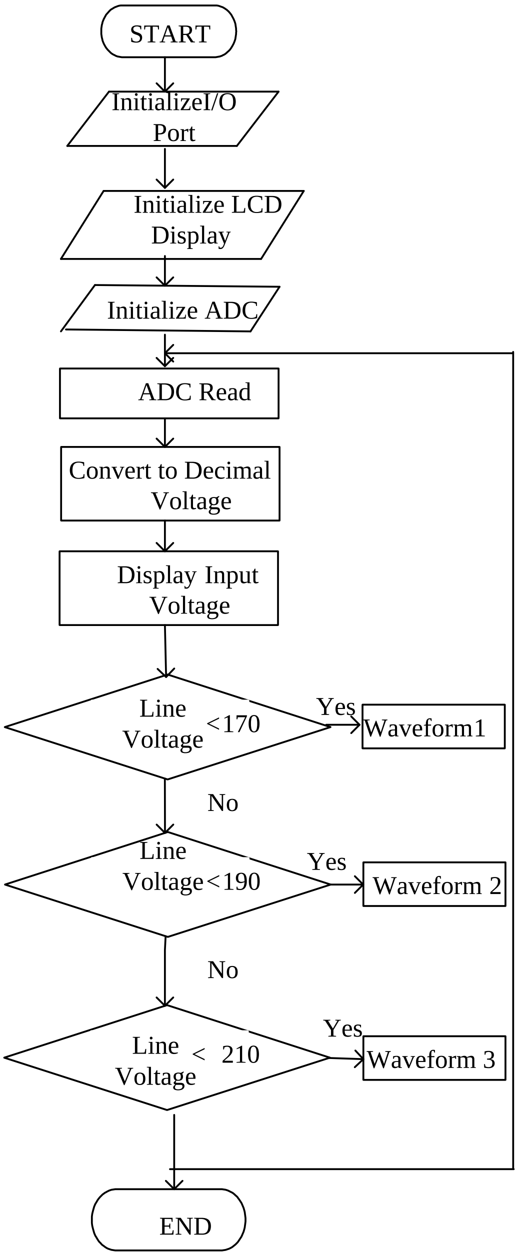

Fig.7 Flow chart of PIC programming for active power filter

V. Simulation Result of Voltage Source Active Power Filter

The simulation result of voltage source active power filter is using ISIS software. The operation of voltage source active power filter is improving power quality. The overall simulation circuit as shown in Fig.8.

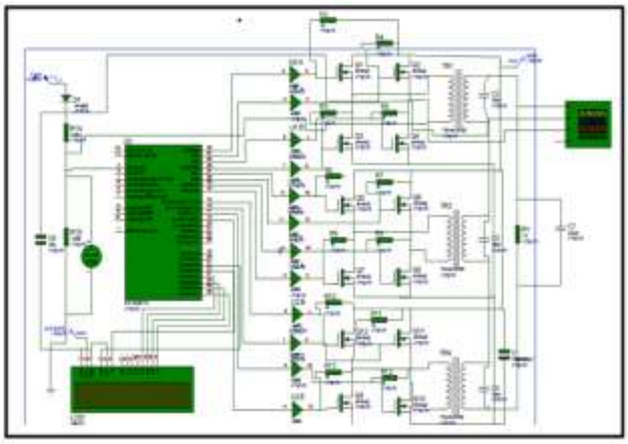

Fig.8. Circuit Simulation in ISIS Software

When the line voltage is 220V, the condition is stable. In this condition, the active power filter is filtering the harmonics voltage and current as shown in Fig.9.

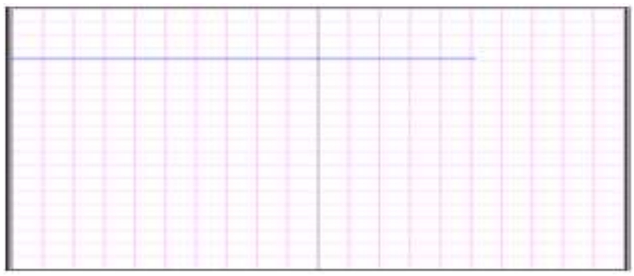

Fig.9. Simulation Results of Active Power Filter When The Line Voltage is 220V

When the line voltage drops 200V, the converter is driven transformer to step-up the required 20V. The result of step-up line voltage as shown in Fig.10.

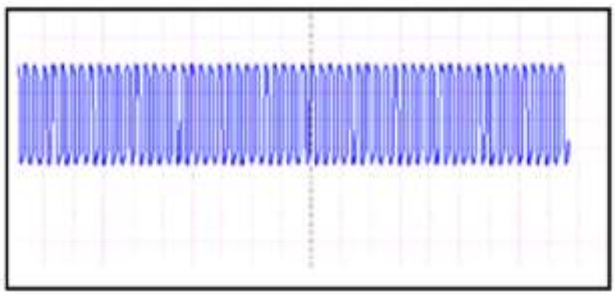

Fig10. Simulation Results of Active Power Filter When the Line Voltage is 200V

When the line voltage drops 180V, the converter is driven transformer to step-up the required 40V. The result of step-up line voltage as shown in Fig11.

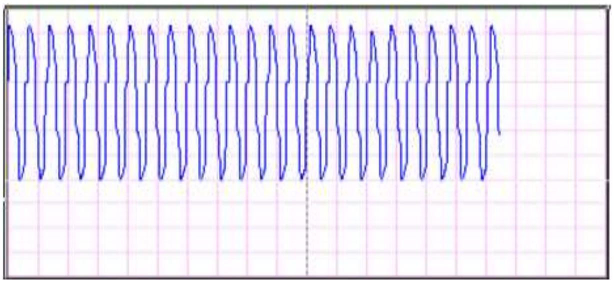

Fig. 11. Simulation Results of Active Power Filter When the Line Voltage is 180V

When the line voltage drops 160V, the converter is driven transformer to step-up the required 60V. The result of step-up line voltage as shown in Fig.12.

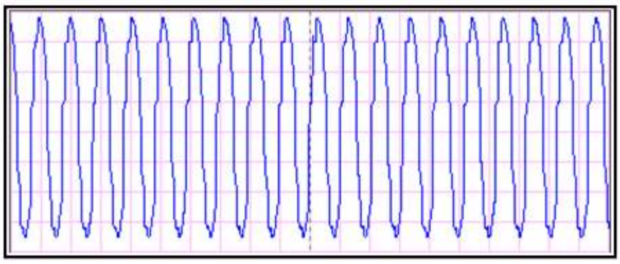

Fig. 12. Simulation Results of Active Power Filter When the Line Voltage is 160V

TABLE1.
COMPARISON OF LINE VOLTAGE DROP AND STEP-UP VOLTAGE LEVEL

Line voltage drop	Step-up voltage level
160V	60V
180V	40V
200V	20V

VI. CONCLUSIONS

A three-stage 27-level inverter using three-state "H" converters was analyzed, simulated, and tested for use as an APF. The advantages of applying active power filters to compensation power distribution systems has been presented. The principles of operation of shunt active power filters has been presented and a brief description of the state of the art in the active power filter market has been described. The shunt active power filter performance under fault power distribution system was discussed. Simulation and experimental results proved the viability of using active power filters to compensate active power filters. Circuit simulations are successfully created by using Proteus 7.8 and the program are written PIC16F877A Assembly Language. The multi-stage converters can be applied to almost every practical situation. Some of them are active power filters, sinusoidal current rectifiers, machine drives, power factor compensators, back-to-back frequency link systems, and traction drive systems. The advantages of this kind of topology are clear when compared with conventional PWM traction drive systems.

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