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UNIFIED POWER QUALITY CONDITIONER (UPQC): DEVELOPMENT OF HARDWARE USING FACTS TECHNOLOGY

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Unified Power Quality Conditioner (UPQC), a relatively new device, can be used simultaneously in voltage or current control mode in power distribution system. But development of hardware with appropriate control circuit is a challenging task. In the voltage control mode, the UPQC can force the voltage of a distribution bus to be balanced sinusoids. At the same time it can also control perform load compensation resulting in the drawing of balanced sinusoidal currents from the distribution system bus in the current control mode. In this paper the hardware of the voltage source converter used for UPQC together with details of microcontroller based control philosophy has been presented.

Key words: Flexible AC Transmission Systems, Distribution STATCOM, Power Quality, Unified Power Quality, Voltage Source Converter.

1. INTRODUCTION

The successful development of FACTS devices (Flexible AC Transmission System) is promoting major changes in controlling power flow in the transmission and distribution sectors of electric power utilities [1-4]. The voltage of a line can be controlled by means of a compensator located at the receiver end of the line. The compensator delivers or draws reactive power in order to compensate for the unbalance or distortion. Traditionally, these compensators have been rotating machines or static var compensators that require large capacitors and inductors. Today, it is possible to replace these machines and devices by a switching converter, a dc capacitor, and a group of transformers. This static synchronous compensator (STATCOM), has numerous advantages over previous compensators. First, it acts much faster and can respond to voltage fluctuations in a matter of one cycle. Second, it can generate far more reactive power when the system voltage is low.

In order to maintain constant sinusoidal terminal voltage and to meet reactive power demand of the rapid perturbations in load, feedback control system becomes essential. Recent trends in the development of processor technology and use of feed back control techniques in power industrial environment have helped in growth of newer types of integrated computer control strategies for utility's voltage control.

FACTS devices are modified to serve in distribution network and, through a modification of a unified power flow controller (UPFC) the unified power quality conditioner (UPQC) [1]. Such solution can solve different power quality problems, such as: sags, swells, voltage imbalance, flicker, harmonics and reactive currents.

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UPQC usually consists of two voltage-source converters (VSC) sharing the same capacitive DC link. One of the converters is an active rectifier (AR) while other is a series filter (SF) with a LC ripple filter and transformer isolation from power supply network.

Extensive research has been directed to control the Voltage Source Convert (VSC) through easily available simple microcontroller in the market. In this paper a thorough investigation on the control of a VSC of the UPQC has been presented. The performance results are also presented in the paper.

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2. POWER AND DRIVER CIRCUITS

The power circuit of the VSC is shown in the Fig.1, where RC snubber protections and fuse protections are inserted. Although a DC supply is shown at the left supply in the test circuit, it would replaced by a suitable capacitor in the practical STATCOM. The three-phase terminals at the right are connected to the supply in parallel and series configurations with a DC link capacitor in between to make a UPQC.

Fig.2 shows the driver circuits for all the IGBT devices shown in Fig.1. Microcontroller generated appropriate pulses are given to the inputs of the optocoupler ICs used as isolation from power circuit to control circuit. The output of the driver circuit is connected to the gate of the respective the IGBT as marked in the figures. The pulses, we get from the microcontroller are not sufficient to run the IGBT. So, these pulses are amplified by the driver circuits.

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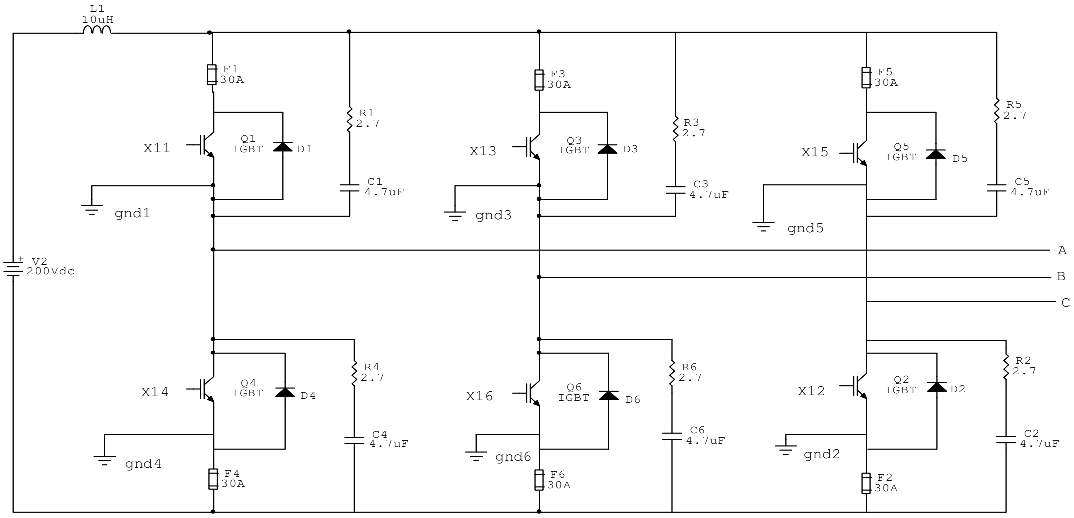

Fig 1 Power circuit with RC snubber and fuse protections

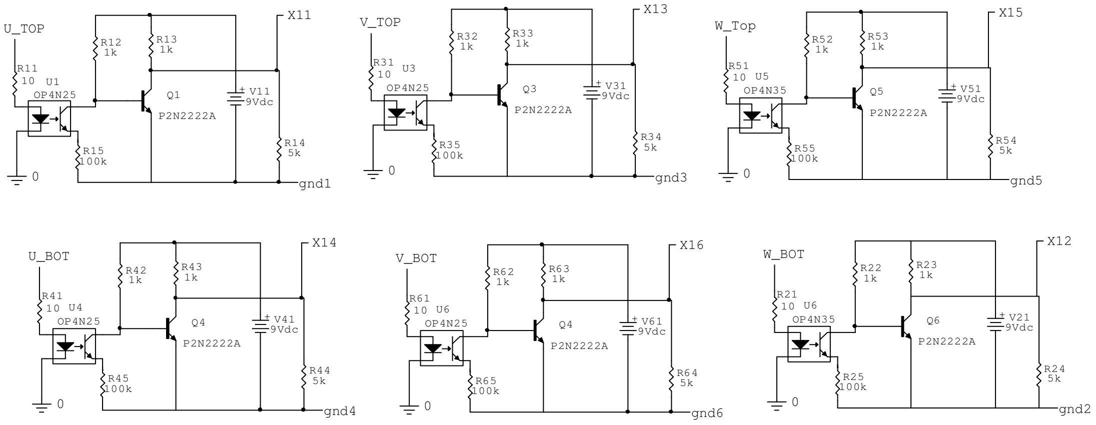

Fig.2 Driver Circuits

3. MICROCONTROLLER BASED CONTROL

For gate pulse generation, easily available popular PIC16F72 microcontroller is used. It belongs to the Mid-Range family of the PIC micro devices. Its program memory contains 2K words, which translate to 2048 instructions, since each 14-bit program memory word is the same width as each device instruction. The data memory (RAM) contains 128 bytes. There are 22 I/O pins that are user configurable on a pin-to-pin basis [5]. Since instruction sets of this microcontroller are unable to efficiently handle mathematical operations common to many algorithms that are repeatedly executed in time-critical loops, an off-line calculations are made and the data are used for PWM pulse generation. This gives a good experience on using microcontroller based control system. Fig. 3 shows the microcontroller used to interface to the gate drive circuits of Fig.2.

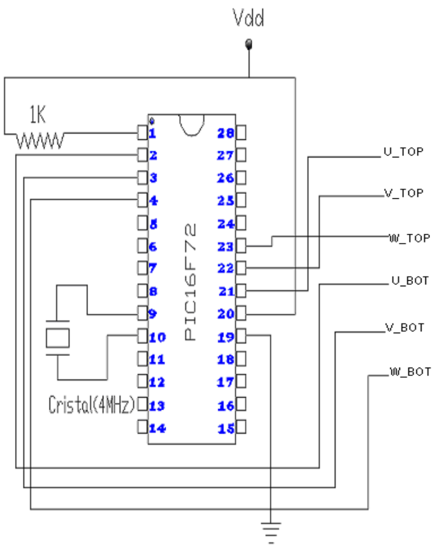

Fig. 3 Connection diagram of PIC16F72 for six phase SPWM signal generation for IGBT gate driver circuit.

4. SPWM SIGNAL GENERATION

4.1 ASSUMPTIONS FOR CALCULATIONS

Let us assume that we have to generate a 50 Hz sine PWM. For this we need a triangular carrier wave with 10 times the frequency of the desired sine wave. For simplicity we denote the factors with some symbols whose are listed below.

V_s = instantaneous voltage of the sine wave
V_m = maximum amplitude of the sine wave
f = frequency of the sine wave (50 Hz)
t = time
T = period of the sine wave (20 ms)
τ = half of the period (10 ms)
V_c = instantaneous voltage of the reference triangular wave
V_{cm} = maximum amplitude of the reference triangular wave
M = modulating index (0.8 is considered here)

4.2 EQUATIONS AND TIME CALCULATION

We have the equation of the sine wave is-

$$V_s = V_m \sin \omega t \qquad (1)$$

For determining t_1 according to Fig. 4 we get the equation for straight line containing t_1 is

$$V_c = -\frac{V_{cm}}{\tau/10}(t_1 - \tau/10) \qquad (2)$$

And the equation for the sine wave remains

$$V_s = V_m \sin \omega t_1 \qquad (3)$$

For determining t_1 according to figure 4.1 we get the equation for straight line containing t_1 is

$$V_c = -\frac{V_{cm}}{\tau/10}(t_1 - \tau/10) \qquad (4)$$

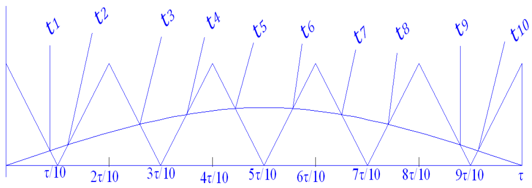

Fig.4 Comparison of positive half cycle

For t_1 we can equalize the two equations as below-

$$-\frac{V_{cm}}{\tau/10}(t_1 - \tau/10) = V_m \sin \omega t_1$$

$$\Rightarrow -\frac{(V_{cm}/V_m)}{(\tau/10)}(t_1 - \tau/10) = \sin \omega t_1$$

$$\Rightarrow -\frac{(1/M)}{(\tau/10)}(t_1 - \tau/10) = \sin 2\pi f t_1$$

$$\Rightarrow -\frac{1.25}{(\tau/10)}(t_1 - \tau/10) = \sin (2\pi\times 50)t_1$$

$$\Rightarrow -\frac{1.25}{(10ms/10)}(t_1 - 10ms/10)$$

$$= \sin 100\pi t_1 \qquad (5)$$

Solving (5) we get the value of t_1

t_1 = 800.8429071 us

Similarly solving the equation considering the straight line containing t_2 we get the value of t_2

$$\frac{1.25}{(10ms/10)}(t_2 - 10ms/10) = \sin 100\pi t_2 \qquad (6)$$

=> t_2 = 1.323 ms

Solving the equation considering the straight line containing t_3 we get the value of t_3

$$-\frac{V_{cm}}{\tau/10}(t_3 - 5\tau/10) = V_m \sin \omega t_3$$

$$-\frac{1.25}{(10ms/10)}(t_3 - 30ms/10) = \sin 100\pi t_3 \qquad (7)$$

=> t_3 = 2.444299507 ms

Similarly other instants **t_4 - t_{10}** are calculated and all are summarized below.

t_1 = 801us
t_2 =1.323ms
t_3 =2.444ms
t_4 = 3.738ms
t_5 = 4.224ms
t_6 = 5.776ms
t_7 = 6.262ms
t_8 = 7.556ms
t_9 = 8.677ms
t_{10} =9.199ms

By subtracting the two consecutive times we find out the duration of pulses. This duration together with the logic states for 10ms are shown in Table 1. These are done only for sinusoidal half wave length for 10 ms from where we create the logic states of PWM signals. Now for the other phases and their logic states we have to calculate the phase shift of the subsequent phases in terms of delay in ms or us.

Table 1: Duration of Pulses

Amplitude States	No.	Durations
0	1	801us - 0 s = 801 us
1	2	1.323 ms - 801us =522 us
0	3	2.444 ms - 1.323 ms =1.121 ms
1	4	3.738 ms - 2.444 ms =1.294 ms
0	5	4.224 ms - 3.738 ms =486 us
1	6	5.776 ms - 4.224 ms =1.552 ms
0	7	6.262 ms - 5.776 ms =486 us
1	8	7.556 ms - 6.262 ms =1.294 ms
0	9	8.677 ms - 7.556 ms =1.121 ms
1	10	9.199 ms - 8.677 ms =522 us
0	11	10 ms - 9.199 ms =801 us

From 0 s to 40 ms (2 cycles) sequentially we get the six logic states for every time intervals which are shown in Fig. 5 and Fig.6.

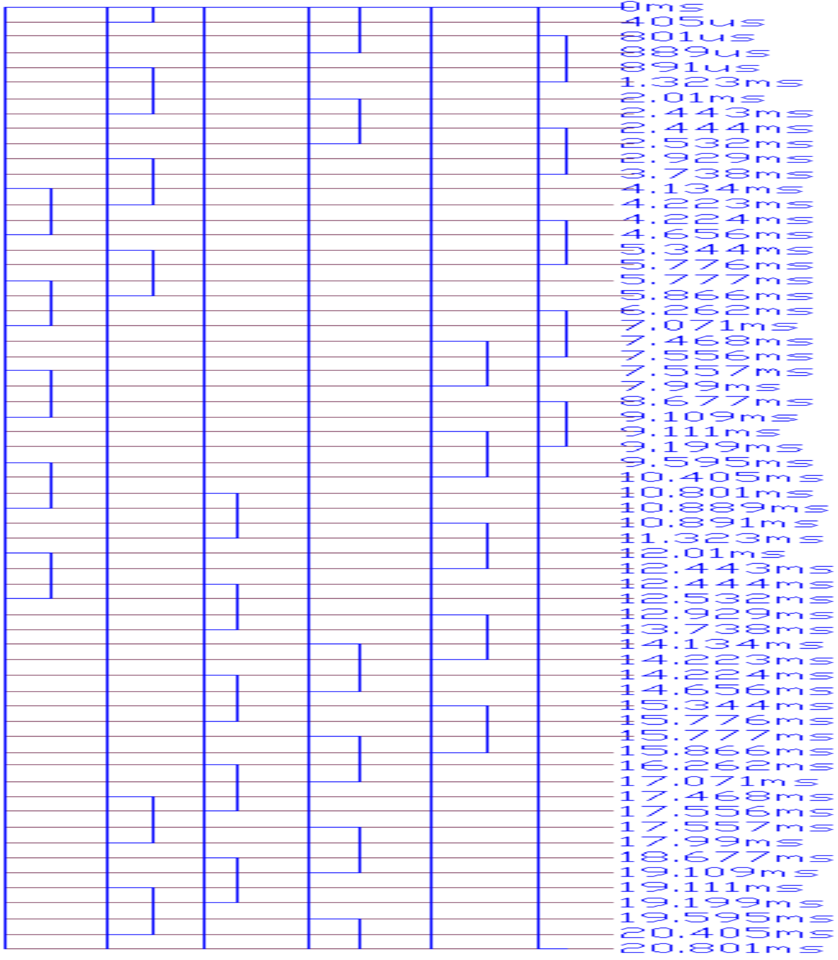

Fig.5 1st half logical states of six phase pulses

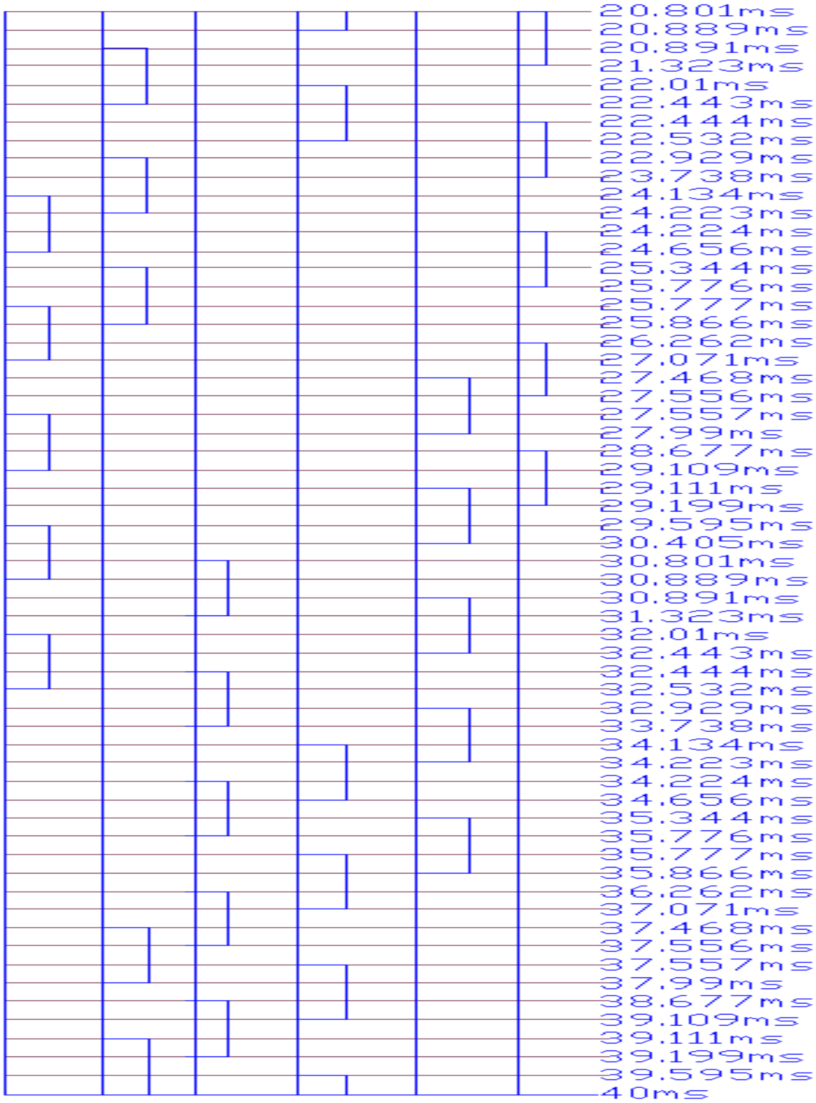

Fig.5 2nd half logical states of six phase pulses

The waveforms of gate pulses for all the devices for the duration of 40 ms as mentioned above are shown in Fig, 6,

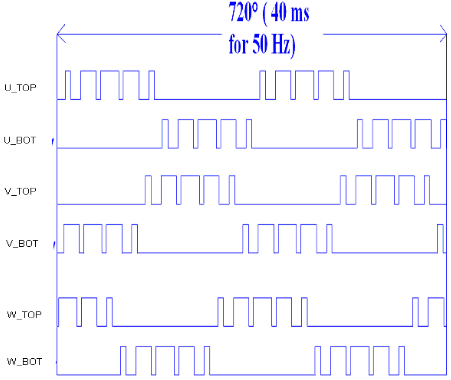

Fig. 6 Three phase waveforms in terms of six gate signals

5. RESULTS AND DISCUSSION

The experimental setup of the hardware based on the circuit configurations mentioned before is shown in Fig. 7.

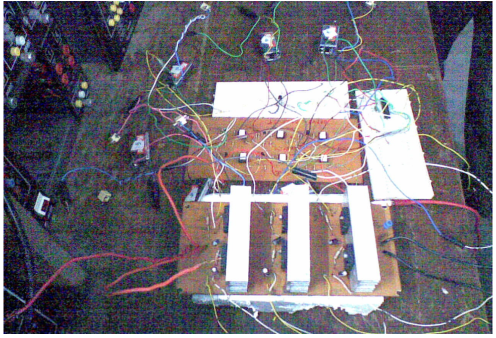

Fig. 7 Experimental Setup

Suitable software has been developed for PIC16F72 microcontroller using mikroC programming language using the logic states and durations as mentioned before. The pulses we get from the microcontroller is enough to run the driver circuits of IGBTs. The high magnitude of the pulse is 4.98 volts when it is connected to the gates of the IGBTs. Output from the driver circuits for different phases are shown Fig.8 to Fig.10.

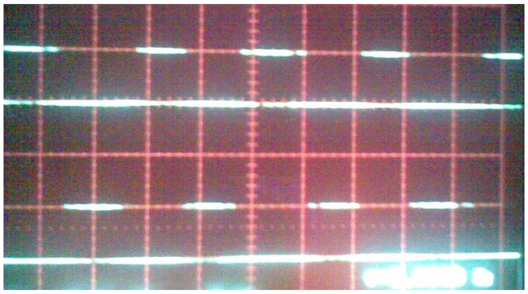

Fig 8: Pulses at U_TOP and U_BOT

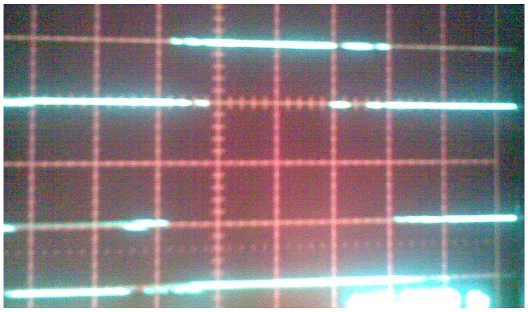

Fig 9: Pulses at V_TOP and V_BOT

Fig. 10: Pulses at W_TOP and W_BOT

It is observed that the output obtained from the experimental closely matches with those of theoretically obtained results.

6. CONCLUSION

FACTS based three phase UPQC system can be implemented to address the power quality issues such as to eliminate voltage distortions or dips, to improve voltage regulation etc with the integration of shunt and series active filter etc. Hardware details of the VSC used for UPQC have been given in this paper. SPWM technique used in this paper for improving power quality is more sophisticated, reliable, economical and feasible, has the ability to suppress certain number of harmonics depending on number of pulses per half cycle in the PWM wave. They also have compatibility with today's digital microprocessor/microcontroller and lower power dissipation. It is observed that as simple PIC16F72 microcontroller is able to generate the required pulses. Complete system integration of an UPQC is of further interest.

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