CHAPTER SIX

NOVEL CONCEPT OF STATCON IN MULTIPLEXED MODE

6.1 INTRODUCTION

During the process of working on the installation for three-phase dynamic reactive power compensator- STATCON, in one of the automobile industry manufacturing line, an interesting need was witnessed. With the installation having some capacitive compensation in place, the requirement for compensation was to have average of the three-phase reactive current component, as the compensating current demand from STATCON to compensate for. An equally similar observation also had been during single-phase STATCON installation at another industry, that all the phases were not simultaneously seeing the compensating demand. On the other side, there also have been need from industrial users who have been deploying the traditional compensation solution (based on passive devices), to switch over to the Voltage Source Converter (VSC) based Solution – STATCON, not from dynamics as the demand but the non-aging, assured kVAR delivery benefits as the fuelling need but economics of solution still was a concern. To address, this aspect, novel concept solution, of using single-phase dynamic reactive power compensation with three phase multiplexing using fuzzy logic algorithms has been conceived. This chapter initially highlights the need for such a solution. It then introduces a novel concept of using single phase STATCON for reactive power compensation demands of three-phase system, particularly for loads which do not have prolonged demand for reactive power compensation on all the three phases simultaneously. Further, the chapter gives details on concept with fuzzy logic based control strategy. Thereafter, it addresses the algorithms developed, simulation results and implementation using Digital Signal Processor (DSP) based control hardware.

6.2 NEED FOR STATCON MULTIPLEXER

Unity power factor operation or complete reactive power compensation (RPC) has become the necessity of the day. Thus, major efforts are being put in reactive power compensation, more so on Dynamic Reactive Power Compensation (DRPC) due to increased load dynamics. Different methods based on traditional approaches as well as based on new generation power electronics are already under use or have been published to achieve the better power factor of operation including based on latest available technologies [19,41,102,196, 224, 230-232].

However, when performance versus economics is considered based on specific load conditions / installations, the method may not match the needs completely. Keeping this scenario in mind, need for a new method /approach, which serves for optimal cost and performance balance in achieving improved power factor requirements for three-phase system [233] still remains as necessity.

6.3 CONCEPT OF STATCON MULTIPLEXER

The concept is based on use of single-phase STATCON for reactive power compensation demands of three-phase system for loads which do not have prolonged / simultaneous demand for reactive power compensation on all the three phases simultaneously. The control concept is based on fuzzy logic. Where the reactive power compensation is required for all the three-phase at a time, the concept allows this single-phase STATCON getting connected to each phase for a computed duration (cyclically) to meet the three-phase reactive power compensation requirement. On the other hand, when reactive power in one of the three-phase suddenly goes high, the single-phase STATCON can latch on to that particular phase to offer the required compensation. The single-phase STATCON is hence, highly flexible to be used for a three-phase system. The concept works by switching the single-phase STATCON in time multiplexing, controlled through a soft logic, which can be adopted based on dynamic load conditions. This is also applicable in a system where individual loads (which are connected to different phases) are variable. It is certainly economical to use such a single-phase STATCON in multiplexed mode as compared to three numbers of single-phase STATCONs or a three-phase STATCON. It also ensures average PF for dynamic loads near unity. Figure 1 below shows the schematic of the proposed method.

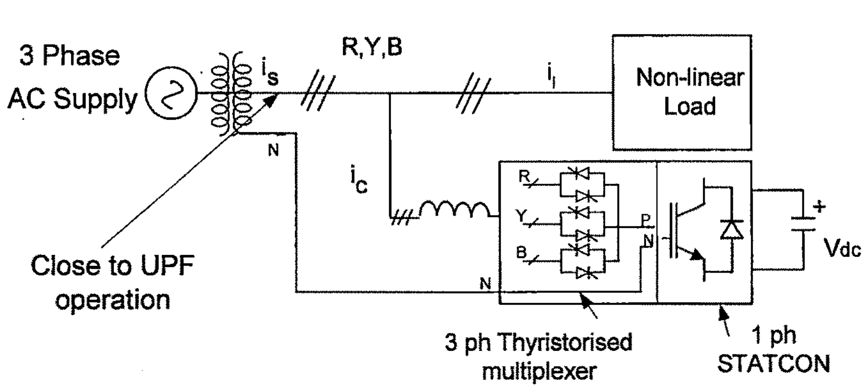


Fig. 6.1 Absorption of unbalanced kVAr through real time multiplexing of single-phase PWM Voltage Source Converter

The single-phase converter is connected to either R or Y or B phase depending upon which thyristor pair is conducting. The concerned thyristor pair can be given continuous pulses and it will ensure the necessary positive or negative cycle conduction for the input current drawn from the phase.

6.3.1 MATLAB MODEL

As shown in fig. 6.2, STATCON model in MATLAB with fuzzy logic rule base is prepared. Basic parameters used for modeling include STATCON offering 50kVAR compensation. Some of the key blocks [(a) STATCON b) Time multiplexing section c) controller section] for achieving desired functional performance are also highlighted in fig. 6.3. In this figure, the term universal bridge basically means single-phase Voltage Source Converter (single-phase STATCON). subsystem to select the respective phase is shown in figure 6.3(b). This is then followed with some basic STATCON simulation waveforms for different load conditions.

Firing pulses for thyristor are totally dependent on voltage across the thyristor. Firing pulses to particular phase is provided assuming that voltage across thyristor is zero at peak of source voltage. Firing sequence for inductive and capacitive mode is inversed. When load current changes from inductive to capacitive, firing sequence to thyristor will automatically reverse.

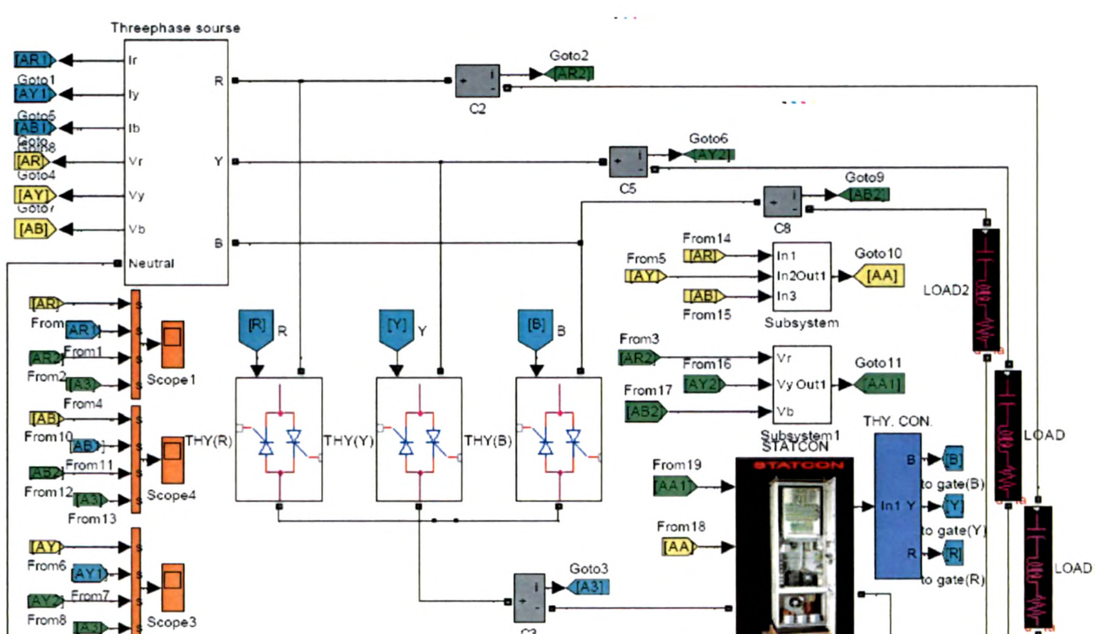
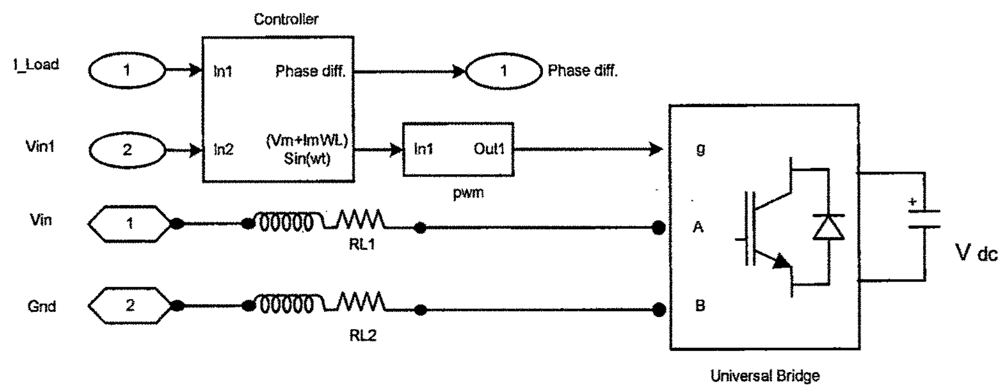
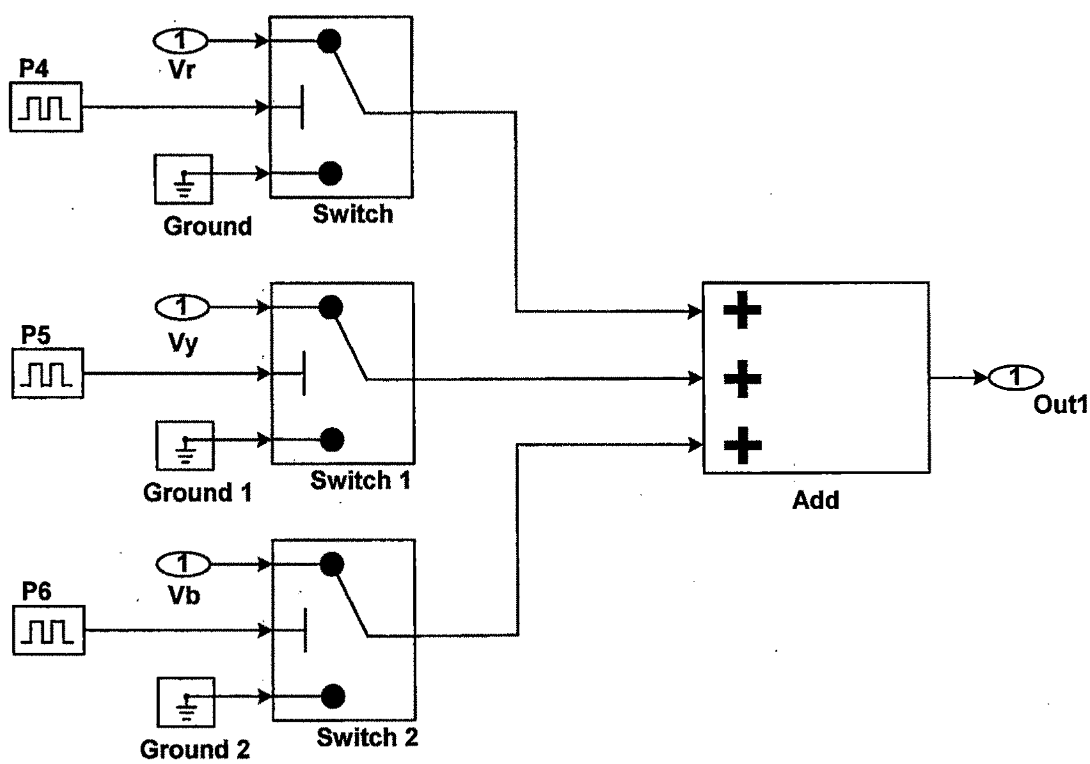


Fig. 6.2 MATLAB Simulation model of STATCON with multiplexing concept



(a) STATCON block



(b)Time Multi-plexing block

Fig. 6.3 Key MATLAB simulation blocks and STATCON waveforms for the concept

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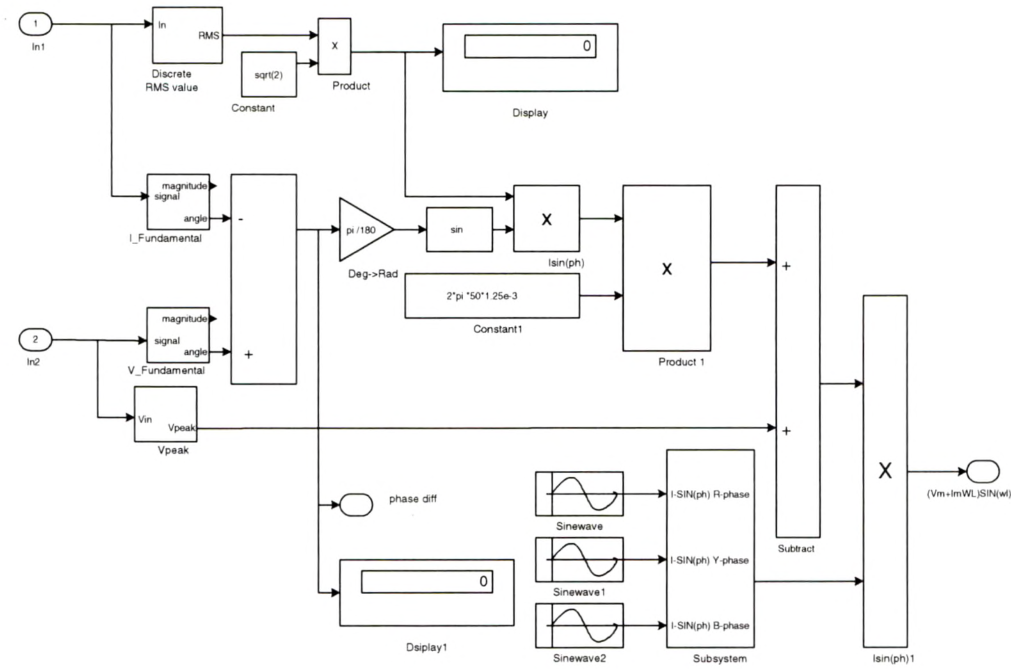
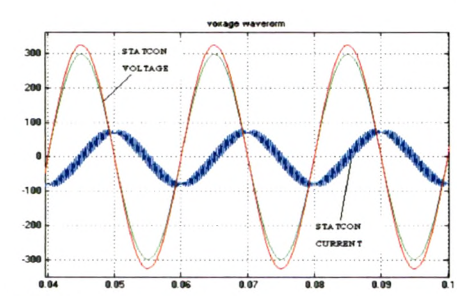
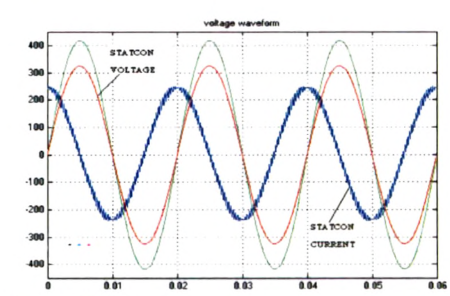


(c) Controller block

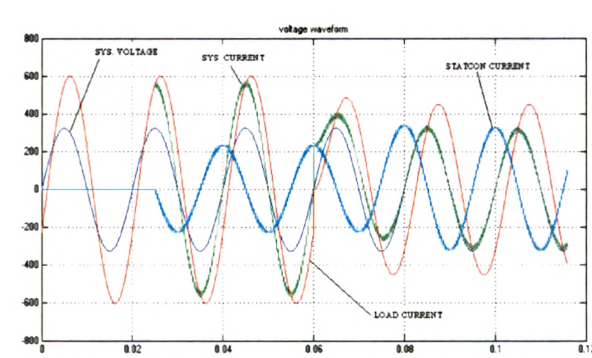


STATCON voltage & current with capacitive load



STATCON voltage & current with inductive load

(d)Waveform showing STATCON voltage & current with capacitive load and inductive load.



(e) Waveform for : STATCON connected to dynamic inductive load

From t =0 to 0.06 S Load is (R= 0.5,L= 0.65e-3) and From t = 0.06 S Load is (R=0.5,L= 1.65e-3)

Fig. 6.3 Key MATLAB simulation blocks and STATCON waveforms for the concept

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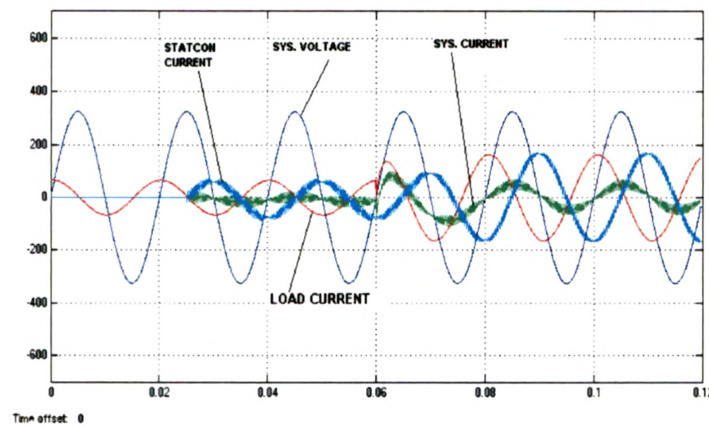
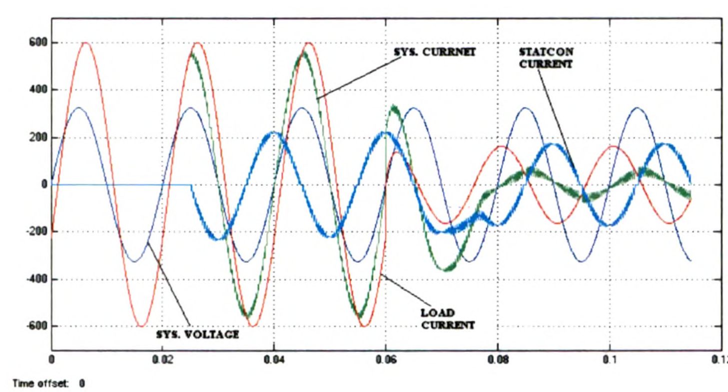


(f) WAVEFORM for STATCON connected to dynamic capacitive load
From t =0 to 0.06 S Load is (R= 0.5,C= 0.65e-3) and Fromt = 0.06 S Load is (R=0.5,C= 1.65e-3)



(g) WAVEFORM for STATCON mode change-over from inductive to capacitive
From t =0 to 0.06 S Load is (R= 0.5,L= 0.65e-3) and From t = 0.06 S Load is (R=0.5,C= 1.65e-3)

Fig. 6.3 Key MATLAB simulation blocks and STATCON waveforms for the concept

6.3.2. FUZZY ALGORITHMS

Main aim behind the use of fuzzy logic controller is to provide compensation to respective phase for computed period of time in accordance with the three phase voltages and three load current conditions. In many industrial situations flexible compensation is required. The normal controller fails in such condition. For the purpose of providing intelligence to compensator system, fuzzy logic controller is selected.

The effective compensation is thus achieved based on time compensation count, which is decided for each phase as per below fuzzy logic rule base.

6.3.2.1. FUZZY DEFINITIONS (MEMBERSHIP FUNCTIONS)

Parameter definition of fuzzy controller is given in Table 6.1.

Table 6.1 FUZZY Controller parameters

TYPE	Mamdani
INPUTS	1. Voltage 2. Reactive Current
OUTPUTS	Cycle Count
Defuzzification	Mean of maxima method

INPUTS

Voltage: Five membership functions	
Very Low	$f(x)=\begin{cases}1, x \le 100 \\ \dfrac{112.5-x}{112.5-100}, 100 \le x \le 112.5 \\ 0, 112.5 \le x\end{cases}$
Low	$f(x)=\begin{cases}0, x \le 100 \\ \dfrac{x-100}{112.5-100}, 100 \le x \le 112.5 \\ \dfrac{125-x}{125-112.5}, 112.5 \le x \le 125 \\ 0, 125 \le x\end{cases}$
Normal	$f(x)=\begin{cases}0, x \le 112.5 \\ \dfrac{x-112.5}{125-112.5}, 112.5 \le x \le 125 \\ \dfrac{137.5-x}{137.5-125}, 125 \le x \le 137.5 \\ 0, 137.5 \le x\end{cases}$
High	$f(x)=\begin{cases}0, x \le 125 \\ \dfrac{x-125}{137.5-125}, 125 \le x \le 137.5 \\ \dfrac{150-x}{150-137.5}, 137.5 \le x \le 150 \\ 0, 150 \le x\end{cases}$
Very High	$f(x)=\begin{cases}0, x \le 137.5 \\ \dfrac{x-137.5}{150-137.5}, 137.5 \le x \le 150 \\ 1, 150 \le x\end{cases}$

Table 6.1 Contd..

Reactive Current:

Reactive Current: Five membership functions	
Extreme Inductive	$f(x)=\begin{Bmatrix} 1, x \le -4 \\ \dfrac{(-2)-x}{(-2)-(-4)}, -4 \le x \le -2 \\ 0, -2 \le x \end{Bmatrix}$
Inductive	$f(x)=\begin{Bmatrix} 0, x \le -4 \\ \dfrac{x-(-4)}{(-2)-(-4)}, -4 \le x \le -2 \\ \dfrac{0-x}{0-(-2)}, -2 \le x \le 0 \\ 0, 0 \le x \end{Bmatrix}$
Zero	$f(x)=\begin{Bmatrix} 0, x \le -2 \\ \dfrac{x-(-2)}{0-(-2)}, -2 \le x \le 0 \\ \dfrac{2-x}{2-0}, 0 \le x \le 2 \\ 0, 2 \le x \end{Bmatrix}$
Capacitive	$f(x)=\begin{Bmatrix} 0, x \le 0 \\ \dfrac{x-0}{2-0}, 0 \le x \le 2 \\ \dfrac{4-x}{4-2}, 2 \le x \le 4 \\ 0, 4 \le x \end{Bmatrix}$
Extreme Capacitive	$f(x)=\begin{Bmatrix} 0, x \le 4 \\ \dfrac{x-2}{4-2}, 2 \le x \le 4 \\ 1, 4 \le x \end{Bmatrix}$

Table 6.1 Contd..

OUTPUTS

Cycle count: Three Membership Functions	
Low count	$$f(x)=\begin{Bmatrix}1, x\le 0\\ \frac{25-x}{25-0}, 0\le x\le 25\\ 0, 25\le x\end{Bmatrix}$$
Medium count	$$f(x)=\begin{Bmatrix}0, x\le 0\\ \frac{x-0}{50-0}, 0\le x\le 50\\ \frac{100-x}{100-50}, 50\le x\le 100\\ 0, 100\le x\end{Bmatrix}$$
High count	$$f(x)=\begin{Bmatrix}0, x\le 75\\ \frac{x-75}{150-75}, 75\le x\le 150\\ 1, 150\le x\end{Bmatrix}$$

6.3.2.2 FUZZY SYSTEM BLOCK DIAGRAM

Fuzzy system block diagram is shown in fig.6 4.

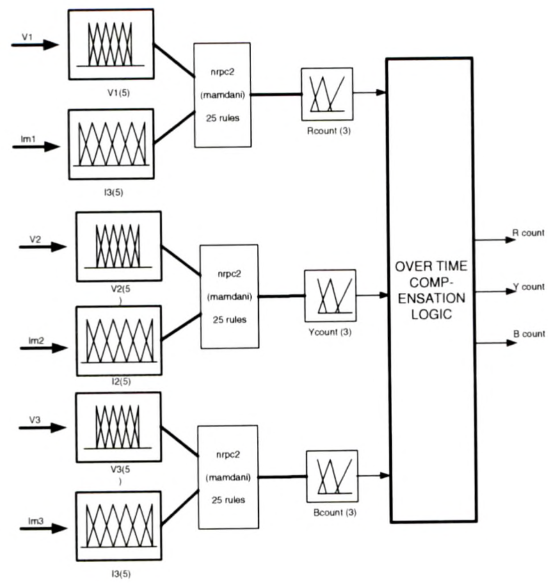
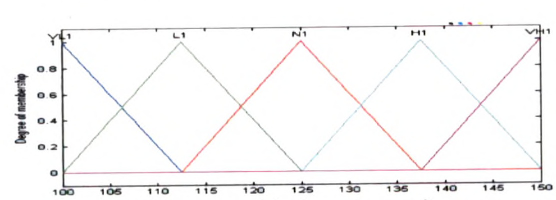


Fig. 6.4 Block diagram of FUZZY system with overtime compensation logic

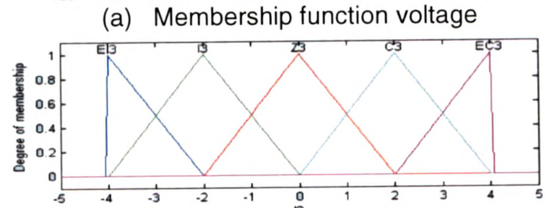
6.3.3 SIMULATION RESULTS

6.3.3.1 FUZZY SYSTEM

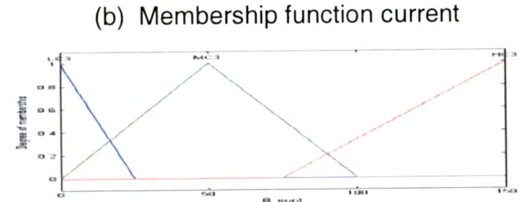
Figure 6.5(a) shows the Membership functions of voltage & Figure 6.5 (b) shows membership function of reactive current input. Figure 6.5 (c) shows the membership functions of cycle count. All results are depicted in figure 6.5 (d)



(a) Membership function voltage

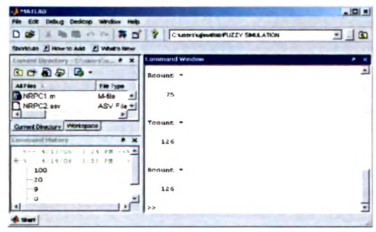


(b) Membership function current



(c) cycle count

Fig. 6.5 Contd...



(d) Representative result of MATLAB Fuzzy simulation

V \ Im	EI	I	Z	C	EC
VL	HC	HC	HC	HC	HC
L	HC	MC	MC	MC	HC
N	HC	MC	LC	MC	HC
H	HC	MC	MC	MC	HC
VH	HC	HC	HC	HC	HC

(e) Fuzzy Logic Rule Base

Fig. 6.5 Fuzzy System

6.3.3.2 COMPENSATION PERFORMANCE

Compensation scheme when implemented based on the above function with STATCON in time multiplexed mode provides compensation for given load condition as illustrated in the below waveforms for R-phase from 0 to 0.2s,Y-phase from 0.25 to 0.45s, B-phase for 0.48 to 0.68s.

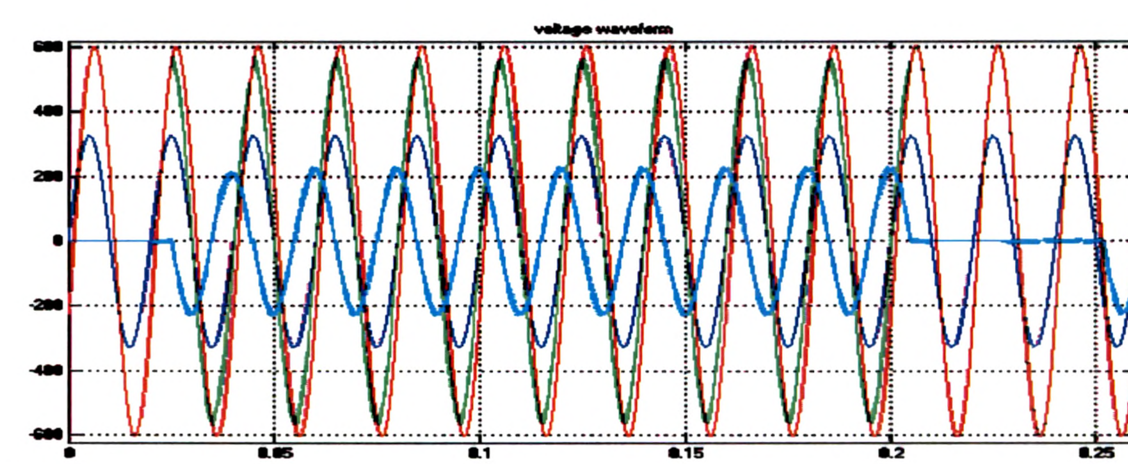


Fig. 6.6 Compensation for R-phase

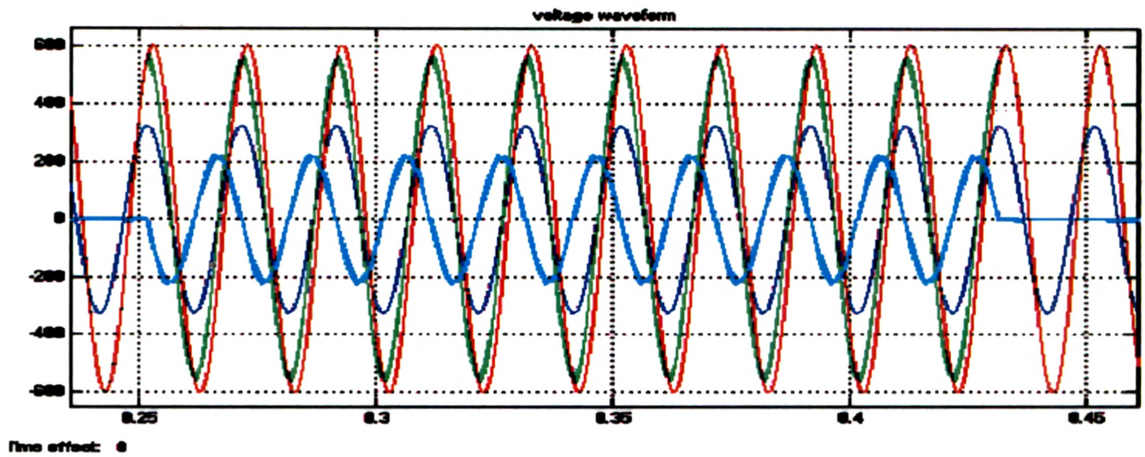


Fig. 6.7 Compensation for Y-phase

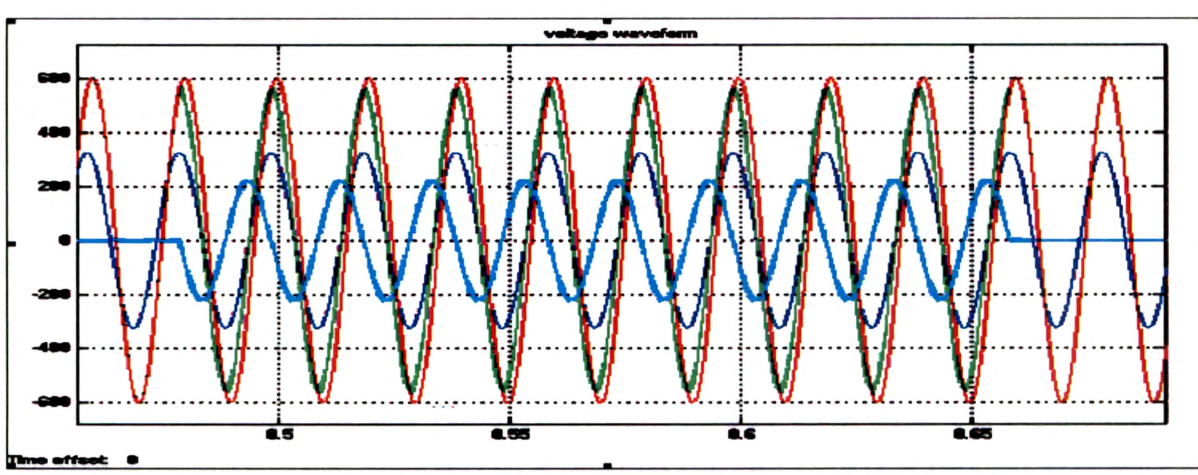
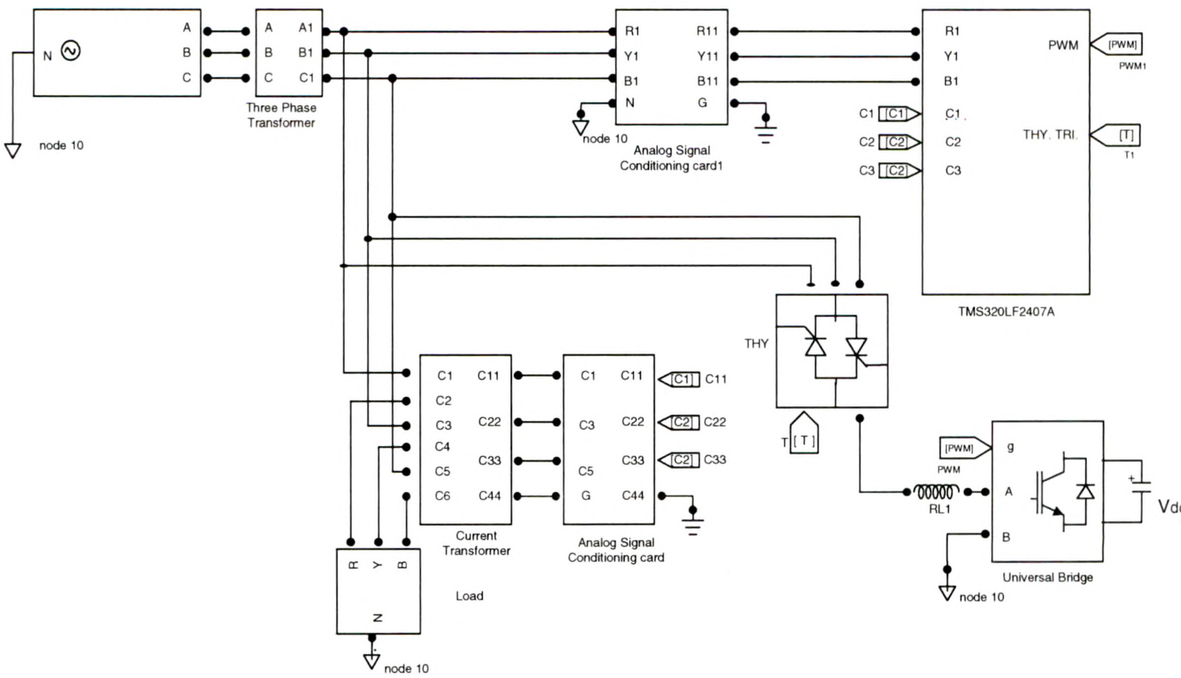


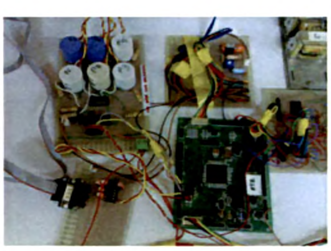
Fig. 6.8 Compensation for B-phase

6.3.4. DSP BASED HARDWARE SETUP

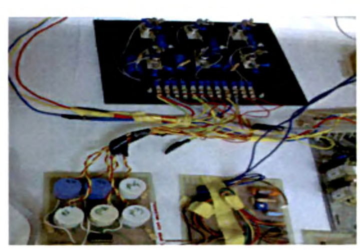
The above logic then has been implemented on the TMS240LF2407A DSP based control hardware set up. Block schematic of the setup is shown in fig. 6.9 (a) while the photographs of setup are shown in fig. 6.9 (b).



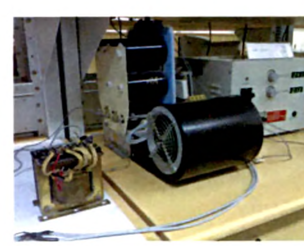
(a) Setup Block schematic



DSP controller module



Thyristor module with snubber



Converter Module

(b) Setup Photographs

Fig. 6.9 DSP set up

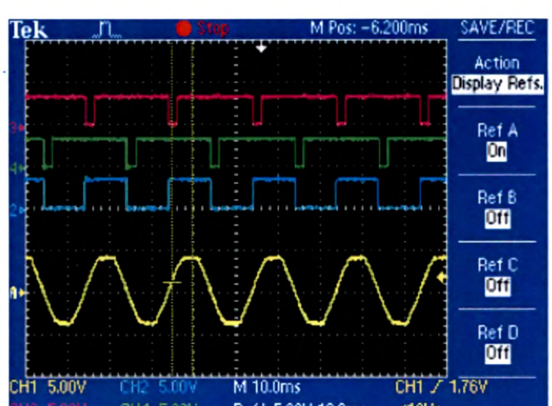
Some of the representative waveforms on the setup are also given in the figure 6.10.

The waveform 6.10(a) shows the pulses to fire the thyristor module, which are synchronized with the system. Channel 1 & 2 shows input and Zero Crossing Detector (ZCD) output of the analog module respectively. On channel 3 & 4 controller output pulses to the gate driving circuit, which justifies the proper operation of the concept, are shown. Same kinds of pulses are generated for all three-phases with time multiplexing, for one phase at a time to ensure the no phase is short-circuited and no devices are damaged.

The Waveform 6.10(b) shows the time-multiplexing operation of the R & Y phases for 10 cycles. For the first 10 cycles converter is connected to R-phase and for the next 10 cycles to Y-phase. Same-way for the next 10 cycles to B-phase and this cycle s continues repeatedly. Channel 1 & 2shows the pulses for the R-phase Thyristor module. Channel 3 & 4 shows the pulses for the Y-phase Thyristor module.

Waveform 6.10(c) shows the compensation to R-phase. Here two-cycle operation of the control concept is shown. Channel 1 & 2 shows the i/p and o/p signal from analog module. Channel 3 & 4 shows the pulses for the R-phase module.

Waveform 6.10(d) shows typical current waveform when the single-phase converter gets connected to one of the incoming phases and draws an inductive current / power. The figure also gives the incoming voltage and the single-phase converter output switching voltage waveforms. Similar results can be obtained when capacitive current is drawn by the converter.



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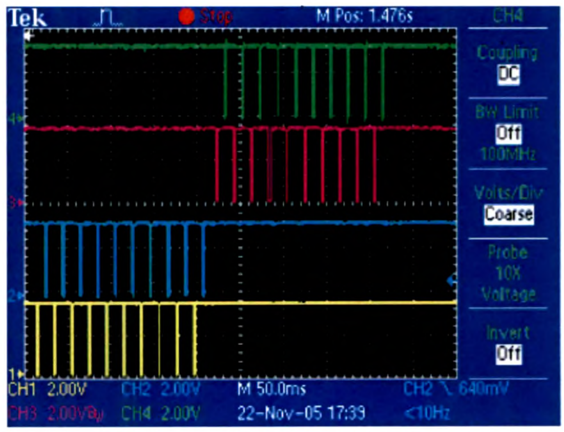
(a) Pulses from Controller to drive Thy. Module

Fig. 6.10 Contd...



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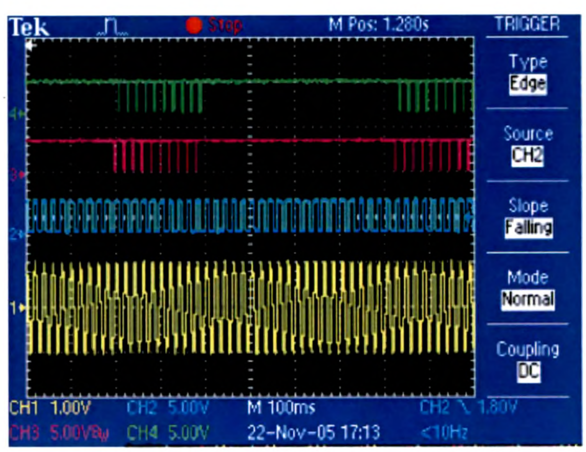
(b) Multiplexing operation proposed in Novel Control Concept



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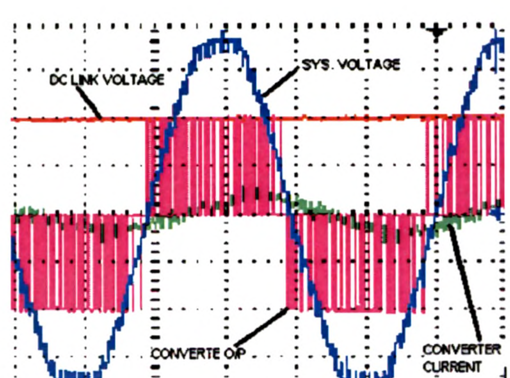
(c) Two cycle operation of Novel Control Concept for R-phase



(d) Typical Input Voltage, Current and converter switching waveforms

Fig. 6.10 Waveforms from the Prototype Hardware setup

6.4. SUMMARY

The proposed concept for the reactive power compensation thus has been simulated and also checked for practical feasibility on prototype hardware setup. Results do indicate cost effective realization of such a concept. Thus the concept can help reduce the cost of per kVAR compensation provided to the system with small compromise on performance if the loads had been balanced on all the phases. The possibility of the fuzzy controller has been evaluated. The implementation of fuzzy logic on DSP controller and the possibility of Artificial Neuro Fuzzy Intelligent System (ANFIS) in future can also be addressed. Different control approach as well as controller (like current generation of Texas F2812) can also be looked in if, so that it can help more robust response while ensuring that the main task of the cost reduction is not diluted. More details are also covered in [234].

6.5 CONCLUSION

Such a concept can be economically good as the cost of the single-phase STATCON installation with proposed novel control concept comparatively becomes lower as against present approach of using three-phase STATCON. Also, this also facilitates in reduction of overall system engineering efforts. A simple concept of using a single-phase Voltage Source Converter in multiplex mode, as suggested here, can be used with three-phase system, especially when the peak load reactive power compensation demands are non-simultaneous. Combination of the converter with back to back connected thyristor switches makes it possible. The converter also gives flexibility for achieving the phase compensation based on any predefined programme. Fuzzy logic allows implementation of such a programme in a way to meet user requirements and even last minute changes as desired by an application. A good application could be spot welding in automobile industries.