CHAPTER SEVEN

NOVEL CONCEPT OF WINDOW OPERATED STATCON

7.1 INTRODUCTION

With growing benefits on application of four quadrant converters using Insulated gate Bi-polar Transistors (IGBT's) and Integrated Gate Commutated Thyristors (IGCT's) for Power Quality improvement, needs for industrial product solutions is also on rise. With time, solutions for power factor improvement or Reactive Power Compensation (RPC) have also undergone substantial change starting from the switched capacitors (electromechanical and thyristorised) to active converter (Voltage Source Converter : VSC) based compensation. Detailed look at the solutions available/offered from different manufacturer do reflect that there has not been effort, however, to practically look at various reactive power compensation methods and also suggest economical way of their implementation. This chapter first describes the need for economical solutions and then introduces the new concept of using window operated STATCON with integrated operation of Thyristor Switched capacitor (TSC) bank for economical reason and also gives simulation results for realization of its control strategy. Thereafter, it addresses implementation using Digital Signal Processor (DSP) based control hardware..

7.2 NEED FOR ECONOMICAL REACTIVE POWER COMPENSATION SOLUTION

A closer look on the existing cost comparison of VSC based solutions like STATCON for reactive power compensation reflects that per kVAR definitely has been higher as against the deployment of traditional solutions like TSC, TCR or APFC. This is described in Table 3.1 in chapter 3. Apart from new technology as aspect, the higher cost of VSC based (viz. STATCON) solutions in many cases creates a situation, where the end user even though is satisfied by the benefits but finds cost prohibitive of total reactive demand being met by VSC solution. Users many a time even have some traditional solution based on capacitors installed or have load variation in terms of reactive demand not dynamic from zero to peak demand value (capacitive/reactive) but has offset in dynamics on base reactive demand.

In such a scenario, while the VSC based solution- STATCON cost cannot be reduced, but by carefully handling the integrated use of STATCON with conventional switched capacitors, the cost challenge can very easily be addressed. Operation of STATCON (+/-reactive power compensation) with any specific available base / step of the TSC is called here as the window operate STATCON.

7.3 CONCEPT OF WINDOW OPERATED STATCON

STATCON typically compensates the reactive power without generating the lower order harmonics (current drawn is nearly sinusoidal) and provides benefit of operating in capacitive as well as in inductive mode. When STATCON is employed only for Inductive- reactive power compensation, the capacity utilization is 50% of the compensation which it can offer as it utilizes only "+VAR" compensation from total "±VAR" which can be supported. Fixed capacitors are therefore used many a times for base level 50% compensation. Thus, zero to 100% load compensation (capacitive VAR) can be achieved. Similar approach can also be used along with 50% fixed inductor to provide zero to 100% inductive VAR compensation for capacitive loads. This kind of approach definitely can improve Cost/kVAR compensation demand. However, in this scenario, installation economics is still dictated by the 50% STATCON capacity.

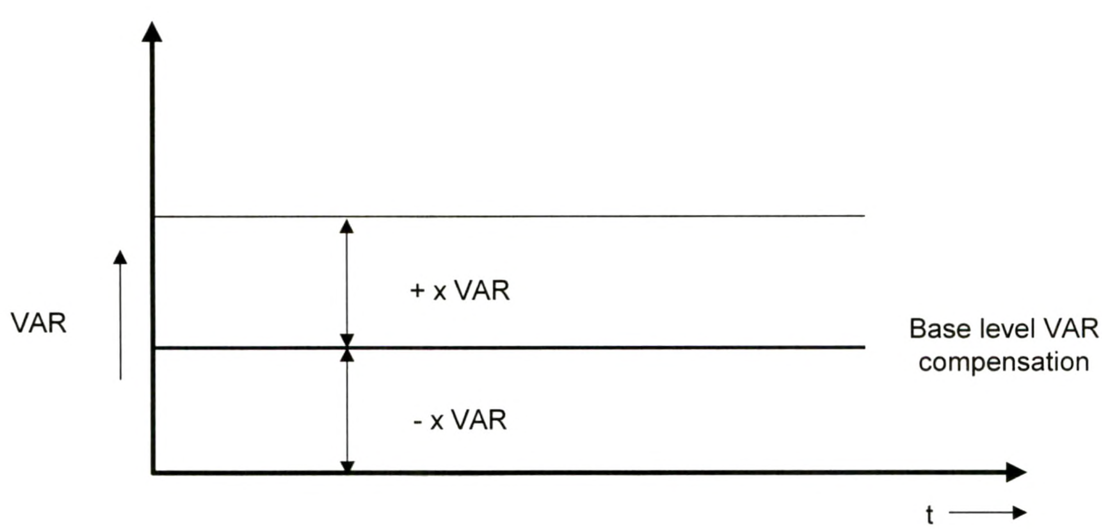


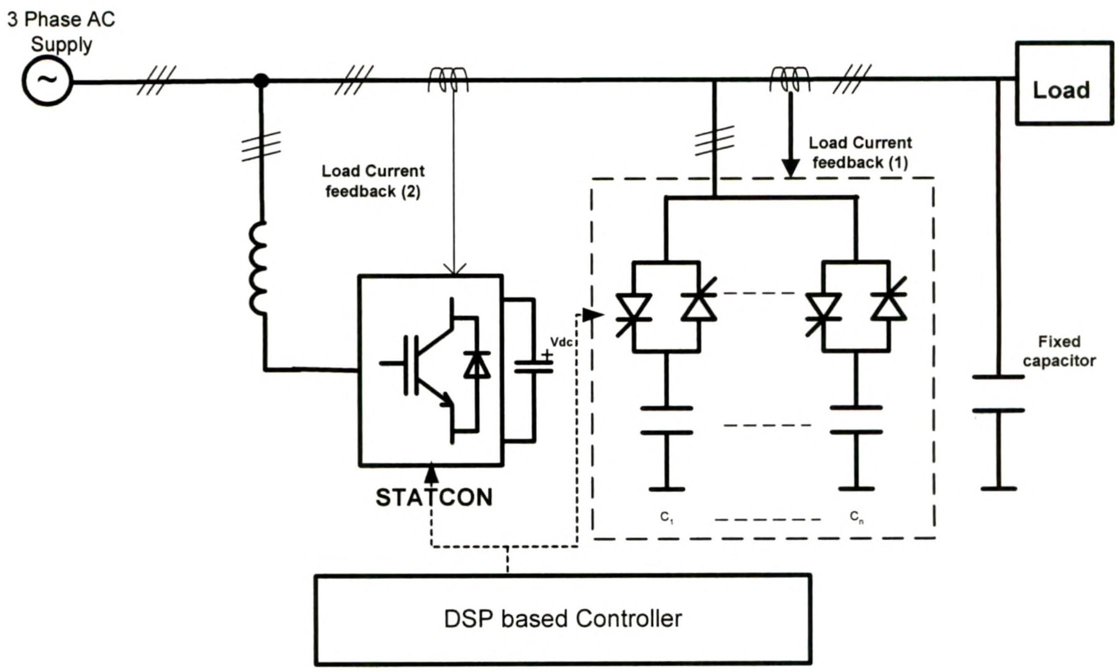
Fig. 7.1 STATCON with base level compensation

To overcome this problem, it becomes worth using combination of TSC and STATCON. For example, if compensation required is 3000 kVAR, one can use fixed capacitor bank of 500 kVAR, four numbers of 500 kVAR TSC banks, and one number of 500 kVAR STATCON. This covers the total compensation range of 0 to 3000 kVAR. Depending upon the load current and the compensation required at any given point of time, the number of TSC banks to be switched on is decided and the STATCON works around this window. Thus if two TSC banks are on, the base level compensation is 1500 kVA and with the STATCON on, it gives compensation from 1000 to 2000 kVAR. Any value of load compensation within this window can now be met. If requirement goes beyond 2000 kVAR the third TSC can then be switched on. The compensation window will then move to 1500 kVA to 2500 kVAR. This is the principle of window operation with the STATCON. The STATCON compensation moves forward and backward with number of TSC banks in on state. This offers a good and economical method for Dynamic Reactive Power Compensation (DRPC); in between the two extremes of TSC and only STATCON based methods. It should be noted that if only TSC is to be used, the number of banks increase based on kVAR resolution required. The solution cost hence is high. On the other hand, if 50% capacity STATCON is used along with 50% base capacitor, the cost is still high. An optimal combination of fixed capacitor, TSC, and STATCON offers cheaper solution without compromising on resolution required for compensation and also the response (which is very fast). Different possibilities of STATCON sizing with STATCON capacity same as TSC step or half of the TSC step can be addressed. Figure 2 shows the schematic of window operated STATCON with STATCON capacity consideration to be of half of TSC step or same as TSC step.

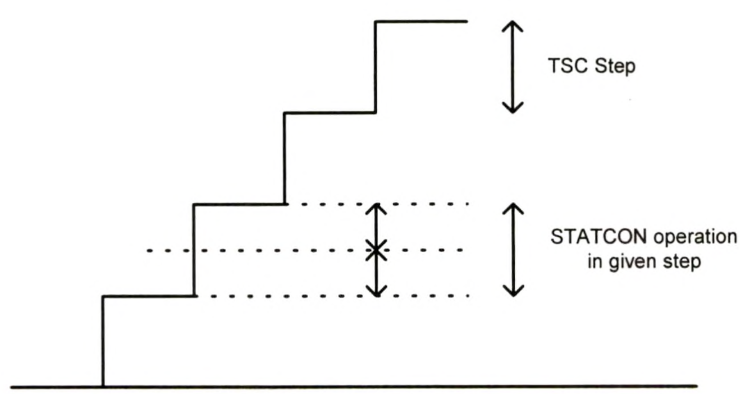
The operating base VAR can be varied in steps with the help of TSC. A single digital controller also can control the switching of STATCON as well as the TSC steps based on the load side current feedback.

It also to be noted that this model of operation is different from the conventional combination of STATCON which offers "±VAR" and getting installed along-with commercially available thyristor switched capacitors panel which offers capacitors compensation switching in 1,2,4,8....binary steps.

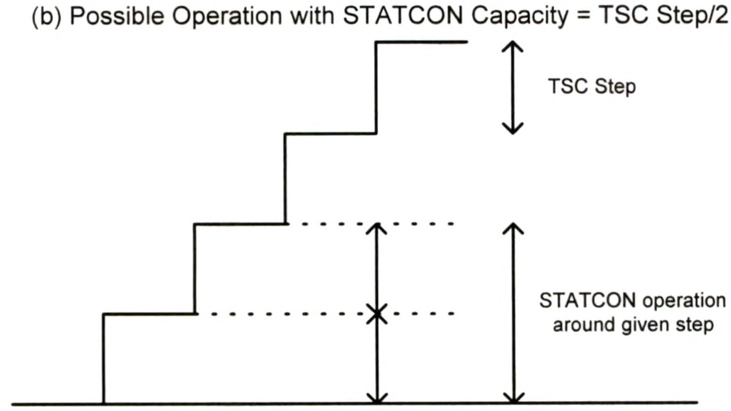
In this proposed concept, granularity of compensation is dependent upon the no. of the steps which can be provided in single product solution and minimum and maximum compensation required for given application requirement. In this concept, all switched capacitors steps can be much larger (not required to be granular), since minimum compensation is already taken care by STATCON dynamics and further all the switched capacitors step can be of same size incorporating capacitors and switches of same rating (this also facilitates maintenance ease). Such a system based on STATCON and TSC is now modeled.



(a) Scheme for Window operated STATCON



(b) Possible Operation with STATCON Capacity = TSC Step/2



(c) Possible Operation with STATCON Capacity = TSC Step

Fig. 7.2 Window operated STATCON

7.4 MATLAB MODEL

Basic MATLAB model for evaluating performance of window operated STATCON (integrated with Thyristor switched capacitors) is developed and is shown in fig. 3.

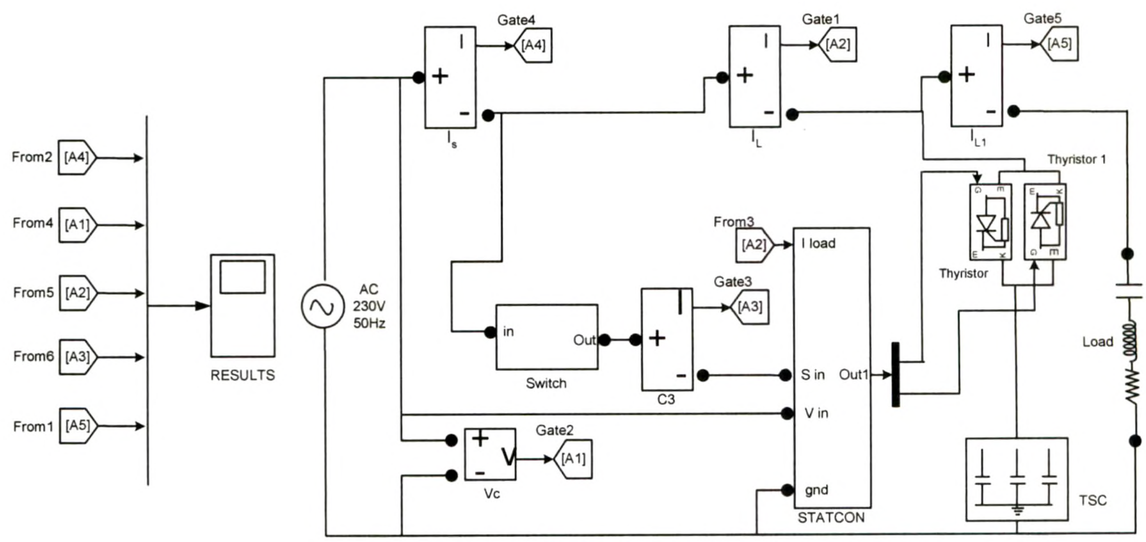
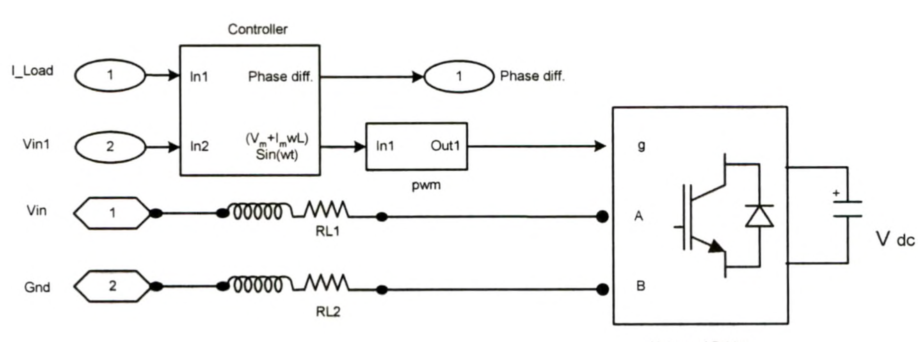
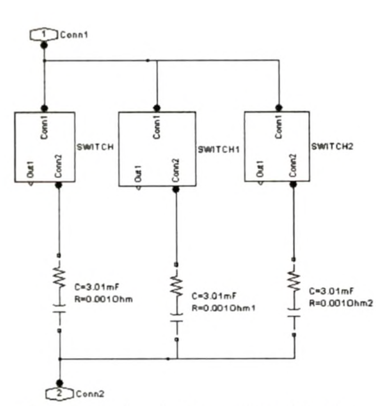


Fig. 7.3 MATLAB Simulation model of STATCON with windowing concept

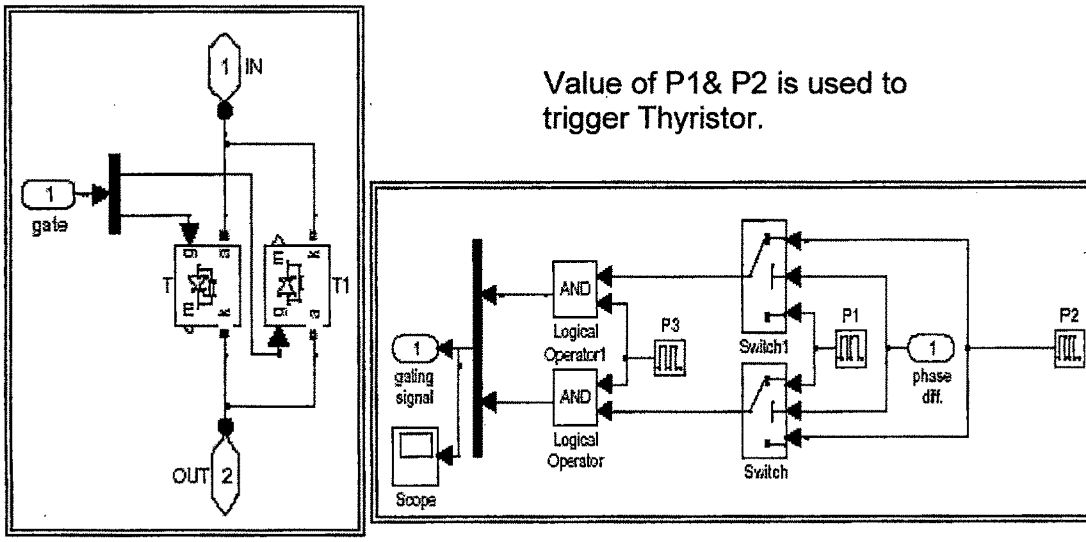


(a) STATCON simulation block for the concept



(b) Switched Capacitor block

Fig 7.4 contd..



(c)Thyristor switching module

Fig. 7.4 Simulation block details

7.5. STEPS FOR THE BASIC LOGICAL CONTROL FUNCTION

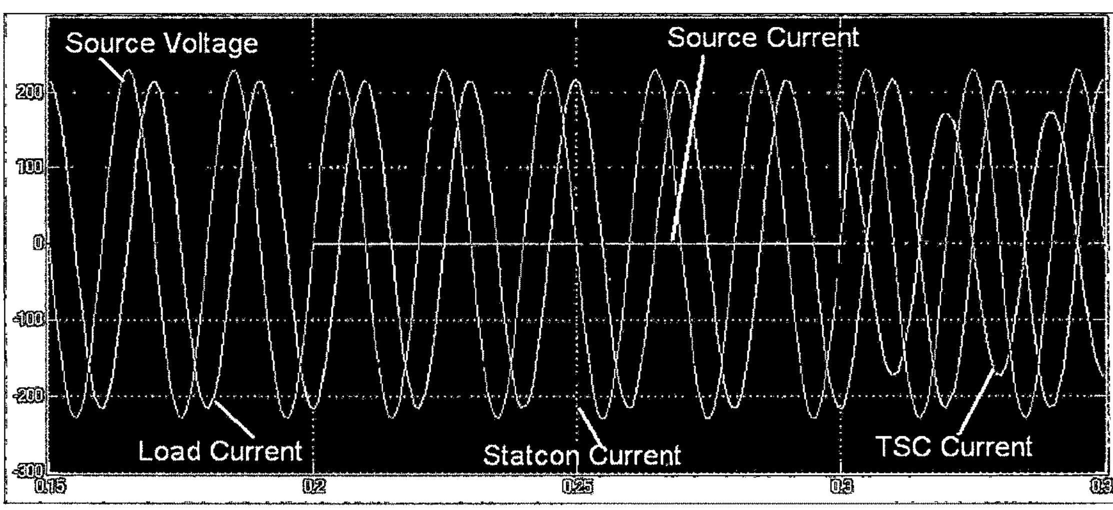
1. Sense the individual phase load current and supply voltage.
2. Sense also the voltage across the switched capacitor
3. Sense also the feedback current (STATCON compensating current for the VSC supplied component) and current flowing through switched capacitors which are integrated to offer capacitive compensation offset.
4. Calculate current displacement from the supply phase voltage and then the power factor of the load.
5. Calculate the reactive power component of the load current (I_L sin Φ). The compensating current to be drawn by STATCON (with integrated capacitor switching control) will now be - (I_{L1} sin Φ).
6. Evaluate the magnitude of compensation demand. This will be based on pre-defined information on the capacitor banks which are available (& health through feedback checks), compensation already provided through switched capacitor and additional incremental / decremental need.
7. The total compensation current command now will combination of actual capacitive compensation already provided by switched capacitor in system, additional capacitor which are required to be switched and the base dynamics/fine tuning of compensation

need from STATCON through VSC block. Non-volatile memory storage of the current compensation provided can help in deciding the next compensation which could be demanded without affecting the dynamics of load response

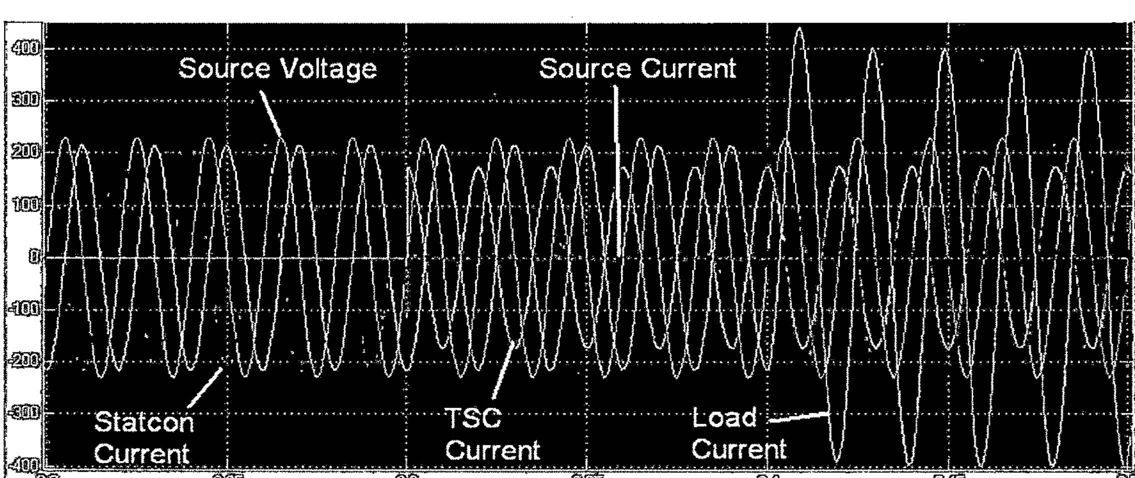
Note: As known that any step voltage given to the capacitor theoretically causes infinite surge current through capacitors. This gives rise to reduction in life of capacitors as well as switching devices. Also it causes undesirable inrush current/ line transients. To avoid this, difference in line voltage and the capacitor voltage across every switch is sensed and whenever it is zero the capacitors are made to turn "on" by firing the associated thyristors.

7.6. SIMULATION RESULTS

Simulation results are now given in fig. 7.5 below



(a) STATCON and TSC driven from the single control unit share the compensation demand



(b) Load dynamics addressed through STATCON and TSC driven from the single control unit

Fig. 7.5 Simulation results for the Window operated STATCON

Figure 7.5 above shows the simulation results about compensating response for dynamic load conditions, when single control unit drives the STATCON and TSC. Figure 7.5(a) the initial part depicts source current, which is same as load current without any compensation. Subsequently once the STATCON turns on the reactive component of current is compensated by STATCON and source current practically becomes zero. Same compensating requirement is also addressed towards the end with the TSC switching on its step and then STATCON current falling down to meet only the shortfall and the dynamics within TSC step. System behavior with load dynamics is further highlighted in the fig. 7.5(b). Where subsequent rise in the compensating demand, for the increase in reactive current drawn by load, but within a TSC step is directly supported through dynamic compensation offered by STATCON. This can also be seen that this combination thereby at all times maintain the practically unity power factor if the capacitor switching instant are properly controlled and by detailed modeling of window operated STATCON.

7.7 EXPERIMENTAL SET UP

The experimental set up along with the overall block diagram is given in fig. 7.6. Hardware has been realized using Texas instruments TMS 320LF2407A DSP. Since the basic STATCON hardware incorporates sub cycle sensing of load current and computation of associated compensating current demand, an integrated control output for the ON or OFF switching of the TSC's is facilitated without any additional control hardware needs. The non-volatile memory available on the controller board facilitates retention of last switched (or none of the TSC's switched) information even in absence of power failure and hence provides very fast convergence to the compensating current demands.

SCRs which are used as a part of experimental setup are with consideration of setup requirement as:

- System voltage available is Vrms= 230V and
- Maximum current to be flow in the system is Irms=22A
- With expected dv/dt = 100 V/us and di/dt = 200 A/us
- Appropriate Snubber network for protecting SCRs is also designed which consists of a series resistor and capacitor (C = 0.1925 μF, R= 47ohm)

SCR selected is 25RIA120 from IRF, with 1200V and 35A as rating.

For Gate driving, the circuit is designed to give firing command, which will ensures the proper turn on of the Thyristor at proper instant. Diode D1 is used to restrict the negative pulse to reach gate, D3 is freewheeling diode. R_{GK} is used to form a gate current I_G. All I/P and O/P waveforms are given in next section.

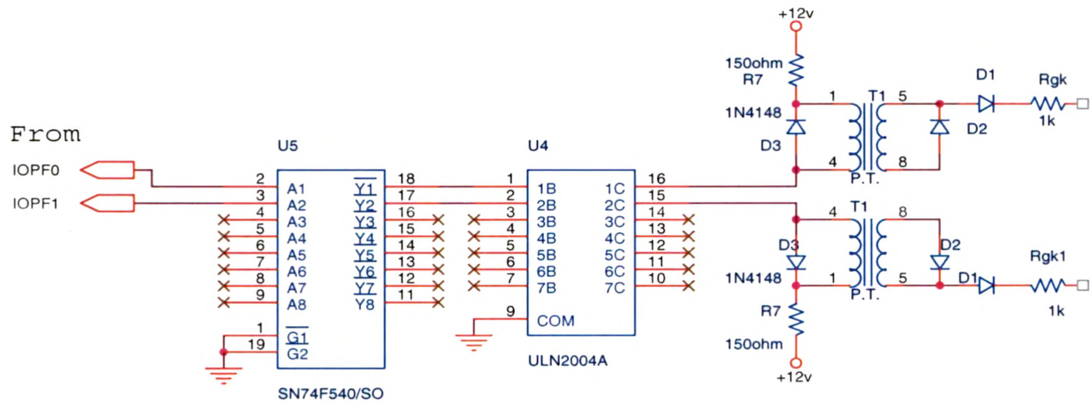
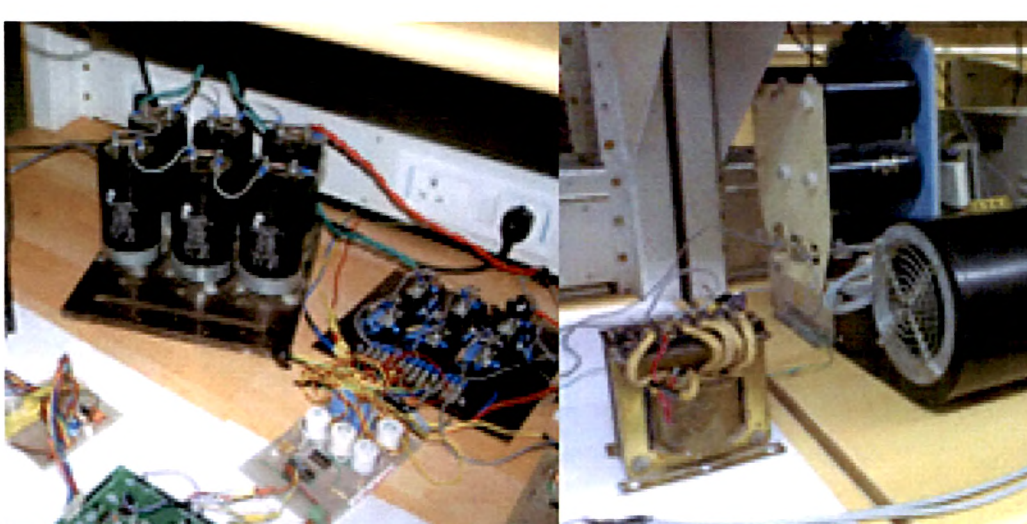


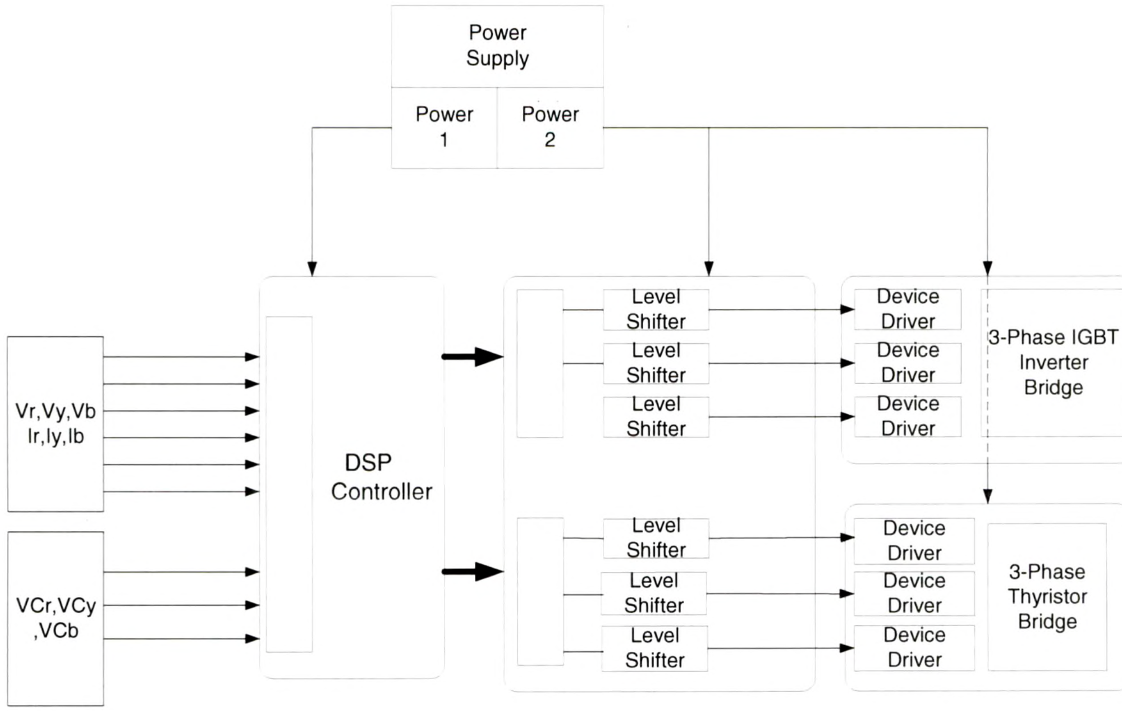
Fig. 7.6 Gate drive circuit

For converter SEMIKRON make SKH 100 GB 122D voltage controlled, N channel device, is used for switching application. SEMIDRIVE SKHI 22A is deployed as hybrid dual IGBT driver. This driver has CMOS compatible input and provides short circuit protection by V_{CE} monitoring and switch off, Isolation by Transformer, supply under voltage protection and error latch/output. Two DC bus capacitor of rating 1500uF/400V is connected in parallel to each leg of converter.



(a) Basic set up

Fig. 7.7 contd..

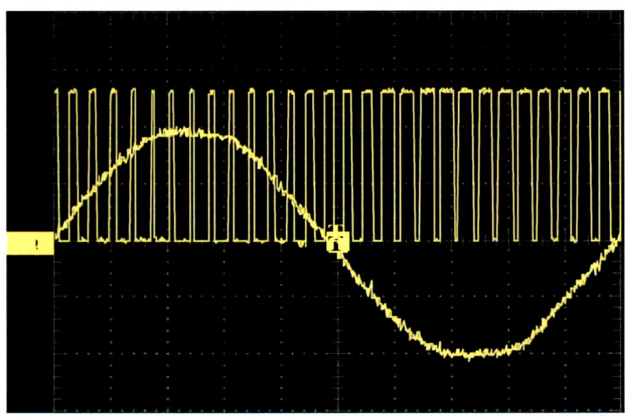


(b) Overall block diagram

Fig. 7.7 DSP based hardware development / environment

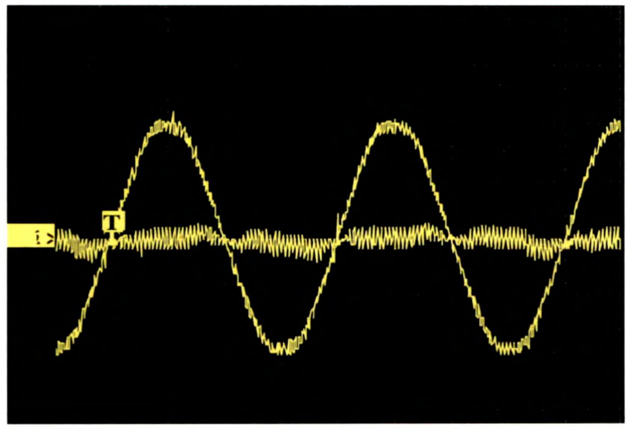
7.8 EXPERIMENTAL RESULTS

On the laboratory Prototype the concept is verified for the integrated operation. Basic functional results are in line with theoretical expectation/simulation results.

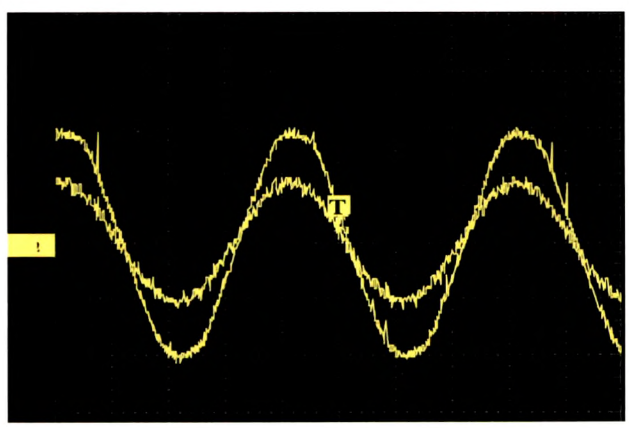


(a) Waveform showing PWM output pulses from DSP at zero current Supported from STATCON (VSC part)

Fig. 7.8 contd..



(b) Waveform showing source voltage and current when compensated by Integrated STATCON



(c) Waveform showing Statcon current and TSC current while offering compensated for the above case

Fig. 7.8 Waveforms on experimental setup

More details are covered in [235-238].

7.9 CONCLUSION

Proposed dynamic reactive power compensation solution using combination of the integrated thyristor switched capacitors and the STATCON can be treated as an economical method, which bridges the cost and response time economics between use of only commercial available TSC's (with its acceptable response) and STATCON (with the most desirable response). DSP based control is to be considered only as a tool, as the controls can also be achieved by using proper and available micro-controllers also.