

CHAPTER TEN

CONCLUSION

10.1 GENERAL

Power Quality has been an area of potential interest as reflected from the emphasis being laid on it in recent publications, industry attention, conformity requirements, and growing number of conferences and symposiums being held for the same. Deployment of the Voltage Source Converters (VSCs) in AC to DC bidirectional power conversion, especially in the area of dynamic reactive power compensation, also appears to be major area of interest for researchers. Continued advancement of technology, both on the power devices and control electronic also facilitates range of solutions getting explored by researchers. However, considering the range of applications and power requirement from few KW to several MW, and co-existence of other equipment with diversified technology already in use in industries and utilities, assuring the power conversion quality at economical costs poses challenges, with requirements demanding multi-disciplinary efforts to engineer a given field solution.

Work in this thesis is oriented to meet this objective of using Pulse Width Modulated (PWM) based VSC based concepts, for dynamic reactive power compensation applications in single and three phase applications. Some of the concepts cover field installations, while the others cover simulation and/or experimental results. The design implementation also addresses current generation of embedded controllers and ensures through novel hardware engineering and software practices, reliable operation in actual field conditions beyond the standard functional experimentations and laboratory performance results [224-6,243-244]. Further additional concepts and methods for addressing power quality concerns (based on the experiences gained while working on emerging industrial/utility requirements) are introduced in later chapters [245]. The thesis thus becomes a comprehensive information base for facilitating further new generation products while bridging the gap being faced on the economical concerns for the method already in use. Overall conclusion based on the work and experiences is given below.

10.2 OVERALL CONCLUSIONS

1. In regards to the basic design of single-phase and three-phase Dynamic Reactive Power compensator, Chapter 3 includes the details apart from field installations and

novel aspects of designs [224-225,243]. Design integration issues to ensure reliable operation in the field, with innovative way of mitigating the challenges faced in the field from hardware as well as software perspective and encompassing from basic power supply design to the selection of power devices on one side and analog components to the digital controller on the other side, with product engineering and integration aspects, makes the product design experience an asset.

2. With emergence of variety of ways of realization of digital core and hundreds of different controllers (Microprocessor, Microcontroller, Digital signal processors) being offered every other day, engineers do find themselves at the cross roads while arriving or establishing the choice for the given control application. Selection approach for the right controller and the growing benefits emerging from new generation architecture requires to be explored, to enhance benefits for realizing Power Electronic applications. Chapter 4, hence, highlights different technological alternatives for implementing the Digital core control (Hardware + Firmware) and later also illustrates that beyond establishing functional performance in the laboratory environment, one needs to be sensitive to the system engineering aspects incl. Electromagnetic Interference and Compatibility aspects while engineering a product to guarantee the performance in the field. This experience has been very clearly brought out in the chapter 4, which details out the practical installation experience and the performance, which then has been achieved [226].
3. Novel concept of VSC (Voltage Source Converter) – STATCON design, which can dynamically compensate reactive power as well as balance active drawn from the source and allowing unity power factor operation at the input supply has been supported with simulation results in chapter 5. As detailed in chapter 5, STATCON can help achieve these demands, by properly adjusting the angle between the system voltage and STATCON voltage, which gets generated based on compensation demand [229].
4. Chapter 6 facilitates the details of a simple but novel concept of using a single-phase Voltage Source Converter- Modified STATCON in power multiplexed mode. As supported by details in the chapter this can be used with three-phase system,

especially when the peak loads reactive power compensation demands are non-simultaneous. Combination of the converter with back to back connected thyristor switches makes it possible. This approach can give flexibility for achieving the phase compensation based on any predefined programme. Fuzzy logic allows implementation of such a programme as one of the ways to meet various application demands and requirements, even to meet on line changes [234].

5. Concept of Dynamic Reactive Power compensation solution using combination of the Integrated Thyristor Switched Capacitor (TSC) and the STATCON, as detailed in chapter 8 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). Further, usage of the single core controller (DSP or microcontrollers based control) for both the blocks can facilitate the economics. Further adoption of this approach, based on the end application requirements can help ensure unity power factor operation for practically any field application [235,236].
6. Electronic Transformer (ET) concept as highlighted in chapter 9 can be economically very viable option, for mitigating major power quality problems by converting all loads close to sinusoidal and achieving unity power factor operation towards the distribution grid side. This if put in practical usage, can help increasing the efficiency of the entire distribution grid, apart from completely mitigating impact of secondary faults and having very low no load losses. Further, this design helps substitute for the conventional oil filled Distribution Transformer (DT) and thus becomes environmentally friendly which is growing need of hour. Although as stated earlier, the ET implementation as compared to the DT could be more expensive. However, the overall system loss reduction and unity power factor benefits will surpass the overall cost and accrued benefits in the long run [245].
7. Novel concept of using Transformer for improving voltage profile of given system, is simple to apply in many applications as highlighted in Chapter 9. Improvements suggested through the concept can have far reaching effects, as it brings improvements in the Low Voltage (LV) distribution at a small additional cost increase.

Such transformer can also be used in combination with Dynamic Voltage Restorer (DVR) depending upon the impact of duration of dips/rise and considering economics of the applications on similar lines as STATCON and TSC combination or purely as DVR for mitigation of voltage sag in an industrial power distribution system. Even, a solution deploying modification of the DT's with this arrangement (set of three secondary windings getting added to each output line internally), can emerge altogether a new green field Distribution Transformer design as product having internal compensation for voltage dip / rise.

10.3 OVERALL REMARKS

It is thus envisioned that a new, technologically advanced infrastructure based on such concepts once installed, can facilitate electric power systems to deliver more power, with greater reliability and higher efficiency. Outages and brownout with such solutions then should be infrequent, localized and quickly resolved. Novel Reactive Power Compensation (RPC) solutions presented can help reduction energy lost in generating, transmitting, and delivering electricity, and can be used with every conceivable source of electric power. Some of the concepts can also help the existing infrastructure getting used in better way.. Further, deployment of such electronics based solutions can facilitate a smart, electronically controlled grid, eliminating much of backup power requirement, fundamentally improving cost and environmental performance. Most of the necessary basic technologies are available, few have already been deployed and progress also can be fuelled on others. On the technical side, though control is fundamental. Hence, the digital control of power grid with comprehensive electronic sensors operating at the same speed as power flow will let utilities re-route power instantly. It will also be hence possible that problems will start getting islanded rather than cascading and thereby ensuring that no outages are there.

Lastly, it is important to note that ensuring good power quality requires good initial design with multidisciplinary approach, effective correction equipments, & co-operation with the semiconductor manufacturers, designers, component manufacturers, involving frequent monitoring and good maintenance. In other words, it requires holistic approach and a good understanding of the principles and practice of power quality improvement. The thesis hence can be looked as a support guide to provide this understanding.

Some of the immediate areas for future continuation of the work can be

1. With the availability of new generation DSP controllers and high capacity power devices, practically single chip or Application Specific Integrated Circuits (ASIC) based controller in combination can be designed, which can facilitate highly improved performance through multi carrier operation for multiple inverters operating in parallel.
2. Harmonic elimination using multilevel waveforms and generalized harmonic reduction technique is also an area which can be examined. Considerable benefits then can be achieved with phase shifted converter waveforms apart from the multi carrier operation as mentioned above.
3. Calculation linked with sizing of DC bus for electronic transformer concept can also give rise to high quality low end dc distribution transmission system.
4. Concept of voltage dip/rise compensation through transformer, by using further cascading of similar compensating device can be consider as economical alternative offering very high level performance equivalent to present generation Dynamic Voltage Restorers (DVR) in process plants and industries.
5. Hardware Prototyping of the STATCON with source side KW balancing and deploying the same for Distribution Transformers (DT's) used in LV networks can greatly aid the very high level of DT capacity utilization in urban and rural sectors.

Patent:

[1] Patent granted and Published in Indian Patent Journal on 11th August 2006 to ABB Limited with authors V.R.Kanetkar, VKShah and P.L.Biswas on Dynamic Reactive Power Compensator (Application No 207/MAS/2003)

List of Major Publications:

[1] P. L. Biswas, C. M. Shylendra Kumar, V. K. Shah and V. R. Kanetkar, "Statcon rules the reactive power world", Proceedings of Seminar on Capacitors organised by CBIP at Pune on 18 - 19 Jan. 2001, pp 17 - 23.

[2] P. L. Biswas, V. K. Shah and V. R. Kanetkar, " Statcon provides an economical solution for fast smooth dynamic reactive power compensation ", CIGRE Regional Meeting New Delhi (India) (International Conference on Bulk Power Transmission System Integration in Developing Countries) Proceedings, 8-10 Nov., 2001, pp VI - 39 to VI - 45.

[3] V. R. Kanetkar, V. K. Shah and V. B. Sriram, " Technology based solutions within practical constraints for LV distribution quality and efficiency improvement ", Seminar on " Power Distribution System " (organised by The Society of Power Engineers (India), Vadodara Chapter and GEB, Vadodara) 24 - 25th Nov., 2001, pp 131- 138.

[4] V. K. Shah and V. R. Kanetkar, " Development experience of trouble free working of low KVA IGBT based PWM converter with emphasis on Electromagnetic Field and Interference suppression ", Seventh International Conference and Tutorial on Electromagnetic Interference and Compatibility (INCEMIC 2001/2, Bangalore) Proceedings, 18-23 Feb., 2002, pp 141-145

[5] V. K. Shah, "Introduction to EMI/EMC and Overview of EMI/EMC in HV Substation environment", Presented at ISTE Workshop on HV Engg. At Polytechnic, M.S.University of Baroda on 18th November 2004.

[6] V. R. Kanetkar and V. K. Shah, " Economical dynamic reactive power control - A challenge ", International Conference on Present and Future Trends in Transmission and Convergence (organised by the Council of Power Utilities in association with Power Grid Corporation of India at New Delhi, India) Proceedings, 4-6 Dec., 2002, pp VII 1-9.

[7] V. R. Kanetkar and V. K. Shah, " Dealing with reactive power control, supply voltage distortion, and harmonic filtering - A consolidated approach", The sixth International Conference on Electrical Rotating Machines, ELROMA -04 (organized by IEEMA in New Delhi) Proceedings, 4-5 Feb., 2004, pp VI 12 - 20.

[8] V. K. Shah, " Power Quality: Reactive power control and Active filter status", Proceedings of National Workshop on Reactive Power organised by ERDA at Vadodara on 29 & 30 Sept 2005.

[9] P. L. Biswas, V. R. Kanetkar and V. K. Shah, " Experiences on installation of first IGBT based advanced real-time, smooth, and dynamic reactive power compensation system at 132/25KV traction sub-station in Lasalgaon for improving power factor", Proceedings of International Seminar on Capacitors (CAPACIT- 2005) organised by IEEMA at New Delhi on 17-18th Nov. 2005. pp II 23-28 **(Received best paper award for the same)**

[10] V. R. Kanetkar, P. L. Biswas, U.K. Deshpande, P.A. Chitre, V. K. Shah " IGBT based dynamic VAR compensator for spot welding applications in Automobile industry", Proceedings of International Seminar on Capacitors organised by IEEMA at New Delhi on 17-18th Nov. 2005. pp II 17-22

[11] V. K. Shah and Rakesh Patel "Experience of using DSP Controller in Power converter board design", IETE Technical review Journal: Nov-Dec'2005, Vol. 22, pp 413-423

[12] V.K.Shah, V.R.Kanetkar, A. Pradeepkumar and S.M.Joshi "Addressing Reactive Power Compensation with Source side Active Power Balancing – Most Desired Requirement", Proceedings of International conference at Gridtech New Delhi 5-6th February 2007, pp164-171

[13] V.K.Shah, V.R.Kanetkar and S.M.Joshi, "Window Operated STATCON" Invited paper cum presentation at International seminar on Power vision opportunity and challenges, at Mumbai on 3rd February 2007

[14] V.K.Shah, V.R.Kanetkar and S.M.Joshi, "Technology based solutions for Power Quality improvement with emphasis on Reactive Power Control" invited paper cum presentation at National conference on current trends in Technology (NUCONE 2007) at Ahmedabad, on 29th Nov-1st Dec'2007, pp 86-92.

[15] V.K.Shah, V.R.Kanetkar, Ujjaval Joshi and S.M.Joshi, "Fuzzy Logic based Three-Phase Dynamic Reactive Power Compensation using Single- Phase STATCON" at International Conference on Power Systems (ICPS),supported by IEEE PES society at CCAR, CPRI, Bangalore from 12-14th Dec' 2007, paper Sr. No. 108

[16] V.K.Shah, V.R.Kanetkar and S.M.Joshi, " Window Operated STATCON with Integrated Capacitor Bank Switching" at International Conference on Power Systems (ICPS),supported by IEEE PES society at CCAR, CPRI , Bangalore from 12-14th Dec' 2007, Sr. No. paper 130

List of other relevant publications/invited talks:

[1] V. K. Shah, "Evolution of Digital Signal Processors", Presented at seminar on "Applications of Digital Signal Processors" organised by IETE, Baroda, 18th March 2001.

[2] V. K. Shah, "DSPs for Motor Control", Presented at seminar on "Applications of Digital Signal Processors" organised by IETE, Baroda, 18th March 2001

[3] V. K. Shah, "Digital Signal Processors, Evolution: Architectures/ Features", Presented at Workshop on "Designing with Digital Signal Processors and controllers" (M. S. Uni. Baroda - India), 11th -17th June. 2004.

[4] V. K. Shah, "C2000 Family of DSP Processors from TI", Presented at Workshop on "Designing with Digital Signal Processors and Controllers" (M. S. Uni. Baroda - India), 11th - 17th June. 2004.

[5] V. K. Shah, "Power Quality and Reactive Power Control", Invited talk at IETE, Vadodara on 4th Nov. 2006.

[5] V.K.Shah, "Power Quality", invited lecture delivered for IEEE Gujarat section at GCET, Changa, Anand, 13th Dec.'2008.

[6] V.K.Shah, "Power Electronics in Power Systems", invited lecture at conference on "In search of fifth fuel- Energy conservation" on 20th Dec.'08 at GETRI, Baroda

[7] Pravin Vadhiyar, V.K.Shah, Hina Chandwani, "Reactive power compensation with cascaded multilevel converter-based statcom," All India National Seminar on Applied Power Electronics-2009 (APE-2009), NIT, Rourkela, 24-25th January 2009