CHAPTER 7

CONCLUSION

In the recent years of power quality applications with voltage source inverters are expected to have output with high quality and efficiency. For this reason, popular traditional pulse width modulation methods are not found to be the best methods for voltage source inverter. The selective harmonic elimination method has emerged as a promising harmonic elimination method for voltage source inverter. But major difficulty for the selective harmonic method is to solve transcendental equations characterizing harmonics, where the solutions are not available for the whole modulation index range, and it does not eliminate any number of specified harmonics to satisfy the application requirements.

Detailed SHE-PWM methods and their analysis are presented for the purpose of elimination of selected harmonics. The switching angles which are well separated can provide enough time for completion of consecutive transitions which can effectively reduce the switching losses and probability of switching damage in inverter bridges, improve the performance of PWM strategy, and extend life of inverter as well as the whole equipment. It is scalable for a variety of application requirements. The programmed method based on computer calculations generates a high quality output waveform through elimination of specific lower order harmonics. The critical factor which can heavily impact the calculation convergence is initial values. The selection of a group of bad initial values leads to a much longer calculation time and create wrong solutions. These transcendental equations are heavily
ill-conditioned when the number of eliminated harmonics becomes large. The drawback of the traditional roots solving techniques is solving the roots with low speed.

7.1 SUMMARY OF THE WORK DONE

The important goal of the research work is to overcome the disadvantages of the original SHE-PWM technique, several optimal harmonic elimination methods are presented in this thesis. Irrespective of the numerical methods used, the process of guessing initial value is quite tedious and deep comprehension of the switching pattern to be solved. Especially when the solution trajectories of the switching angles do not smoothly increase or decrease, it is more difficult to set appropriate initial value for the whole modulation index range. To conquer the problem for the selective harmonic elimination method, evolutionary algorithms are used to find all the solutions to the harmonic equations and the calculated solutions or the switching angles which are used to construct the switching pattern for the voltage source inverter to eliminate the lower order harmonics in the whole range of the modulation index to satisfy the application requirements. By optimizing the switching angles distribution, the harmonic content can be flexibly redistributed and high quality output waveforms are obtained. This thesis presents generalized evolutionary algorithms to calculate the switching angles using harmonic elimination PWM scheme for odd number of switching angles per quarter cycle. The results indicate that the proposed methods were accurate enough to substitute for the original harmonic equations for VSI.

Few evolutionary algorithms have been introduced in this work for the most general case of three phase voltage source inverter. These algorithms successfully solve the non-linear transcendental equations of SHE-PWM techniques. Genetic algorithms are one of the stochastic techniques applied to solve the non-linear equations. The calculation of roots with this genetic
algorithm does not depend on the initial values. Since the roots are calculated independently of each other, the algorithm is easily implemented for parallel processing. As the theory of SHE suggests N-1 harmonics are eliminated while controlling the fundamental at a predefined value. For the three phase system considered here in this thesis, all the non-triplen harmonics need to be controlled are 5th, 7th, 11th and 13th. It is found to be that all the targeted harmonics are absent and the fundamental is controlled at a predefined value. However, it converges relatively slowly, especially when solutions approach the actual roots.

Evolutionary programming is the second heuristic method to solve these transcendental equations with N switching angles to eliminate N-1 non-triplen harmonics in the voltage source inverter. Using evolutionary programming approach, an additional 17th and 19th harmonics are eliminated along with the N-1 non-triplen harmonics. This method does not use the dual transformer to eliminate 5th and 7th harmonics in the voltage source inverter.

The variable neighbourhood search is the next heuristic method used and it is applied to solve the non-linear transcendental equations along with genetic algorithm. A combination of genetic algorithm and variable neighbourhood search has been found very suitable for SHE-PWM problem. Genetic algorithm is used to find the feasible best solution for non-linear transcendental equations for SHE-PWM problem. This solution obtained using genetic algorithm is used as the initial feasible solution for variable neighbourhood search. The basic idea is to determine N switching angle to eliminate N-1 harmonic contents in the voltage source inverter. This technique also eliminates the 17th and 19th harmonics additionally from the output voltage waveform of voltage source inverter. This method is applied to solve SHE-PWM problem more efficiently, and it is more suitable compared
to the traditional numerical algorithm due to its ability to search and find the optimal value in the global space.

The fourth method is the hybrid method using genetic algorithm and tabu search to find N switching angles to eliminate the N-1 non-triplen harmonics in the voltage source inverter. The genetic algorithm is used to supply the initial values of switching angles because of its ability to handle huge amount of data and avoid local optimal points. By using this hybrid method, harmonics up to 25\textsuperscript{th} are eliminated in the voltage source inverter load voltage and current. The usage of the twelve pulse rectifier circuits and the dual transformer are avoided in the proposed research work. The usage of these equipments leads to extra cost and increase the size of the equipment. The additional non-triplen harmonics are eliminated using this approach. The efficiency of this method is the elimination of additional lower order harmonics, other than N-1 harmonic order. The switching angles are solved by the evolutionary algorithms to eliminate lower order harmonics which is used to construct the switching pattern for the voltage source inverter switches. The results obtained using the simulation software are compared and validated with the experimental results.

### 7.2 CONTRIBUTION OF THE WORK

Many researchers have proposed suppression of harmonics in the output signals of the inverter circuits. A very few have attempted to eliminate the harmonics using non-traditional methods. These methods are used to eliminate only 5\textsuperscript{th} and 7\textsuperscript{th} harmonics in the three phase inverter circuits. Hence more efficient methods are required for the elimination of harmonics higher than the order 7\textsuperscript{th}. The hybrid method proposed in this thesis eliminates the lower order harmonics up to 25\textsuperscript{th}. The result obtained by all the above said methods successfully verifies the validity of the harmonic optimization technique by experimentally implementing the technique in a prototype
selective harmonic elimination pulse width modulation voltage source inverter. The hardware design for the converter/inverter circuit was developed using MOSFET gate driver. Optimal switching patterns for the inverter were generated through optimization programs. The switching pulse patterns were generated through ATMEL microcontroller by embedded C code. The design has been tested in the laboratory and its performance was as expected. The simulation results and laboratory experimental results were similar for all the modulation indices. This optimization method can dramatically decrease the switching frequency and losses. It has the advantage of easy computation, and is also applied to voltage source inverter.

7.3 LIMITATIONS OF THE WORK

Though some multiple solutions are available, it is beyond the scope of this thesis to treat the cases where multiple sets of solution can be found. Due to high complexity, solving the harmonics elimination equations on-line during real time operation has been considered impractical. The proposed off-line methods reduce the cost and enhance the system reliability, which has a significant impact on PWM applications. By optimizing the switching distribution with the SHE-PWM technique, one can flexibly redistribute the output spectrum to obtain a high quality waveform.

7.4 SCOPE FOR FURTHER DEVELOPMENT

All the proposed methods in this thesis are for a time variant systems. This assumes all the equal or unequal voltages will not change with time. However, the voltages for a practical system will change with time. Therefore, it is recommended to propose a new real time algorithm to eliminate harmonics for time variant systems.
The combination of lower order elimination SHE-PWM and a well separated consecutive switching angles control can be considered. Other criteria can be added as the optimal constraints, such as total harmonic distortion. The composite optimal output spectrum control can help to generate higher quality waveform as the design requirements dictate.

The high speed and large memory capacity digital signal processing chips, field programmable gate array chips or very large scale integrated circuits are recently in the spotlight, these kinds of advanced micro processing chips can be adopted to generate the pulse pattern from the switching angles. With the help of these methods, the real time on-line process of harmonics elimination in power electronic equipments is possible.

Recently introduced optimization techniques can largely influence the speed of convergence of the algorithm. Other advanced optimization algorithms could be used to solve the complex non-linear transcendental equations. These minimization techniques can be combined with the random search to solve set of non-linear equations results in finding solutions to harmonic elimination problems.