INVESTIGATION ON CHB MULTILEVEL INVERTERS USING IMPROVED SHE AND SHM MODULATION SCHEMES

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

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(Regn. No. NITD/PhD/EE/2017/00994)

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Abstract

The continuous advancement of high-voltage, high-power rated semiconductor devices, with the concurrent exponential growth in digital signal processor/microcontroller, supports the development of multilevel inverter (MLI) topologies with advanced modulation and control schemes. Among different MLI structures, the cascaded H-bridge (CHB) inverter has been considered as a potential and viable option in medium-voltage high-power applications because of several advantages including simple modular structure, redundancy in switching and fewer requirements of components. Over the few decades, various modulation schemes have been developed and reported in the literature that have been used to control the CHB MLIs. They have different operating principles, implementation, and performance. The selection of a particular one is directly related to the type of application, its power range, and its dynamic requirements. The development of modulation strategy for a particular family of converters indirectly depends on several parameters such as harmonic generation, distortion, switching frequency, losses, and the speed of response. Among modulation schemes, carrier-based pulse width modulation (CBPWM) and space vector pulse width modulation (SVPWM) schemes are not suitable or unusual for the aforesaid CHB MLI-based medium-voltage high-power applications as they produce higher switching losses and reduce the inverter efficiency. Therefore, a reliable and efficient operation of CHB inverter for medium-voltage high-power level applications demands low-switching frequency (LSF) based modulation schemes.

The dissertation work has focused on the study of design, development, and implementation of some efficient and reliable low-switching frequency (LSF) pre-programmed modulation schemes [selective harmonic elimination (SHE) and selective harmonic minimization (SHM)] to improve the output voltage waveforms quality for cascaded H-bridge multilevel inverters (MLIs).

In the case of LSF pre-programmed PWM schemes, the major challenge is to solve the non-linear transcendental equations. Researchers over the past few decades have made great efforts to develop and enhance numerous solving methodologies and algorithms for obtaining the optimal set of solutions for these schemes. They are primarily divided into three categories: (i) numerical methods, (ii) algebraic methods, and (iii) optimization-based (intelligent) methods. Recently, researchers have focused more to use evolutionary algorithms over other numerical and algebraic methods

because of numerous benefits such as being independent of initial guess, conceptually simple, easy to implement, flexibility of acquiring an exact solution, less time complexity, and a higher probability of convergence.

Considering the benefits of optimization techniques, a comparative statistical study between three well-known traditional algorithms [genetic algorithm (GA), BEE algorithm, and particle swarm optimization (PSO)] and recently reported optimization techniques [backtracking search algorithm (BSA) and differential search algorithm (DSA)] has been carried out based on different performance matrices such as possibility of attaining global minima, rank of convergence rate, computation time, and inverter performance analysis (5^{th} and 7^{th} order harmonic components with respect to fundamental component, deviations of fundamental value from desired value, and deviations of %THD up to 50^{th} harmonic) while applying them to find the solution of switching angles for the seven-level staircase SHE-PWM problem.

A modified SHE-PWM scheme has been proposed for a three-phase seven-level CHB inverter that uses two additional switchings in the first cell as compared to conventional SHE-PWM while the second and the third cells are switched at advanced switching angles. It enhances the power utilization capability of the inverter by sharing the desired amount of power among the H-bridge cells and also eliminates both 5^{th} and 7^{th} order voltage harmonic components from the inverter output voltage, maintaining the desired fundamental voltage component for a wide range of modulation index.

An improved staircase SHM pulse amplitude modulation (PAM) scheme with variable and unequal voltage level approach has been introduced for a three-phase seven-level cascaded H-bridge (CHB) inverter that produces better power quality by minimizing each odd non-triplen low-order harmonics and %THD up to 25^{th} order harmonics below the grid code limits specified by CIGRE WG 36-05/EN 50160 and also ensure a good power utilization capability by sharing an equal proportion of power between the H-bridge for the full modulation index region. Here, the switching angles are considered as constant values for the whole modulation index range, at the same time, the magnitude of voltage for each level vary linearly (from zero to their maximum level) with the modulation index and provide the desired output fundamental voltage component for the whole modulation index range. This scheme can control more number of harmonics with a reduced number of switchings in a fundamental cycle and the %total harmonic distortion (THD) and %weighted total harmonic distortion (WTHD)

values of the output voltage and current waveforms also remain constant for the entire range of modulation index and it does not affect with the change in modulation index value. But these advantages come at the expense of increased complexity in the power circuit configuration required for the regulation of individual dc voltages to the required level especially in closed loop implementation. The superior performance of the proposed SHM-PAM scheme over the conventional SHE-PWM scheme and a prior SHM-PWM scheme has been established in terms of percentage active power-sharing between each H-bridge cell with respect to the per-phase active power, fulfillment of grid code limits CIGRE WG 36-05 and EN 50160, the percentage ratio of actual and desired fundamental voltage component, and %THD of line voltage up to 25^{th} order harmonic for the total modulation region based on the obtained optimization solutions.

Finally, improved SHM-PAM has been analyzed for five-level, seven-level, and nine-level CHB inverters utilizing the least possible number of switchings based on different predefined quarter wave symmetry (QWS) and half-wave symmetry (HWS) types of waveform formulations to meet some national or regional (CIGRE WG 36-05, NRS 048, and ER G5/4) and international (IEC 61000-2-12, IEC 61000-3-6 and EN 50160) stringent grid code standards. The in-depth mathematical synthesis of the proposed periodic voltage waveforms has been carried out by Fourier series expansion using an infinite sum of harmonically related sine and cosine functions. The choice of fitness functions and their corresponding constraints for the given problems have been developed, and proper justification has been given for their judicious selection. While fulfilling a particular grid code standard, a comparison between the proposed QWS and HWS based SHM-PAM schemes has been carried out based on several performance indices such as waveform quality and number of switchings required in a fundamental cycle. It is found that HWS waveforms require a lesser number of switching angles in a fundamental cycle and/or provide better waveform quality than QWS waveforms. The efficacy of the proposed schemes has been established by comparing with the existing SHE and SHM modulation schemes in terms of the number of switching angles used in a fundamental cycle while satisfying a particular grid code standard.