Abstract

Multilevel inverters (MLIs) have drawn much attention in recent years in medium and higher power applications because of their low switching frequencies and ability to withstand higher voltages without requiring high voltage rated power devices. The primary benefits of MLIs are lower electromagnetic interference, lower total harmonic distortion of the output voltage, higher efficiency and the ability to operate at higher voltages. In general, MLIs can be classified into diode-clamped MLIs (DC-MLIs), flying capacitor MLIs (FC-MLIs) and cascaded H-bridge MLIs (CHB-MLIs). DC-MLIs have been utilized in high power AC motor drives, pumps and mills. FC-MLIs have been used in medium voltage traction drives. CHB-MLIs have been used in applications such as reactive power compensation, uninterrupted power supplies and photovoltaic inverters. DC-MLIs have been much prevalent in the industrial applications due to their simple structure. However, they require large number of diodes. On the other hand, FC-MLIs provide more flexibility than DC-MLIs, but require higher number of floating capacitors. Hence, complicated capacitor voltage balancing mechanism is required in them. CHB-MLIs avoid the use of diodes or capacitors, but larger number of isolated DC voltage sources are required to generate higher output voltage levels, which makes it uneconomical.

In earlier published works related to CHB-MLIs, each H-bridge module was supplied by separate DC sources. Subsequent works showed that single DC source or a battery can be used to supply some of the H-bridges of MLI and the remaining H-bridges of MLI can be

supplied by capacitors. Such a topology is known as hybrid cascaded MLI (HC-MLI), wherein the capacitor voltages are maintained constant at desired values.

The methods used for switching HC-MLIs are either based on sinusoidal pulse width modulation (SPWM) or space vector modulation (SVM) techniques for higher switching frequencies and staircase modulation technique for fundamental switching frequency. The switching losses are more and harmonics also appear at higher frequencies in SPWM. The computational intricacy is considered as a significant drawback of SVM, which limits its real-time applications. In case of staircase modulation technique, the switching losses are less but harmonics appear at lower frequencies of the generated output voltage. Several methods have been reported to selectively eliminate lower order harmonics of HC-MLIs in case of staircase modulation technique, out of which the selective harmonics elimination PWM (SHE-PWM) is the most widely used technique. The major complexity associated with SHE-PWM method is to solve the non-linear transcendental equations using Newton–Raphson or mathematical theory of resultant method. These methods are not suitable for solving large number of switching angles as the degree of polynomials in the equations become high and it becomes difficult to solve them.

The aforementioned problems can be solved using modern stochastic search techniques such as genetic algorithm (GA), particle swarm optimization (PSO), whale optimization (WO), grey wolf optimization (GWO), etc. These optimization methods have many limitations. The two major limitations related to GA are its premature convergence and weak local search ability. Unlike GA, PSO has no evolution operators, such as crossover and mutation. PSO locates nearly optimal solution with a fast convergence speed. However, increase in number of switching angles in PSO results in increase in complexity of the search space and ultimately it is trapped in the local optima of the search domain. In order to take care of this problem, a local search technique, named as mesh adaptive direct search is combined with PSO to accelerate the convergence rate and refine the local search of the algorithm to prevent it being stuck in the local optima. The method thus evolved is named as modified PSO (MPSO).

WO is a recently developed optimization algorithm, which mimics the social behaviour of humpback whales. WO has improved feature of exploration due to its rapid position updating mechanism. However, the encircling mechanism in WO mostly focuses on the exploration in search domain. Hence, WO has less capability to jump out from local optima, in case it falls in it. To improve the convergence speed and to avoid local optima stagnation during encircling mechanism, a local search algorithm, called chaotic search mechanism is combined with WO. The evolved method is named as modified WO (MWO) in this work.

GWO is one of the recently developed meta-heuristic algorithms, which mimics the hunting mechanism and leadership hierarchy of grey wolves. The GWO algorithm also suffers from premature convergence and weak local search ability. In order to take care this problem, a local search algorithm, called chaotic searching mechanism is combined with GWO to enhance the rate of convergence and avoid it from being stuck at local optima. The method thus evolved is known as modified GWO (MGWO).

SHE-PWM technique implemented through MPSO, MWO and MGWO has been used for synthesizing an eleven-level output voltage of three-phase HC-MLIs in this work. The capacitor voltage balancing, even at higher modulation indices, has been resolved by exploiting the redundant switching states of HC-MLI. Finally, the performance of the three-phase, eleven-level HC-MLI has been verified through simulation and experimentation in this work. The results obtained through MPSO, MWO and MGWO are compared with the results obtained through GA, PSO, WO and GWO in terms of convergence rate and harmonic content. It has been found that MGWO gives improved results in comparison to other optimization methods discussed in this work.

In order to reduce the number active, passive components and capacitor voltage balancing issues in HC-MLIs, switched-capacitor multilevel inverters (SC-MLIs) have been evolved recently. To further improve the SC-MLIs, two new topologies, namely, a 17-level diode assisted switched-capacitor MLI (DASC-MLI) and a 17-level reduced voltage stress switched-capacitor MLI (RVSC-MLI) are proposed in this work. These topologies generate higher output voltages using single DC voltage source and lower number of active and passive components along with reduced total standing voltage (TSV) and peak inverse voltage (PIV). The capacitors are periodically charged and discharged without any additional balancing circuit in DASC-MLI and RVSC-MLI. The performance of the proposed DASC-MLI and RVSC-MLI are validated through simulation studies and experimental prototypes.