Abstract

The energy demand of inflated population and expanding global economy has enormously increased in the last few decades. The increased energy demand is met out by the power generated from conventional energy sources or fossil fuels (coal, oil and gas). Although fossil fuels are the prime sources of electrical power, the methods of processing and generating electricity from them are causing enormous impacts on the environment such as greenhouse gas emissions, global warming, acid rain, air pollution and so on. Power generation from alternative sources is required to overcome these issues. Renewable energy sources (RESs) are sources of clean energy, which can produce energy from natural sources like sunlight, wind, rain, tides and geothermal. Among the RESs, solar photovoltaic (PV) cells are best suited for residential and commercial AC power distribution systems due to lack of moving mechanical parts, lower maintenance cost and its abundancy. However, the solar PV cells are low voltage energy sources having variable DC output. Therefore, power electronics converters (PECs) with high voltage gain are essentially required to generate power from solar PV cells or low voltage DC sources.

In this thesis, three types of PECs are proposed to supply AC and DC loads of residential distribution systems operated by low voltage energy sources. The three types of converters are (1) high gain DC-DC converters used as front-end converters for a two-stage AC residential distribution system, (2) high-gain DC-AC converters for a single-stage AC residential distribution system and (3) hybrid AC/DC converter for a hybrid AC/DC residential distribution system.

A two-switch high gain DC-DC converter (TSHGC) as a front-end DC-DC converter has been proposed for the two-stage (DC-DC and DC-AC) AC residential distribution system. The TSHGC has circuit configuration similar to a single-phase quasi-Z-source inverter. It has high gain at low duty ratio (D) using lesser number of elements. It gives continuous input current because of input inductor. A comparison is made among TSHGC and some reported high gain DC-DC converters in terms of number of elements, voltage gain and device voltage stress to show its advantages. Although the TSHGC has continuous input current, it requires a high value of input inductance for achieving low ripple in input

current. Also, the TSHGC has a floating output ground and experiences moderate voltage stresses on the power semiconductor devices. To address these issues, a high-gain interleaved boost converter (HGIBC) is proposed as another front-end DC-DC converter for two-stage AC residential distribution system. The HGIBC has lesser number of elements as compared to TSHGC. The HGIBC has two parallelly connected inductors at the input side to achieve low ripple in input current and common ground between the input and output voltages. The HGIBC is capable of operating in three operating regions based on two switching logics; 180^{o} phase-shifted and complementary switching, which results in three different voltage gains. As the HGIBC operates in three regions, devices experience different voltage/current stresses which leads to cost-effective device selection for a particular application according to the voltage gain requirement. It has low ripple in the input current and output voltages with reduced energy storage elements due to its interleaving nature and switching. It also has better power density due to lesser number of elements and reduced passive elements. Some reported non-isolated high gain interleaved converters are considered for comparison with the proposed HGIBC in terms of a number of elements and voltage gain. Simulation and experimental studies are carried out in this work to investigate the performance of TSHGC and HGIBC.

Although the two DC-DC converters (TSHGC and HGIBC) are well suited for two-stage AC system as front-end high gain DC-DC converters, a DC-AC converter is also required when the AC loads/grid are supplied through them. This arrangement leads to increase in volume and weight and decreases the reliability of the overall system due to the use of additional DC-AC converters. To overcome the disadvantage of having a two-stage AC system, two single-phase switched LC Z-source inverters (SLC-ZSIs) are proposed in this work, which are Type 1 SLC-ZSI and Type 2 SLC-ZSI. These SLC-ZSIs can be used as single-stage DC-AC power converters by excluding DC-DC converters. The SLC-ZSIs are operated on two control variables; shoot-through duty ratio (D_{st}), which is used to enhance the input DC voltage to higher voltages and modulation index (M), which is used to convert the enhanced voltage into the desired AC voltage. The SLC-ZSIs have higher voltage gains at low values of D_{st} with reduced components as compared to SL-ZSIs. As they operate at low values of D_{st}, M can be made near to unity, which gives power inversion at reduced harmonic distortion. As the two SLC-ZSIs are non-isolated and based on a switched-inductor (SL) concept, some reported non-isolated high gain ZSIs based on SLs are considered for comparison; in terms of number elements, voltage gain, current and voltage stresses on the elements. Although the two SLC-ZSIs have high gain inversion as compared to reported ZSIs, they have more ripple in input current and moderate voltage/current stresses on the devices. To overcome these issues, an enhanced high gain switched LC Z-source inverter (eSLC-ZSI) is proposed in this work, which is an improved version of Type 2 SLC-ZSI. The eSLC-ZSI has high gain inversion at low D_{st} with reduced elements as compared to reported ZSIs and with two more elements as compared to SLC-ZSIs. The eSLC-ZSI has continuous input current with low ripple and low device voltage/current stresses as compared to some reported high gain ZSIs. Also, it has a lower size of energy storage elements. The operation and mathematical modelling of two SLC-ZSIs and eSLC-ZSI are carried out using a modified unipolar sinusoidal pulse width modulation (SPWM) technique. Further, the performance of three SLC-ZSIs is verified through simulation and experimental results.

The three SLC-ZSIs are better choices for a single-stage AC residential distribution system because of their high gain inversion. However, in recent times, DC loads are gradually increasing along with existing AC loads in modern residential systems which require hybrid AC and DC system. To supply AC and DC loads simultaneously, the proposed converters (TSHGC, HGIBC and three SLC-ZSIs) are not appropriate with their current circuit configuration. They also need additional power converters for supplying AC and DC loads, which increases the volume and decreases the reliability of the system. An interleaved hybrid converter (IHC) is proposed to supply AC and DC loads simultaneously through a single power converter, which is developed from the switching concept of HGIBC and SLC-ZSIs. The IHC has two operating conditions ($D + M \leq 1$ and $D + M \geq 1$), unlike the conventional hybrid converters (CHCs). Due to two operating conditions, the IHC has wider ranges of D and M, which leads to independent control of AC and DC outputs. Further, the IHC has three operating modes for giving different AC and DC voltage gains in two operating conditions. As the IHC is interleaving nature, it uses low values of inductors to obtain continuous input current with less ripple. In addition, low current/voltage rated devices can be used for high power applications, which results in economical prototype design. The IHC also has better electromagnetic interference immunity due to its inherent shoot-through protection capability similar to SLC-ZSIs. Finally, detailed mathematical modelling of the IHC is carried out and its performance is investigated through simulation and experimental results.