Design and Development of Improved Topologies for Microgrid Connected Bidirectional Converter with Energy Storage

Synopsis submitted by

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Abstract

Fossil fuel is the primary source of energy in power generating units of thermal power plant. More such units to meet increased load demand is harmful for the environment because of its induced effect on pollution and global warming. In last decade, there is a major shift towards generating green power using renewable energy sources across globe as per different SDGs of UN. Photovoltaic (PV) and wind turbine-based power generation hold majority of percentage of renewable energy adaptation. However, intermittent nature of PV, wind power which depends sun irradiation and wind speed respectively makes the power extraction from these sources difficult. Storage units are essential for these systems especially with PV. Storage units are of low voltage and high current type. Series connection of multi storage units are not possible due to charge imbalance problem. Generally, storage units (low cost lead acid battery) are of 24V-48V DC system. PV panel also inherently generate low DC voltage which can't be converted to single phase RMS 230V AC voltage. Thus, high gain single stage boost converter is essential which can increase PV panel voltage to 300V-380V DC voltage so that by using inverter single phase line voltage 230V RMS can be generated. The similar system is required for three phase AC system. Therefore, storage unit should be interfaced to 300V-380V constant DC link voltage. The storage unit can maintain the intermittent nature of PV generated power. The interfacing converter between storage and common DC link voltage should have sufficient voltage gain and capability to flow power in both ways i.e. from battery to DC link or vice versa. Thus, single stage high gain bidirectional DC-DC converter is essential to interface low voltage storage to 300V-380V DC common link. The same circuit is also useful in EV to supply momentary power from ultracapacitor during acceleration and can store during deceleration. In this thesis a single switch generalized high voltage gain non-isolated boost converter using coupled inductor is proposed which has less switch current and voltage stress. The converter can also have high efficiency. The proposed circuit solves the common problem of excessive high switch current stress in high voltage gain non-isolated boost converters. The boost circuit is then modified to have buck stage in the same circuit to derive a novel non-isolated bidirectional DC-DC converter (BDC). The proposed BDC has high voltage gain/conversion factors in both directional of power flow. Single coupled inductor turn is used while developing the circuit. The proposed BDC has inherent soft switching i.e. zero voltage switching turn ON feature which

further reduce the converter loss. Therefore, proposed circuit has high efficiency of operation >94% for both mode of operation. The efficiency improvement of proposed BDC can be further enhanced by 1-1.5% margin by replacing MOSFET to GaN-FET. The testing of GaN-FET based BDC using reliable gate driver is also tested in this current work. Another common problem of BDC while interfacing with storage is large ripple current. This ripple current can be filtered by using large filter capacitor at low voltage side. But this makes system bulky and any fault in the capacitor degrade battery life as battery has to supply the ripple current. Thus, modification in the BDC circuit topologies are essential to achieve less ripple current (ideally zero) especially at low voltage without any filter. In this work a new coupled inductor based non-isolated BDC circuit is proposed which has flat input ripple current of very low magnitude at LV side for wide variation of duty ratio. This circuit can also replace the necessity of interleaved structure of high voltage gain BDC circuit for interfacing storage. The proposed circuit has less component usage and inherent soft switching (ZVS turn ON) of all active switches which enhances operating efficiency. This proposed circuit is a good alternative of interleaved non-isolated BDC for achieving low ripple current, high efficiency and voltage gain.

The application of BDC converter connected to microgrid is very important. BDC should operate instantaneously during any power mismatch between sources to load. The mismatch problem is critical when source is PV panel due to its intermittent power generation. Therefore, for maintaining constant DC link voltage is necessary for stable microgrid operation and it is a major challenge. The BDC should operate instantaneously but power converter cannot alone make the system fast and reliable. The system components are also source of delay during transition event. The large delay make system unstable even though BDC's are highly efficient and fast acting. Therefore, proper selection of system components especially passive components like capacitor, inductor is very critical. In this work the passive components selection procedure for BDC connected microgrid is discussed.

Original Contribution of the Thesis

The requirement of bidirectional DC-DC converter (BDC) for microgrid storage interface and for EV is indispensable. The dependency on power electronic converters is very essential for moving towards clean power and energy sustainability. Especially, for Indian context the converter should be of higher operating efficiency and faster response time. High power density is also an important requirement from these converters to have portability. These motivates to find topological solutions of bidirectional DC-DC converter for application in microgrid and EV. Also, there is a requirement of high voltage gain, high efficiency, and single unit bidirectional DC-DC converter for integrating storage unit in microgrid. Therefore, the main research interest of this work is to propose and design suitable topologies of BDC connected to microgrid. Extensive review is performed in terms of topological requirements and existing problems especially with non-isolated BDC. From the detailed review of non-isolated BDC and its application requirements, the specific objectives in the form of research question (RQ) are derived as

RQ-1 *Is it possible to formulate a generalized circuit that can reduce peak current of the main switch during boost operation without sacrificing voltage conversion factor and efficiency with lesser component usage?*

RQ-2 *Is it possible to design single stage high efficiency, high gain bidirectional DC-DC converter which has current sharing characteristics at low voltage side? The circuit should be derived from generalized boost stage circuit (RQ-1) which has inherent less peak current at main switch.*

RQ-3 *Is it possible to design BDC form RQ-2 for further efficiency enhancement and achieving high power density using GaN-FET switch?*

RQ-4 *Is it possible to formulate a circuit which can replace the interleaved structure of DC-DC converter to reduce the input current ripple at low voltage side as well as improves voltage conversion factor from RQ-2 without using extra switches?*

RQ-5 *Is it possible to improve transient performance and power extraction efficiency of PV panel used in the microgrid through proper system parameter design with BDC?*

All, these answers are the original contributions of this thesis.