Efficient Boost/Step-Up Direct Current-Direct Current (DC-DC) Converter

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BACKGROUND

Renewable energy sources such as solar photovoltaics (PV) and wind turbines are used for clean power generation to address the ever-increasing energy consumption. With large-scale integration of renewables, battery storage becomes essential in the grid to meet supply-demand volatility. In these scenarios, direct current (DC) grids offer multiple benefits over alternating current (AC) grids such as, improved efficiency, controllability, reliability and reduced cost. Isolated voltage boost/step-up DC-DC converters are used for interfacing PV and wind energy sources with DC grids and DC-DC converters serve such applications and environments.

Existing DC-DC converter designs have known weaknesses. For example, shunt-resonant converter capacitors require a dedicated charging interval in every switching half-cycle, which does not contribute towards energy transfer and results in duty-cycle loss. Since the shunt-resonant capacitor is designed to hold resonant energy sufficient for a rated current condition, resonant energy is fixed for all loading conditions. At reduced loading, reduced resonant energy is sufficient but shunt-configuration has no means to achieve this control. Although this may be mitigated by using two additional switches, this arrangement leads to increased losses and cost. At reduced loading, duty-cycle loss increases significantly because the reduced current results in longer capacitor charging time. This severely restricts the operation range of converter. Smooth current commutation and zero-current-switching (ZCS) are also lost at overload conditions since the capacitor is designed for rated-current condition. The shunt-resonant capacitor is expected to hold its voltage/energy during the operating mode when input inductor charges. However, a leakage path exists through the transformer winding parasitics, which results in capacitor discharge. As a result, the capacitor energy must be overrated to compensate for this loss, which further aggravates all of the aforementioned issues. In another example, series-resonant capacitors must also be charged to a voltage higher than the reflected voltage across the transformer-primary. Peak voltage-rating of primary-side components (e.g., switches and input inductor) is also increased. Series-resonant capacitor also transfers energy to the output during the time interval when resonant current commutation occurs, which requires using capacitors having a higher rating. At reduced loading, the series-resonant capacitor does not have enough voltage to satisfy the resonant condition. Switching frequency may be used as an additional control parameter without using extra switches. Reduction in switching frequency results in increased charging time and hence, higher voltage, while ripple content increases and requires larger filters due to varying switching frequency. Overall, while traditional DC-DC converters like the aforementioned meets some requirements, it may be desirable to have new DC-DC converter approaches to smoothly onboard and operate PV and wind energy production with DC grids.

TECHNOLOGY DESCRIPTION

To help address these challenges, investigators at UC Santa Cruz (UCSC) have researched and developed an efficient, full-bridge, boost-type DC-DC converter which achieves ZCS operation and smooth current commutation. The UCSC device includes a dual-capacitor resonant circuit having a first capacitor, which is connected in series with the transformer-primary winding and acts as series-resonant capacitor. The dual-capacitor resonant circuit also includes a second capacitor, which is connected in parallel with the secondary winding of the transformer and acts as a shunt-resonant capacitor. This approach provides a number of benefits over older converter designs that traditionally require precise control of resonant energy. The leakage inductance of the transformer acts as an inductor forming and inductor-capacitor (L-C) circuit with the first capacitor (i.e., the series-resonant capacitor). Current commutation uses L-C resonance between leakage inductance of a high-frequency transformer having the primary winding and a secondary winding and resonant capacitor. The first capacitor stores adaptive resonant energy, which is dependent on the input current and the second capacitor stores fixed resonant energy under all operating conditions. The second capacitor is configured to store a portion of rated resonant energy and may also be used as a design parameter to adjust the overall resonant impedance of the L-C resonant circuit.

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OTHER INFORMATION

KEYWORDS

DC-DC converter, Adaptive resonant energy, Quasi-resonant, Zero current switching (ZCS), Resonant current communication, Series resonant capacitor, Shunt resistant capacitor, High frequency transformer, Leakage inductance

CATEGORIZED AS

- **Energy**
  - Solar
  - Transmission
  - Wind
- **Engineering**
  - Other

RELATED CASES

2019-509-0

APPLICATIONS

- ▶ Renewable energy infrastructure
- ▶ Grid infrastructure

ADVANTAGES

- ▶ Adaptive resonant energy is realized without requiring additional switches or variation in switching frequency. This results in reduced cost, losses and filtering
- ▶ As the shunt-resonant capacitor stores only a fraction of rated-resonant energy, duty-cycle loss is reduced which improves the operation range of converter;
- ▶ The parasitic winding capacitance can be utilized as a shunt-resonant capacitor without using additional physical capacitors since a small capitance value will be sufficient;
- ▶ At a reduced loading rate, the series capacitor stores less resonant energy and the shunt capacitor mainly supports the commutation process. At a higher loading rate, the series capacitor stores more resonant energy and mainly supports the commutation process;
- ▶ Under overload conditions, smooth current commutation and zero current switching are still maintained due to the series-resonant capacitor adaptively storing higher resonant energy;
- ▶ The series capacitor need not be charged to a voltage higher than the reflected voltage across the transformer-primary. This reduces the peak-voltage rating when compared to converters using only series capacitor.

INTELLECTUAL PROPERTY INFORMATION

Country	Type	Number	Dated	Case
United States Of America	Issued Patent	11,336,189	05/17/2022	2019-509
United States Of America	Published Application	20220278609	09/01/2022	2019-509

RELATED MATERIALS

- ▶ Current-fed Full-Bridge Boost DC-DC Converter with Adaptive Resonant Energy - 10/01/2018

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