ELECTROLYTIC CAPACITOR-LESS RESONANT POWER CONVERTERS FOR SOLAR PV APPLICATIONS

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by

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Chapter 6

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6.1 Introduction

In the earlier chapters, various electrolytic capacitor-less isolated DC-DC resonant converters are discussed. These converters are further utilized for solar PV integration to verify their efficacy under partial shading conditions. This chapter presents the conclusions drawn from the research conducted in earlier chapters and outlines the scope for future work in this area.

6.2 Conclusion

To address the vulnerability associated with the use of electrolytic capacitors, two electrolytic capacitor-less isolated DC-DC resonant converters are presented. The proposed converters, the Dual Half-Active Bridge Resonant Converter (DHABRC) and the Asymmetrical Dual Active Bridge Resonant Converter (ADABRC) use film capacitors for voltage smoothening as they are more reliable and don't suffer from the aging effect like the electrolytic capacitors. The converters are analyzed using the fundamental harmonics approximation technique, which operates them with soft-switching. The DHABRC is suitable for low-power applications and utilizes a half-active bridge configuration (with active switches in one leg and film capacitors in another) at the input and output terminals. In contrast, converter ADABRC is suitable for low to medium-power applications and utilizes a full-active bridge configuration at the input side and a half-active bridge configuration at the output side. To improve the low load efficiency, the converters utilize an LLC resonant tank, and their values are optimized using the design constraints. The film capacitor used in the resonant tank acts like a DC blocking capacitor, avoiding the saturation of the high-frequency transformer caused by any voltage imbalance due to film capacitors at the output side. Using sufficient soft-switching conditions, the value of the parallel inductance is further optimized, and a suitable value of the dead-band time required between the primary and secondary side complementary gating signals is derived. This optimized value of the parallel inductance reduces the circulating current, optimizing the converter efficiency further. The value of the film capacitors (utilized for voltage smoothening) is calculated based on the evidence that their current rating capability per unit capacitance value is much higher than the electrolytic capacitor. So, the current passing through them is calculated, and the optimal value is obtained. The theoretically derived values are compared with simulation and experimental values to exemplify the accuracy of the analysis presented for the proposed converters. A laboratory-scale prototype of 500 W of both converters is designed and tested for steady-state conditions. The soft-switching operation of the converters is also tested. The converters operate with zero voltage switching where the primary bridge current lags behind the primary bridge voltage, and the secondary bridge current leads ahead of the secondary bridge voltage. To verify the feasibility of using film capacitors, the voltage across the film capacitors is measured under startup transient, load dynamics, and steady-state conditions.

The proposed converter DHABRC is further integrated with the solar PV to extract solar energy efficiently. A Chromas' solar PV emulator (Chroma 62100H-600S) is utilized to emulate the behavior of the solar panels, and various PV curves for uniform irradiance conditions and partial shading conditions are emulated. In solar PV panels, multi-peak PV characteristics are observed when the panels are subjected to any obstruction in the path of sunlight. The conventional maximum power point tracking (MPPT) algorithms fail to track the global peak power point under multi-peak PV characteristics, underutilizing solar energy. So, two heuristic MPPT algorithms, particle swarm optimization (PSO) and grey wolf optimization (GWO), are used to harness the power at the global peak point under partial shading conditions. To observe the performance of solar PV integrated DHABRC, a 500 W converter is designed and tested for partially shaded and uniform irradiance conditions in simulation and hardware environments. Due to a heuristic algorithm, the steady-state oscillations in the voltage and current waveforms are avoided when the MPPT point is achieved.

The proposed ADABRC is cascaded with a three-phase voltage inverter to feed the power to the three-phase AC grid. The outer film capacitor leg of the ADABRC is utilized like a DC link, proposing a pseudo-DC link-based isolated two-stage topology. To ensure stable and efficient power transfer from solar PV systems to the grid, the inverter's AC output must be synchronized with the grid's characteristics. This work employs a Synchronous Reference Frame (SRF) based Phase Locked Loop (PLL). The SRF method involves two key transformations: the Clark transform and the Park transform, which simplify grid voltage analysis. The control method consists of the design of a cascaded control structure. The inner current control loop precisely regulates grid current, enhancing power quality and providing overcurrent protection. The outer voltage control loop maintains the DC-link voltage, ensuring balanced power flow within the two-stage topology. The modulus optimum tuning criterion is applied to tune the inner loop. The outer voltage loop control is tuned using the symmetrical optimum tuning criterion. The proposed converter is first tested for open loop conditions for resistive load under simulation and hardware environment. The proposed converter successfully harnesses the maximum power under partial shading conditions and feeds the power to the AC grid. Then, it is tested for grid integration operation. The proposed pseudo-DC link-based isolated two-stage topology successfully transfers the solar power to the AC grid.

Solar PV systems typically generate low-voltage DC power, while the utility grid requires higher voltages for efficient transmission and distribution. A high-gain power converter boosts the DC voltage from the solar panels to the desired AC/DC grid injection level. An impedance network is added to the input side of the isolated resonant converters to achieve high gain. The impedance network effectively accommodates a wide input voltage range, ensuring regulated DC output varying with Duty. Furthermore, impedance networks protect against shoot-through faults or short circuits caused by misfiring, enhancing the system's resilience against electromagnetic interference (EMI). The used impedance network is expandable, and with each stage, gain varies accordingly. Thus, an expandable input impedance-sourced isolated resonant converter (EIISIRC) is formed. The EIISIRC is also an electrolytic capacitor-less isolated DC-DC converter. A 500 W hardware prototype of the EIISIRC is developed and integrated with solar PV using PSO-based MPPT to test the steady-state and partial shading conditions.

6.3 Scope of the Future Work

The potential future extensions of the proposed research work can be given as follows:

1. A novel modulation technique for the electrolytic capacitor-less converters DHABRC and ADABRC can be proposed to reduce the turn-off switching losses.
2. The SiC-based active switches can be employed to build the hardware setup to improve efficiency.
3. A hardware prototype of higher power rating can be designed for the two-stage topology.
4. A mixed-source system can be developed to ensure continuous operation by integrating alternative energy sources as supplement of solar power during periods of unavailability.

5. Different modulation techniques for the three-phase inverter can be adapted to reduce the need for DC link capacitance.
6. The hardware implementation of pseudo-DC link-based isolated two-stage topology for grid integration, utilizing advanced control technique, can be performed in future extension of work.