Single-stage topologies integrating battery charging, high voltage step-up and photovoltaic energy extraction capabilities

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The concept is presented of converters integrated in such a way as to obtain, in a single conversion stage, the maximum energy extraction from photovoltaic panels, battery charging and discharging dynamic control, and high voltage step-up to the inverter DC bus, also operating with soft-switching capability. Although this idea can be applied to most of the high voltage gain topologies, this presented report is based on structures derived from the half-bridge boost converter. Thus, a 500 W prototype, with input voltage of 24 V and output voltage of 200 V, has been developed with the purpose of obtaining experimental results and validating the proposed concept. High efficiency is achieved, above 92.5%, confirming the expected operation and functionalities necessary for the proposed application.

Introduction: The growing use of alternative energy sources, such as photovoltaic panels, wind energy conversion systems and fuel cells, brings new challenges for the power electronic society and industry. In particular, small and distributed generation systems, isolated or grid-connected types, are the future trends for this technology. It is predictable that in the future most small consumers could act as an energy seller to the utility. Then the optimisation of the efficiency, volume, weight, and cost of power converters will be key features regarding the viability of these technologies.

In the last few years, photovoltaic panels have been used only in isolated systems, in order to charge battery banks or in pumping systems, and the traditional power converters have been able to achieve maximum power point operation and battery charge control. Nowadays, many systems use an AC power supply and a low voltage inverter associated with a low frequency transformer to provide a sinusoidal voltage waveform with the appropriated voltage level. However, this solution presents high weight and appreciable losses owing to the high currents processed by the inverter and owing to the low frequency transformer. Thus, an additional stage is necessary to step the low level voltage up from the battery bank (12, 24, or 48 V) to the higher voltage level of the inverter DC link (200 or 400 V). As traditional step-up converters are not feasible for providing such high voltage gain, typical solutions use one high frequency isolated stage to achieve the high step-up voltage gain. Recently, non-isolated DC-DC converters with high voltage gain capability were successfully introduced [1, 2]. However, in systems where photovoltaic panels and battery banks are required, two DC-DC stages are still necessary, as shown in Fig. 1*a*.

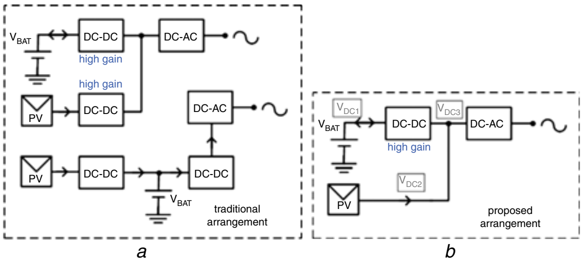

Fig. 1 *Conventional and proposed arrangement*

a Conventional
b Proposed

In this context, in this Letter we propose the integration of the battery charger stage, the photovoltaic power stage and the high voltage step-up stage in a single-stage power converter. From this new concept, many high step-up voltage power converters can be obtained, resulting in new topologies with all the aforementioned characteristics.

Conception of topologies: Some high voltage gain topologies have three DC links as shown in Fig. 1*b*, where V_{DC3} feeds the inverter with a higher voltage than that of the remaining ones. According to the proposal, the battery bank and the photovoltaic panel can be connected to the low voltage V_{DC1} or V_{DC2}, depending on available voltage levels. Considering typical applications under 2 kW, battery bank voltage levels can be 12, 24, or 48 V (in order to avoid the connection of many units in series) and photovoltaic panels can be arranged to establish a DC link with voltage level equal to about twice that of the former link. The bidirectional characteristic of the half-bridge topology allows either charging the battery from the PV array or feeding V_{DC3}. Also, the use of resonant capacitors in the half-bridge capacitors allows soft switching (ZVS or ZCS) of the switches. The integrated topology resulting from the boost half bridge is shown in Fig. 2. The main advantage of this topology is the low voltage stress across the active switches, low input current ripple and simplicity, which result in higher efficiency. Applying the concept to new topologies, such as those based on the three-state switching cell [3, 4] (Fig. 3, with higher efficiency characteristic), and to voltage multipliers cells [5, 6] (Fig. 4, with reduced magnetic volume), it also results in integrated topologies with similar characteristics, as many other topologies can be created.

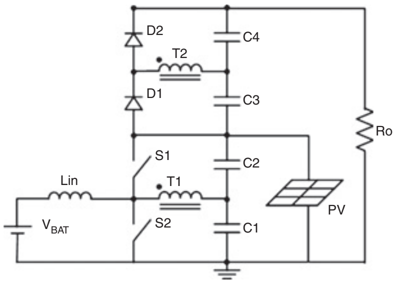

Fig. 2 *Structure 1 using PV system and battery*

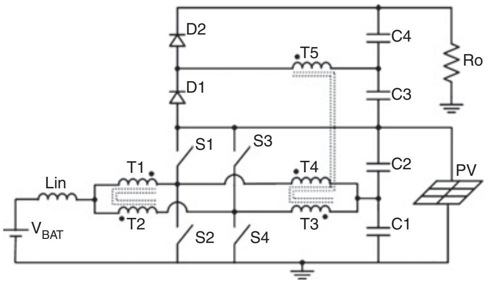

Fig. 3 *Structure 2 using PV system and battery*

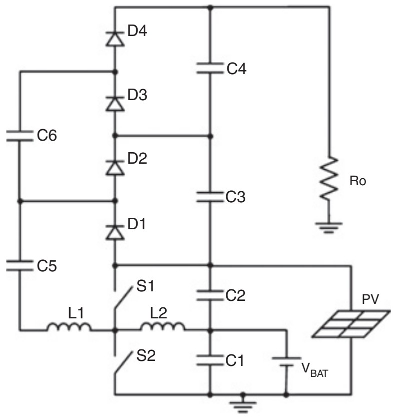

Fig. 4 *Structure 3 using PV system and battery*

Operation principle: The main contribution of this Letter lies in the fact that the referred topologies present bidirectional behaviour between the low voltage sources and present inherent operation to the structures themselves, as follows: if the solar incidence is adequate and the photovoltaic panels are able to fully supply the load, then the whole generated energy is delivered to the load, being processed through only one conversion stage, while any energy excess charges the battery without any intervention of external control. On the other hand, if the panel is not able to fully supply the load, the battery associated to the converter becomes responsible for partially supplying the load. Finally, if there is no solar incidence at all, the battery completely assumes the responsibility to deliver energy to the load without any intervention of external control as well. This way, it will be noticed that the proposed structures operate together in order to naturally supply the load through photovoltaic panels, batteries, or both, maintaining an acceptable voltage regulation across V_{DC3}, i.e. around 10%. It is still important to emphasise that, during the described operation, the implemented control technique behaves as a maximum power point tracker (MPPT). In case the battery becomes fully charged, the control becomes a voltage regulator, maintaining the fluctuation voltage across the battery constant.

Conclusion: We have presented the concept of topologies with integrated capabilities as battery charging from a photovoltaic panel, large step-up voltage gain to feed a DC link of an inverter and soft-switching, in a single stage. During the MPPT operation, the battery charge, discharge and DC link feeding management is inherent to its operation and provides an acceptable voltage regulation. Applying this concept, some topologies derived from the half-bridge boost converter were obtained and have been described, such as the voltage-multiplier rectifier and also a structure based on the three-state commutation cell. Experimental results obtained from a 500 W prototype validate the concept, with high efficiency along a wide load range (>92.5%), and confirm the satisfactory performance of the structures. Thus, the idea of integrating converters in a single stage seems to be promising on the path to obtain additional topologies feasible to photovoltaic and fuel cell applications.

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