Nowadays, the Low Voltage (LV) distribution grid is integrated into the Medium Voltage (MV) grid through Distribution Transformers (DTs), which are the backbone of the distribution electric grid, allowing for an efficient voltage transformation while being a robust solution. Nonetheless, they only provide voltage regulation using tap changers, slowing the voltage regulation. The Solid-State Transformer (SST) has been proposed as a direct replacement for the conventional DT. SSTs provide very high and fast controllability. Nonetheless, the SST is far from a real solution for the distribution grid because it is costly, complex, and has low short-circuit capability.

The Hybrid Distribution Transformer (HDT) has been proposed to address the issues of DTs and SSTs. HDTs combine a DT with power electronics converter (PEC). The most popular HDT configuration includes a series PEC for voltage regulation and a parallel PEC for current-based power quality compensation.

The experience and previous work of the applicants have shown that some HDT configurations present drawbacks, such as integrating the series PEC into the grid via Coupling Transformers (CTs) to keep the galvanic isolation. The CTs must be overrated to avoid saturation under varying and fast compensation voltages. The CTs increase the total weight and volume of the HDT. This issue can be avoided by employing an intermediate isolated DC/DC conversion stage based on high-frequency transformers, such as dual active bridges. This solution provides high-efficiency conversion, bidirectional power flow, high power density, and the required galvanic isolation to integrate the series PEC into the MV grid. Another issue with HDTs is the existence of Circulating Active Power Flow (CAPF) between the main DT and the PECs, which worsens the efficiency. The CAPF can be eliminated by connecting DC sources to HDT. Therefore, using an HDT as an interlinking PEC for a hybrid AC/DC microgrid is a natural method to eliminate the CAPF. The scientific community has not researched this topic.

The objectives of this work are the proposal of a new highly efficient HDT configuration, PEC topology, and control algorithm to allow the operation of the HDT as an interlinking PEC while improving the power quality of AC loads and MV side currents.

This work will consider the proposal of an HDT configuration suitable for hybrid AC/DC microgrids. HDT will be mathematically modeled and comprehensively analyzed, considering CAPFs, efficiency, and operating limits. Local control for the HDT will be proposed to ensure a robust operation, considering the DC-Link voltage regulation, voltage compensation by series PEC, and parallel PEC current compensation. An external control layer will be designed for the interlinking operation of the HDT to manage the power flows efficiently between AC/DC, avoiding CAPFs.

The proposed HDT will be simulated using PLECS software, considering different scenarios, such as balanced, unbalanced, and distorted grid voltages and load currents. Moreover, the transition from grid-connected to islanded mode, and vice-versa, will be simulated, for which correct synchronization algorithms are mandatory.

An optimization algorithm for a hybrid microgrid will be designed and then simulated in real-time in Hardware in the Loop for extended microgrid with embedded many AC and DC sources and loads. The proposed interlinking HDT will be only one element of the microgrid. The optimization algorithm will act as the supervisor controller, considering primary, secondary, and tertiary control layers.

Finally, a scaled-down laboratory setup of the HDT will be developed and experimentally verified. Only the local control of the HDT will be considered in this stage.

The innovativeness of this research lies in extending the application of HDTs for the DC operation. The application of an HDT will be researched in the context of LVAC and LVDC microgrids. Besides providing conventional services, the HDT must operate as an interlinking converter between DC and AC microgrids. The control of the HDT must ensure efficient operation and smart power flow management between the subsystems while maintaining the grid's safety by providing frequency support, AC and DC voltage support, and enabling the islanded mode operation. **The scientific community has not researched this topic**.

Although the HDT is a more real solution than SSTs for the future distribution grid, research is still being conducted. Therefore, in addition to the control capabilities already studied for HDTs, the HDT will offer a much more diverse palette of services by employing them in DC applications. Therefore, transitioning from conventional distribution transformers to smart solutions such as the HDT can be accelerated to create a more diverse, reliable, and efficient future distribution grid.