BACK TO BACK CONVERTERS. STATE OF THE ART

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Nomenclatures

Abbreviation	Description term
BTB	*Back-to-Back Converter*
DC-link	*Direct Current bus link.*
GaN	*Gallium Nitride*
SiC	*Silicium Carbide.*
SG	*Slip Generator*
SWOT	*Strengths/Weaknesses/Opportunities/Threats*
DCB	*Direct Current Bus*

Section I. Introduction

The current model energy policy, both from the state level and from the regional, is based on financial instruments that offset cost overruns of isolated systems. It is in this scenario related to generation systems with natural and renewable resources where it is required to make a thorough analysis of the technologies to be used, the energy needs which can be met, and assess the load limit of the insular electrical systems and emerging countries. Besides taking into consideration that environmental zones in fragile environments electrical systems are under evaluation [1].

In addition, the behavior of electrical systems when incorporated into the distribution network energy from renewable sources, especially wind power, must be accesed. In the European Union and Spain, the island energy systems are less efficient, any solution that improves the efficiency of them and allow the incorporation of renewable energy generation will be a relief for the coffers of the states that so far offset the extra cost the current generation model systems to be weak, with difficulties stability of the electrical network, where there are models of distributed generation [2].

Depending on the scale of wind turbines, today there are two concepts in electrical converters transmission system of electricity, which are:

Doubly-fed Converter

An asynchronous generator is used, where the rotor windings are connected to a converter using small manifolds rings and brushes, as shown in Figure 1.

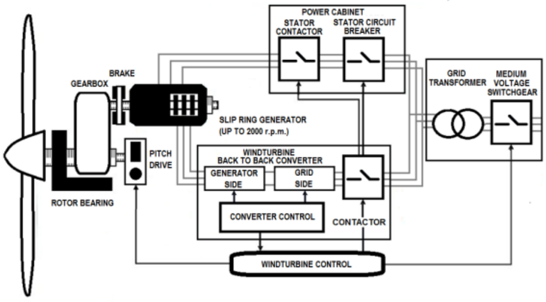

Fig. 1.- Diagram of a wind turbine coupled to a system that includes a Doubly Fed converter.

Conversion in this system, compared to operation of constant speed turbines is allowed at variable speed to increase power production, and also supplies reactive power to support the grid. It is an economical technical solution for meeting the requirements of the power grid.

Full Power Converter

This converter decouples the generator and the mechanical drivetrain from the power grid, as shown in Figure 2. All of the generated power flows through the converter to the grid. Synchronous (permanent magnet) and asynchronous generators are typically used. This converter provides torque and speed control of the generator [3].

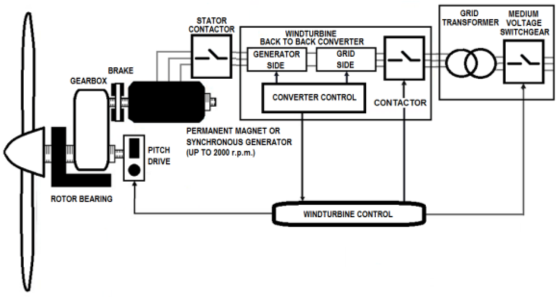

Fig. 2.- Diagram of a wind turbine coupled to a system that includes a full Power Converter.

Within the different configurations of Full-Power converters, the most used, because of its constructive and operational advantages, it is called "Back-To-Back" (hereinafter BTB), which incorporates the stages of rectification, inverter and filtering on a single equipment [4]. The term BTB refers to the antiparallel position of both stages, where the only possible link is a coupling DC capacitor called "DC-link". In Figure 3, the block diagram of a BTB converter coupled to a wind turbine is shown.

The properties of this converter are well known in the field of power electronics and wind energy, as it is essential to inject electricity with appropriate electrical components (voltage, frequency, phase ...).

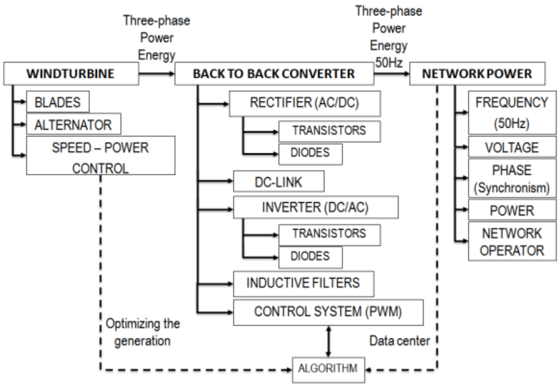

Fig. 3.- Diagram of a BTB converter coupled to a wind turbine.

Section II. Analysis of BTB converters

One of the drawbacks of the BTB converters configuration is that between rectification stage and inverter, known as continuous or channel bus, it must be a DC-link capacitor, whose voltage is regulated from power flow that is injected into the power grid, and must exceed the maximum peak voltage supported by the converter to ensure the increase in useful energy from the generator when operating below its rated power. In Figure 4, the placement of the Direct Current Bus (DCB) to the Slip Generator (SG) output is shown.

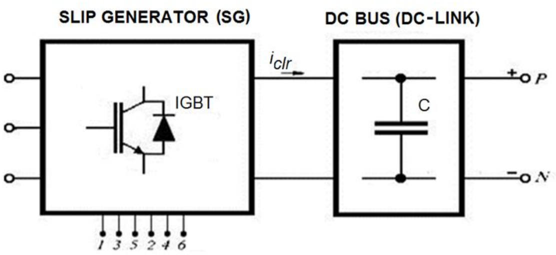

Fig. 4.- Simplified diagram of DC bus to the output of a Generator Slip.

A key property that this type of converter offers, is a fast and effective control of the power flow, since a uniform flow allows DC-link Capacitor to operate at constant tension within their design temperatures and extend the life of components. Another advantage of this configuration is that in some applications the braking energy can be dumped to the network instead of wasting it is a braking resistance by Joule effect [5].

Furthermore, the presence of this type of control allows reducing the size of these elements without affecting the quality of energy, becoming quite compact with a film capacitor [6]

Size reduction of DC-link capacitor and other passive components are conditioned by harmonics levels, which cannot be damped by themselves.

In Figure 5, the subsystem that controls the level of DC voltage and serves to provide the input parameter to the controller subsystem bridge inverter current through a Discontinuous Conduction Mode (DCM) signal is shown.

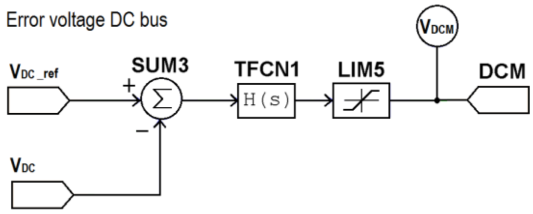

Fig. 5.- DC Bus Controller Blocks.

This control is obtained by comparing the voltage of the real DC Bus (V_{dc}), with the desired DC Bus reference voltage ($V_{dc\text{-}ref}$). The error between these two signals is processed by a Proportional-Integral controller, whose output provides the active power reference P_{Sred}^{ref}, that needs to be transmitted to the network and can be determined by dynamic analysis of DC link with the help of Figure 6 [7, 8 and 9].

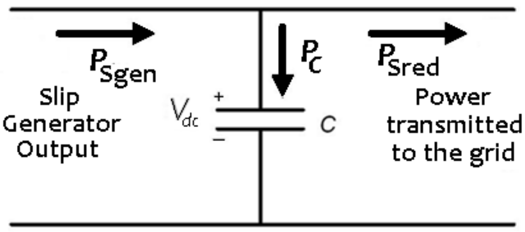

Fig. 6.- DCB branches.

From Figure 6, the following expression is deduced (Equation 1):

$$P_C = P_{Sgen} - P_{Sred} \quad (1)$$

Where P_C is the active power passing through the capacitor, P_{Sgen} is the active power generator output (transmitted to the DC bus), and P_{Sred} is the active power transmitted from the DC bus to the power grid. The ratio of DC voltage (V_{dc}) can be expressed in terms of the output power of the generator by Equation 2:

$$V_{dc} = \sqrt{\frac{2}{c}\int (P_{Sgen} - P_{Sred})dt} \quad (2)$$

An alternative to this limitation is to introduce these fluctuations into the network, but with the disadvantage that, not being strong enough, harmonics can be introduced in the converter. Although, in general, are relatively harmless compared to the harmonics of protection diodes in the rectifier, must be taken into account in high power conditions, such as the proposed in this paper.

Another alternative that has come to be implemented is the use of the energy stored in the mechanical train, which are usually several orders of magnitude greater than that stored in DC-Link Capacitor.

Thus, there are three possible configurations for a BTB converter: matrix, multilevel and resonant, as seen in Figure 7, Figure 8 and Figure 9, respectively. The main advantages and disadvantages are listed in Table I [10, 11, 12, 13, 14, 15 and 16].

TABLE I

TOPOLOGY	ADVANTAGES	DRAWBACKS
Matrix Converter (Figure 7)	The switches operate under the same conditions: • Less heat stress. • No need capacitor.	• The output voltage is limited to 86.6% of the input. • With no capacitor can distort the voltage.
Multilevel Converter (Figure 8)	• For the same distortion, the switching frequency is reduced to 25%. • Increase overall efficienc.	• Imbalances between DC voltages. • Heat stress in semiconductors.
Resonant Converter (Figure 9)	• Less switching losses.	• More control to maintain resonance • Voltage unbalance continuously.

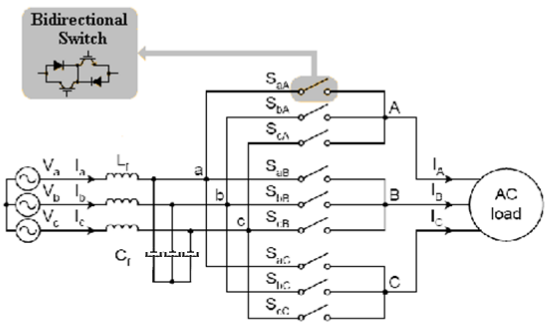

Fig. 7.- Three-Phase Matrix Converter.

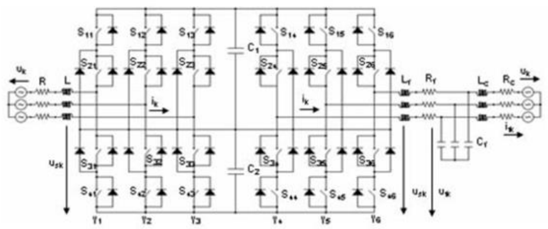
Fig. 8.- Multilevel Phase Converter.

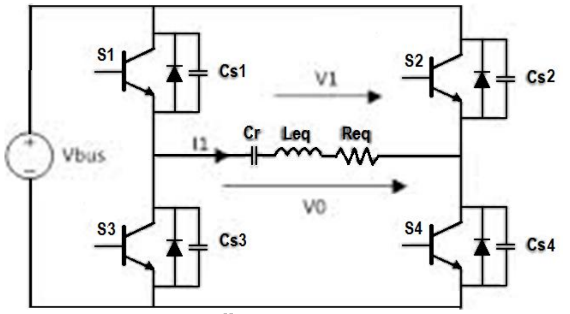

Fig. 9.- Resonant Full Wave Converter.

Regarding the process of designing a converter, it is required to complete a series of stages directly related to its components and their technical requirements, as shown in Figure 10:

1. **Decide which topology** is most suitable for the application for which it is intended the power converter, taking into account the advantages and disadvantages that arise during operation. Depending on the selected topology, the most appropriate method of control is established to ensure the converter operation.

2. **External requirements** of the application, such as the voltage and frequency of the power grid, or the characteristics of the electric generator to regulate.

3. **Select what type of semiconductors** (static switches) are the most appropriate, taking into account the operating voltages, currents (power) of each branch and their trigger frequency. This process is iterative, since the choice of semiconductors is subject to simulation boundary conditions, whose performances curves allow progressively to choose those that show best performance, including the corresponding thermal study to assess the need and consumption of the associated cooling system.

4. **Dimensioning of passive components,** both inductances and network connection to the generator as DC-link capacitors, taking into account the requirements demanded by manufacturers [17].

5. **Simulation converter** that allows to obtain spectra of signals to ensure perfect coupling of the different stages of the converter, taking into account, not only the electrical aspects, but also the thermal issues.

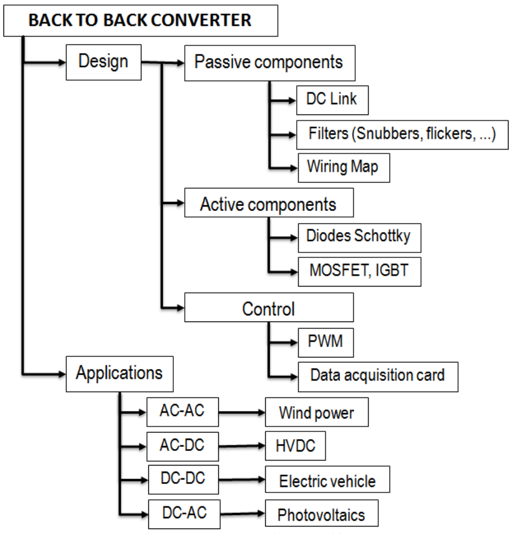

Fig. 10.- Design stages for different BTB converter applications.

Large wind farms [18] are being developed in many countries. These wind farms can make a significant contribution of energy in the overall calculation system and play an important role in power quality and control of power systems.

Consequently, the technical demand is maximal in the generation units to carry out frequency and voltage regulation and active and reactive power regulation, or a quick response in transient situations, for example, reduce nominal power to 20% in two seconds. Power electronics plays an important role in system configurations and control of wind farms in order to meet these requirements. Some possible electrical configurations of BTB converters in wind farms, are shown in Figure 11 and Figure 12, corresponding to a dual power supply system and an induction generator with Controlled Speed, respectively. [19, 20 and 21]

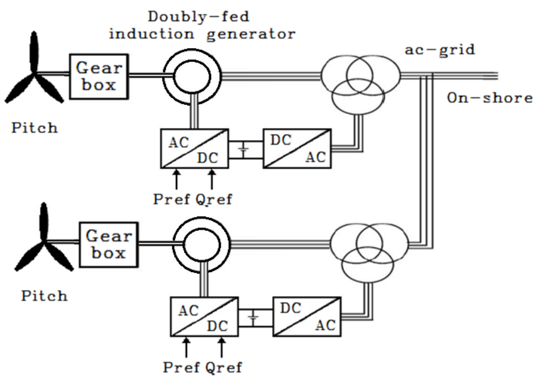

Fig. 11.- Dual power supply system with AC mains.

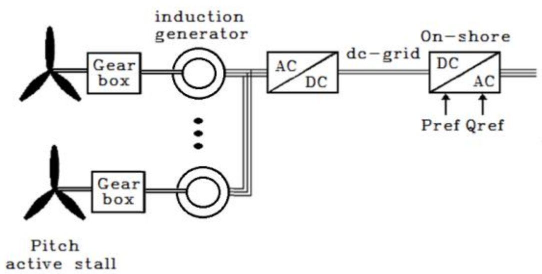

Fig. 12.- Induction generator controlled speed with common power grid and continuous mechanical transmission.

Section III. Technical-economic barriers BTB converters

The wide bandgap semiconductors, such as those based on Silicon Carbide (SiC) and Gallium Nitride (GaN) have great potential for applications requiring high frequency work, with high power and high temperature [22].

Devices based on GaN and SiC can amplify signals of frequencies and powers much higher than those modulated by devices made from Silicon (Si), Silicon-Germanium (Si/Ge), Gallium Arsenide (GaAs) or Indium Phosphide (InP). Power electronics and energy transport are the main candidates to integrate these new elements [23], being SiC, for our case study, the one which provides more options, since more electronic devices are available supporting breakdown voltages higher to other existing semiconductors. Moreover, the magnificent thermal conductivity of Silicon Carbide can work at temperatures several times higher than those supported by Silicon. This advantage results in more robust and less bulky equipment, since the need of cooling elements is reduced. [24, 25, 26, 27 and 28]

In Table II, a summary table is presented with a SWOT analysis of BTB power converters based on SiC active components. It has been believed convenient to synthesize, the advantages and barriers that have related technologies from a technical and commercial view [29].

TABLE II

STRENGTHS	WEAKNESSES
• Properties of SiC improve the efficiency of devices based on this material. • The current filter technologies are very mature and capacitors to meet new technical requirements. • The control algorithms pulse width are well known and efficient. • For certain applications it can reach without cooling systems with coolant	• The need to put in parallel transistors SiC for high power applications. • The need for new techniques for SiC semiconductors encapsulation. • Passive components subjected to greater thermal stress due to switching frequencies. • Major manufacturing cost. • Commercial products very limited in terms of functional specifications
OPPORTUNITIES	**THREATS**
• The renewable market developments, bet on more efficient devices, as current technology go saturating. • The need to improve the overall energy efficiency of electrical and electronic systems. • The Smart-grids and infrastructure for electric vehicles will boost the market for power electronics based on new SiC and GaN semiconductors.	• Other types of semiconductors such as GaN can get better results for low power applications. • The renewable market downturn may affect orders and development of technology.

Section IV. Conclusions

The preparation of this work has allowed to elaborate an overview of the current state of BTB power converters and the future of the new SiC and GaN semiconductors in the field of Power Electronics and the Electric Power in general.

With the presence of generation systems based on renewable energy in our society, different ways in which electricity is present make it necessary to use the resources offered by the power electronics.

However, their use entails an energy penalty that should be minimized as much as possible, and even more so considering that this type of clean energy start with a large initial disadvantage: its profitability is compromised by the nature of natural energy resources (solar radiation, wind, tides,...) and it is much lower than conventional nonrenewable sources (nuclear, combined cycle,...).

For this reason, the power electronics, as an interdisciplinary field, is continually evolving and integrating new elements and materials that can transform or process energy for end use and minimize losses. An example of this are the BTB power converters that are currently used in wind power generation systems, since they allow full control (bidirectional) energy flow and offer more compact and lighter designs [30 and 31]. This type of power converter is the most promising for the sector of renewable energies and future electric vehicles, because its integration capacity [32]. This is where the new transistors based on Silicon Carbide or Gallium Nitride play a key role, because it is possible to manufacture devices for this type of converters, allowing operation at switching frequencies in high power configurations, although GaN devices are more promising in a lower power bracket, but at higher frequencies [22, 33, 34].

However, taking the transistors at higher frequencies force the passive elements such as capacitors or coils to be existed to high thermal stress. Hence, the choice of materials and the design is another key factor to ensure the operation and service life of electronic devices. The emergence of new ferromagnetic materials and new formats capacitors, as indicated throughout this study, demostrate that the in current technological development will respond to the needs of the energy sector quickly and effectively to all levels of power and frequency for the next generation of semiconductors [35].

It is also very important to develop new and better models of energy storage equipment in the DC bus for a better characterization of the performance of BTB converters.

Previous experiences, both theoretical and experimental, have shown that the use of Silicon Carbide represents a number of significant advantages for the aforementioned applications, since they can operate at higher switching frequencies and temperatures without changing its physical properties, which translates directly into higher system efficiency. Although the price does not provide the replacement of Silicon-based transistors in current systems, as the industrial sector go demanding these devices and showing that the improvement in system efficiency is appreciable, manufacturing processes of this material will continue to improve and reduce their costs in order to offer a more attractive final product for any application.

Given the information collected and analyzed in the present study, it is considered that future wind turbines will be based on permanent magnet alternators BTB converters, consisting of SiC semiconductors controlled algorithms based on Pulse Width Modulation (PWM), that will integrate all future progress to be made in power electronics and power ranges on the order of megawatts, without ruling out other configurations which can be adopted, especially for economic reasons (investment and maintenance).

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