B-TRAN™ Applications and Benefits

Ideal Power's B-TRAN™ Power Switch

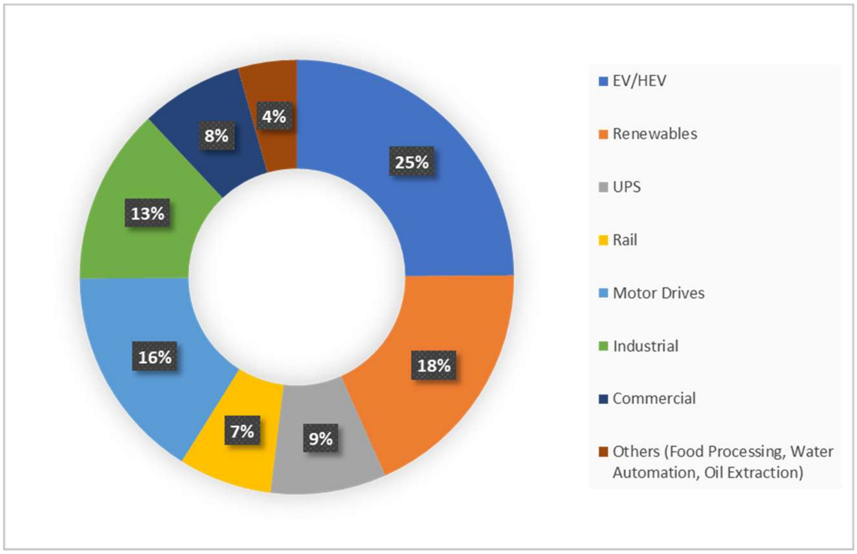
Ideal Power has developed and patented an innovative, proprietary semiconductor power switch called the Bi-directional Bipolar Junction Transistor, or B-TRAN™. Compared to conventional power switches, such as Insulated-Gate Bipolar Transistors, or IGBTs, B-TRAN™ offers significant improvements in efficiency, reducing power losses by 50% or more depending on the application. The higher efficiency of B-TRAN™ results in less heat being generated and thus significantly lower thermal management requirements. This in turn results in significantly smaller surface area required to dissipate the heat and thus potentially smaller OEM products. In addition, B-TRAN™ offers the industry's only symmetric bi-directional operation, reducing the number of components by 75% as compared to a conventional bi-directional switch utilizing IGBTs and diodes. This highly efficient and unique symmetric operation provides a strong competitive advantage in bi-directional applications which are growing at rapid rates due to the electrification of transportation and the shift to renewable energy coupled with energy storage.

Power switches are ubiquitous in all types of electronic power equipment and are a key component in modern high-power clean energy applications such as electric vehicles (EV), EV charging and solar and wind inverters paired with batteries. Their function primarily lies in the distribution, generation and conversion of power within these systems. Power switches perform the critical roles of converting energy to/from alternating current (AC), to/from direct current (DC), and setting the proper voltage to meet the end use requirement. As these functions are a significant source of loss in power electronic equipment, power switch efficiency has a major impact on overall efficiency and size of the system.

Market and Industry Overview

The total addressable market for B-TRAN™ is currently estimated at approximately $6 billion and is estimated to grow to $9.4 billion by 2025[(1)]. The two largest segments of that market are EV / hybrid EVs and renewables, such as solar and wind inverters, and related energy storage applications. Other attractive markets segments are in the industrial space such as data center uninterruptible power supply (UPS), systems, motor drives, consumer appliances, medical imaging equipment and other industrial and commercial applications. Currently these markets are dominated by the IGBT semiconductor switch which B-TRAN™ is targeted to replace due to its higher efficiency, inherent bi-directionality and the ability to have potentially smaller OEM product designs due to reduced thermal management requirements. Generally, there has not been significant innovation in recent years in the power switch market other than the use of high-cost wide band gap materials, such as silicon carbide (SiC). As SiC matures as a technology and becomes more economic, B-TRAN™, as a device architecture, can retain its long-term competitive advantage by manufacturing B-TRAN™s in SiC.

IGBT Power Switch Market Overview [1]



- $5.9B IGBT market (2020) expected to reach $9.4B by 2025
- 9.7% projected CAGR
- EV/HEV segment to drive the growth

Applications

Below are just a few of the targeted applications where the advantages of B-TRAN™ provide competitive advantages over conventional IGBTs.

Vehicle Electrification

The power switch market for EV and hybrid EV vehicles was approximately $1.5 billion in 2020 and is the fastest growing segment of the power switch market growing at a forecasted CAGR of 15%[1]. Power semiconductors account for about 20% of the total electric power losses in hybrid EVs[2] and potentially more of the losses in an EV. Based on a study conducted by Toyota, a 16% improvement in power semiconductor efficiency in a hybrid EV would improve fuel efficiency of that hybrid EV by 2.4%[2]. As B-TRAN™ could potentially improve efficiency by 50% or more compared to IGBTs, it is reasonable to assume B-TRAN™ could improve fuel efficiency of a hybrid EV by 7-10%.

Although batteries are the largest cost component of EVs, the second highest cost is the drivetrain, which is typically 15-20% of the cost of the EV. The largest cost component of the drivetrain is the power semiconductor switches which make up 8-10% of the total electric vehicle production cost[3].

Three specific and significant applications within this market are as follows:

EV Powertrain / Main Inverter and On-Board Battery Charger

The main traction inverter converts battery power into AC required by the motor responsible for producing the torque required to propel the vehicle. It is the highest power component in an EV. Therefore, performance of this module significantly contributes to the overall efficiency of the vehicle, both in terms of its acceleration and driving range. The semiconductor switches in EVs until recently have been exclusively IGBTs and, since EV drives also need to work bi-directionally to charge the battery when coasting or braking, B-TRAN™ offers significant competitive advantages.

An on-board battery charger converts DC power from the battery subsystem into AC power for the main drive motor. When the vehicle is receiving external power from the grid, the device's rectifier circuitry converts AC power into DC power to recharge the battery. The system also harvests kinetic energy created by the vehicle's momentum through regenerative braking and sends that energy to the battery as well.

B-TRAN™ Advantage:
Replacing the existing IGBTs used in traction inverters and on-board battery chargers with B-TRAN™s will increase drive cycle efficiency. This results in reduced cooling requirements and an increase in the range of the EV and/or a reduction in the battery size and cost. In addition, IGBTs and other semiconductor switches do not conduct in the reverse direction requiring additional switches and other components for bi-directional power flow. These additional components create additional energy losses and require additional thermal management. With B-TRAN™ this functionality is inherent in a single device with a significantly higher round-trip efficiency. As a system, a bi-directional EV inverter or on-board battery charger can be more efficient overall, smaller and lighter, all of which help to boost range.

Bi-directional charging of EVs enables vehicle-to-grid (V2G), economic benefits. This enables energy from the vehicle's battery to be exported to the grid during times of peak energy demand. The consumer can monetize this power provided back onto the grid improving the economics of EV ownership and helping to correct imbalances in our utility grid infrastructure. The higher the efficiency of the charger the greater the benefit.

EV Charging – Off-Board/Stationary Battery Chargers

There are three main types of off-board chargers for EVs – Level 1 and 2 AC chargers are primarily used in residential and commercial sites, respectively, and can fully charge a vehicle between 3 to 6 hours. Most consumers plug their vehicles in overnight so charging time is not as critical. The newer Level 3 chargers, or fast chargers, offer a significant reduction in charging time, fully charging an EV in as little as 30 minutes depending on the vehicle type. To address the concerns over range anxiety for EVs, a significant build-out of level 3 chargers is occurring globally. It is forecasted that 1 million new fast charging systems will be installed in the next 5 years[4] as governments make infrastructure investments and growing electric bus, taxi and truck fleets help drive usage. Similar to EV themselves, power switches make up a significant portion of the cost of these systems.

Fast chargers can improve their efficiency using B-TRAN™ to convert high power from the utility grid to DC for charging the vehicle battery. The economics of these chargers is significantly impacted by the efficiency of the semiconductor power switches they use.

B-TRAN™ Advantage:
The heart of these chargers is an AC-DC converter that uses IGBT or silicon MOSFET switch technology depending on power level. B-TRAN™ offers approximately 50% lower losses than currently available IGBT switches. For fast chargers utilizing B-TRAN™s and benefitting from the lower losses, charging time would be reduced and the cost would be less for the consumer (or margins higher for the fast charger owner). If paired with buffer storage, the charging cost would be further reduced as time of use and/or peak demand charges imposed by utilities, which may represent up to 50% of the electricity bill for a commercial installation, could be mitigated. Also, less heat generated from the lower losses would result in simpler thermal management, lower operating costs and potentially smaller, lower cost chargers for the OEM.

Renewables

The power switch market for renewables was over $1.1 billion in 2020 and is expected to grow at a 12% CAGR to approximately $1.4 billion by 2022[1].

The cost of large solar and wind farms has declined dramatically making them one of the lowest cost sources of generation in many locations. Public policy has been very supportive of the growth in renewable energy and, under the new Administration, this growth is expected to increase. Due to the intermittency of both solar and wind, renewables will increasingly be coupled with energy storage to mitigate their impact on the grid. For commercial and industrial customers, adding batteries to renewable generation mitigates time of use and/or peak demand charges imposed by utilities. The pairing of renewables with energy storage will require the use of bi-directional switches in the power converters to be able to store energy in the battery at times of peak generation and discharge energy from the batteries when solar and wind generation decline during the day.

B-TRAN™ Advantage:
Inverter efficiencies are expected to approach 99% utilizing B-TRAN™s, compared to up to 97% with standard IGBT based designs. This results in more usable electricity at lower costs to consumers, lower thermal management costs and potentially smaller and lower cost inverter

designs. The bi-directionality of B-TRAN™ in the solar and wind inverters paired with battery storage offers further advantages, including significant round-trip efficiency improvements in the battery charge / discharge cycle all of which improve the economics of renewables coupled with storage.

IT Infrastructure – Cloud Computing - Data Center UPS

The power switch market for UPS systems was approximately $0.5 billion in 2020, growing at an estimated 6% CAGR through 2022[1].

Computing and connectivity are key parts of our infrastructure, and every processor, memory bank or wireless base station needs power. The size, density and demand for new data centers are growing rapidly. The largest operational cost for data centers is electricity consumption. Improving the power conversion efficiency at every stage in the power distribution architecture is a critical factor to reduce cost. All the power coming into a data center must pass through UPS systems. Because UPS systems must react quickly in the event of a power outage, they rely on power semiconductor switches to react to power outages or disruptions and engage battery backup systems. The conduction losses associated with these power switches are a significant source of a data center's energy cost.

B-TRAN™ Advantage:
In a UPS data center application, the lower conduction loss of B-TRAN™ is expected to result in annual electricity savings. UPS systems represent 6% of data center total energy losses[6]. This wasted energy impacts the cost and complexity of data center cooling system. Using B-TRAN™s in the UPS systems in lieu of IGBTs could significantly improve UPS efficiency. In a typical large commercial data center improving UPS efficiency from 90% to 95% would represent $2.2 million of annual electricity savings.[1] [5] [6]

Solid State Circuit Breakers (SSCB)

The demand for medium and high voltage DC distribution and transmission systems and microgrids is resulting from the growing adoption of DC-based generation, such as solar and wind, and the increased deployment of DC charging networks for electric vehicles. Studies have shown DC-based transmission is lower cost than AC-based transmission which is prevalent today. The wide adoption of DC-based distribution and transmission systems has not occurred to date due to the lack of a fast-acting solid state circuit breaker. Based on a recent study by MIT, SSCBs in DC transmission systems are required to accommodate the continued growth of solar and wind and to economically reach zero-carbon power[7].

A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by excess current from an overload or short circuit. Its function is to interrupt current flow after a fault is detected to prevent hazardous conditions such as fire or shock. Circuit breakers today are mechanical switches which suffer from slow response times, inadequate for DC-based transmission. SSCBs operate a thousand times faster than mechanical switches thereby preventing arcing due to interrupting high current flow while reducing electrical stress on the system. Since circuit breakers are continuously conducting devices, the conduction losses of the semiconductor power switches are critical to their economic operation. Although an SSCB can be made with conventional semiconductor power switches such as IGBTs, the high conduction losses can be up to 0.4% of the total energy losses in DC transmission systems[8]. These high losses coupled with the cost and complexity of the cooling systems to remove the heat have made IGBT-based SSCBs uneconomic.

B-TRAN™ Advantage:
B-TRAN™ is an enabling technology for SSCBs. B-TRAN™ offers potentially more than a 50% reduction in conduction losses compared to IGBTs allowing much more useful energy to be transmitted with lower cost and less complex cooling systems. These benefits significantly impact the economics of SSCBs and enable the economics of DC-based transmission and distribution.

Summary

This whitepaper discussed the applicability and growing need for higher efficiency power switches such as B-TRAN™ that serve mature and emerging high growth market segments such as electric vehicles, renewables, data center and industrial applications. This market is already a $6 billion market and is currently expected to grow at an almost 10% CAGR, driven by the immediate needs of each segment. Also highlighted was B-TRAN™s lower losses than currently available IGBTs. These losses are 50% lower than conventional switches and up to 80% lower in bi-directional applications. Lower losses result in electricity savings and reduced heat generation with the associated benefits of simplified thermal management systems and thus smaller overall OEM products, resulting in material cost savings that are valued by market segment participants. And, not to be missed, the performance characteristics of B-TRAN™ architecture have the potential to enable new markets such as SSCBs for applications such as vehicle electrification and DC transmission.

1 – Global Insulated-Gate Bipolar Transistor Market (2016-2022) by Mordor Intelligence
2 – A Novel Carrier Accumulating Structure for 1200V IGBTs without Negative Capacitance and Decreasing Breakdown-Voltage by EHV Electronics Design Division, Toyota Motor Corporation
3 – IGBTs Critical to EV Cost by David Manners
4 – Electric Vehicle Fast-Charging System Market–Research & Markets, Oct 2020
5 – Assumes 50MW data center load and $0.10/kWh electricity cost
6 – *Electrical Efficiency Measurement for Data Centers* by Neil Rasmussen
7 – MIT Study: Transmission Is Key to a Low-Cost, Decarbonized US Grid by Jeff St. John
8 – HVDC Circuit Breakers: A Review Identifying Future Research Needs by Christian M. Franck