WHITEPAPER

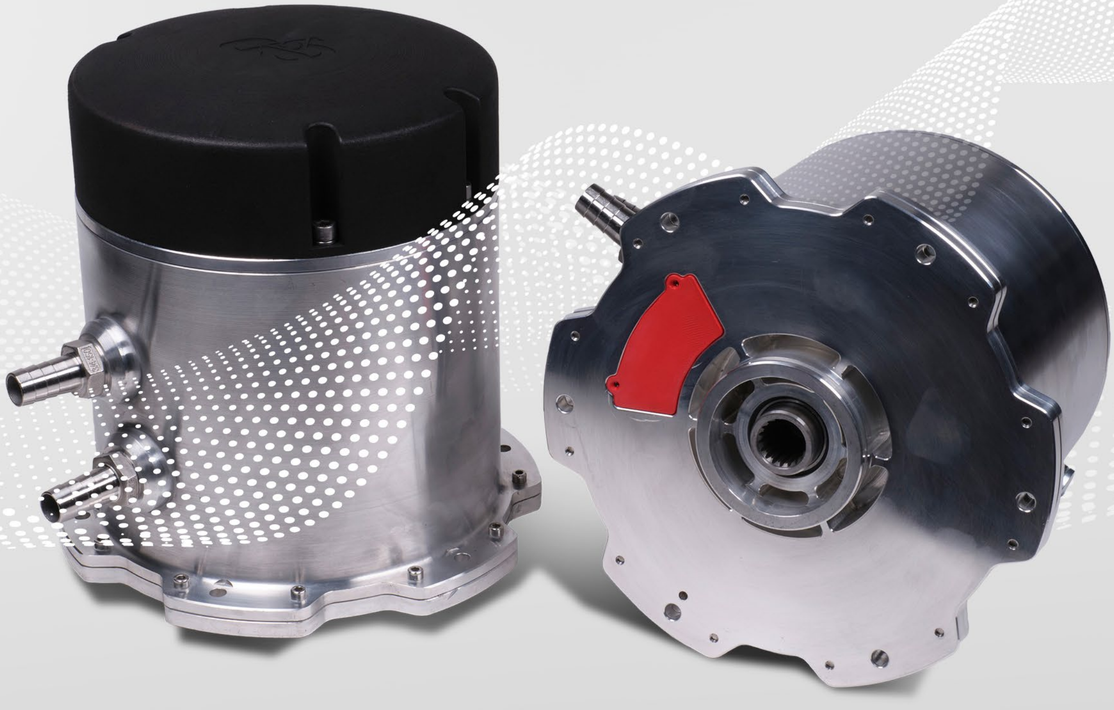
ePROPELLED™

Dynamic Torque Switching:

TECHNOLOGY OVERVIEW

ePropelled is the leader in magnetic engineering innovations that dramatically improve electric motor and generator efficiency, delivering at least 15% improvement in motor performance. The most revolutionary among our solutions is the patented **Dynamic Torque Switching™** technology or **eDTS™**—the "e" in its name represents the technology's flexible nature. It stands for electric, environmentally friendly, economical, efficient, and emerging. It's a truly versatile solution that evades a simple description.

This paper discusses the **eDTS** technology, compares it to conventional motor design, and outlines how it affects vehicle performance and efficiency.



System Overview

The **eDTS** technology is an innovative electric propulsion solution for a range of electric vehicles (EVs). It delivers a significant improvement in power efficiency and performance, which translates into a net reduction in vehicle cost through smaller battery packs, extended range, or a combination of the two.

ePropelled's take on efficiency is very broad and focused on getting more output from the same input, unlike other technologies. More specifically, we use energy more intelligently and economically to deliver superior performance. Most motors' highest power efficiency is only available in a very narrow band (a small island we refer to as a "sweet spot") on the power map. The **eDTS** technology allows vehicles to operate at maximum efficiency at a much wider efficiency band (a very large island) on the power map.

ePropelled has patented the technology[1] that allows the electric motor to provide high torque at low speeds without drawing high current from the batteries. It also provides high speeds at low torque levels without using deep field weakening and at much reduced winding losses, thereby increasing the efficiencies throughout. This technique utilizes the motor magnets and the motor windings optimally and improves the overall drive cycle efficiency, allowing the range of the vehicle to increase by at least 15% (based on New European Driving Cycle—NEDC—simulations).

The eDTS technology is based on our patent for reconfigurable windings and the system comprises three main components:

1

The **eDTS motor** is a brushless permanent magnet synchronous machine. In this example it is an interior permanent magnet motor (IPM motor) where the rare earth magnets are embedded in the rotor. The stator and rotor consist of laminated cores. The distributed phase windings are divided into sections and inserted in the stator.

The cooling of the motor is achieved and maintained by using integrated water-cooling ducts in the housing. Our expertise in magnetic engineering is manifest in the choice of active materials used and how they are implemented in the magnets, windings, and laminations. This motor design provides an ideal combination of high torque, high power density, and high efficiency.

2

The **power electronics drive** is paired with the motor for best performance. It includes a high voltage inverter and a control system. Based on vehicle demand, the control system will automatically select the most efficient operation mode, which will save battery energy and increase driving range. The control system uses real-time adaptive shift maps and machine learning to control the switch matrix and the motor parameters for optimum propulsion system performance. The unit is liquid cooled and we leverage SiCFET technology to ensure optimal efficiency.

1 Magnetic Gearing of Permanent Magnet Brushless Motors.

3 The **switch matrix** links the many windings of the motor to the phases of the drive. Based on the input from the control system, the switch matrix connects the sections of the windings in a series, series parallel combinations, or all in parallel. Among others, this manages the control of the induced back electromotive force (back EMF), current draw and density, and magnetic flux linkage, resulting in switching the torque, speed range, and constant power range.

The **eDTS** technology is a combination of motor design, material science, and software control, and produces a much more efficient method of electric propulsion at various torque and speed levels.

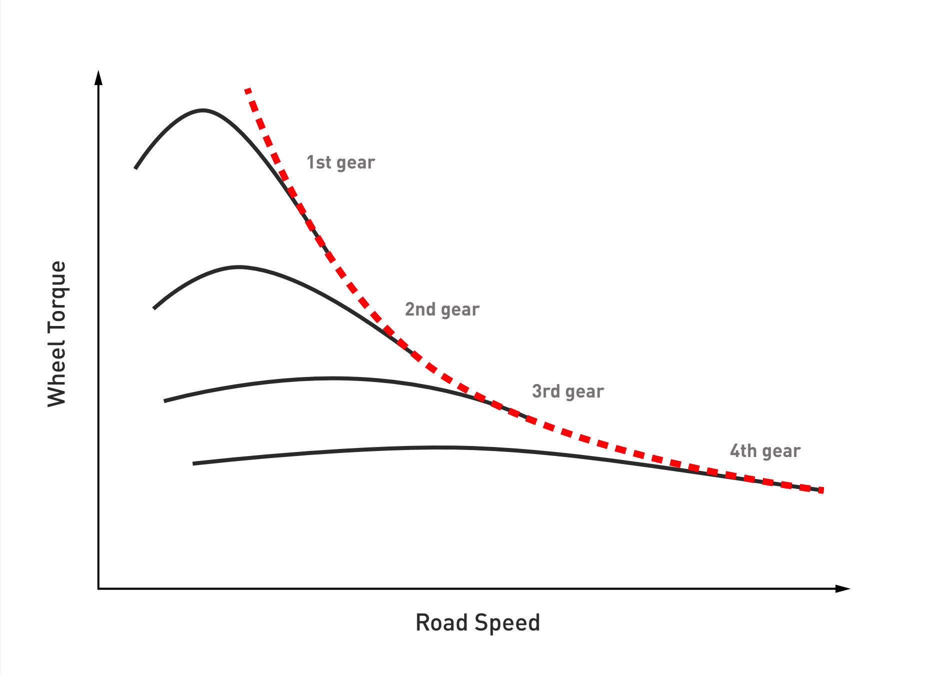
The system is scalable:

- The motor size can be altered, based on the continuous and peak power requirements of the vehicle.
- The inverter is a modular design where the control board remains the same but the power stage scales with power requirement.
- The switch matrix can be changed based on the performance requirements of the vehicle.

The Power Curve

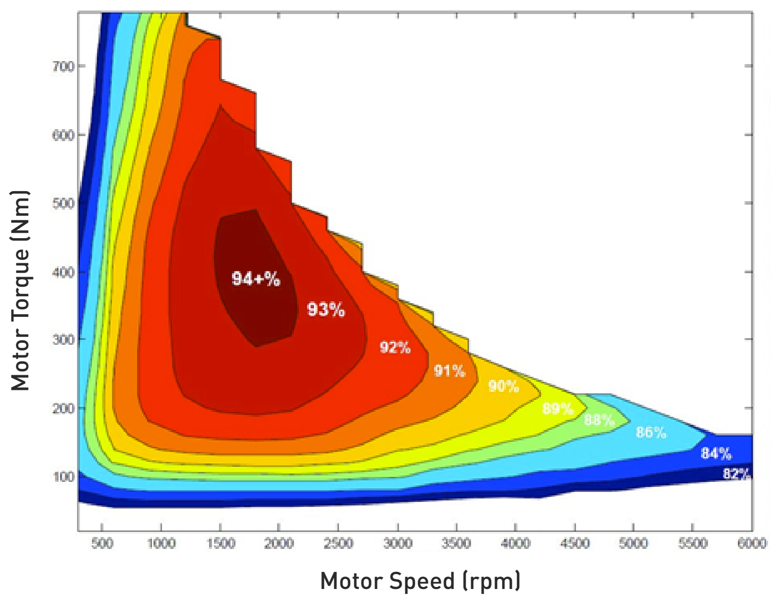
Internal combustion engine (ICE) vehicles are typically limited to an operating range of 1,000 to 6,000 RPM and require complicated, expensive, and heavy multi-ratio gearboxes to produce usable power over the operation range that extends from a standstill all the way to its maximum speed. However, the result is a smooth torque curve across the full operating range.

ICE Torque/Speed Profile



Conventional EV motors can produce a similar curve, but at the cost of efficiency. As is seen in the diagram, the peak efficiency occurs in a relatively small area—the "sweet spot" (an island) for the motor—and it tails off markedly at higher speeds.

Conventional EV Motor Efficiency Map[2]



To maximize an EV's range for a given vehicle and battery, engineers use a process called efficiency mapping to determine the powertrain "sweet spots" and design the components to operate in the maximum efficiency zone as much as possible.

The two main challenges are:

- Optimizing the motor performance under a variety of conditions because the optimal design for a low-speed/high-torque condition will not be the same as the optimal design for a high-speed/low-torque one.
- Operating the machine optimally and limiting its power consumption for any given speed and torque.

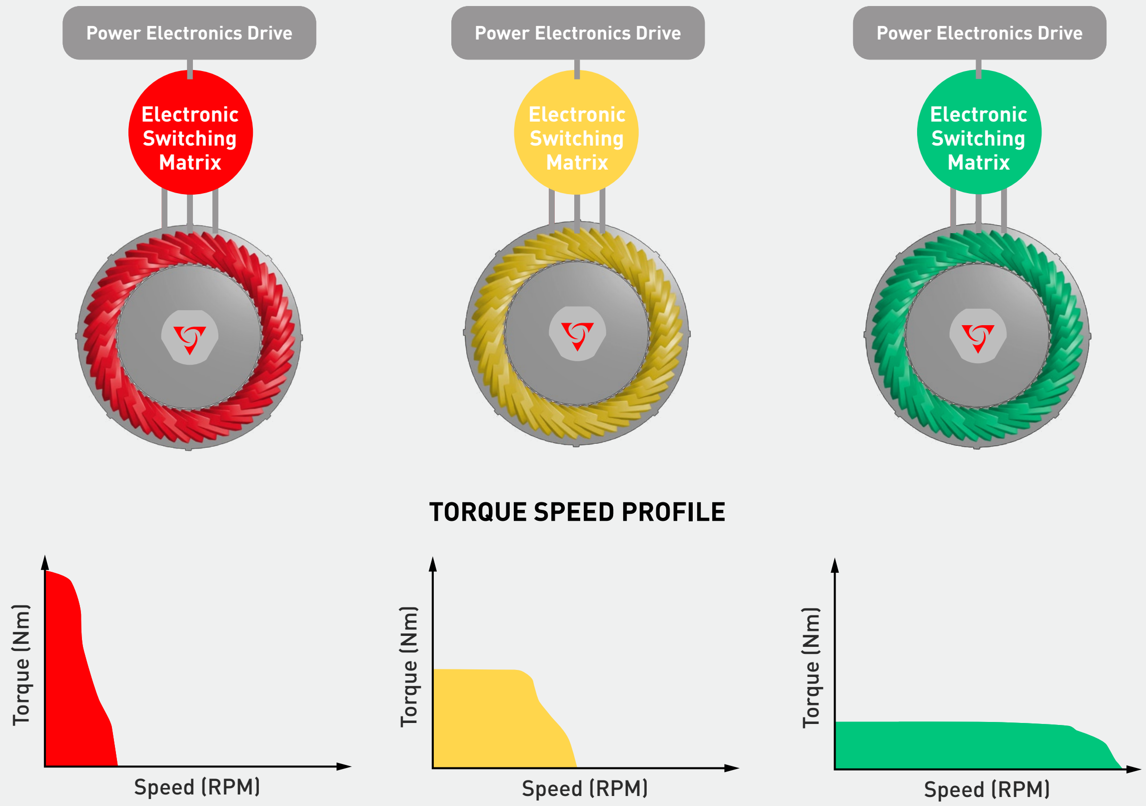
The **eDTS** technology overcomes these limitations and delivers a smooth power curve with high efficiency throughout. The different *modes* that **eDTS** creates can provide multiple "sweet spots" that correspond to the operational needs of the vehicle, such as high torque for starting from a standstill to high efficiency at highway speeds.

2 https://x-engineer.org/automotive-engineering/vehicle/electric-vehicles/battery-electric-vehicles-bev-automotive-industry/

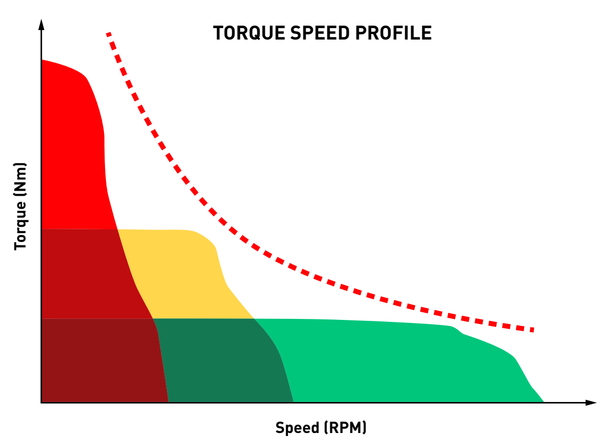
How It Works

Based on the operating needs, the control system determines (in real time) where the system should be on the adaptive shift map. The control system then configures the switch matrix, which enables the various modes.

The power electronics drive uses adaptive shift maps to determine the optimal mode and reconfigures the switch matrix to change how the windings are energized in real time. Each of these modes delivers a different profile with optimized performance characteristics. This reduces the current draw while ensuring high efficiency, which reduces the need for costly battery packs.



High efficiency is delivered across a greater range of the torque/speed profile.



Conventional Motor Design vs eDTS Technology

Conventional permanent magnet brushless motors can provide variable speed outputs, with their motors generating high torque at low speeds and high speed at low torque levels. However, the range of speed and torque characteristics are not sufficient to efficiently cover the desired range, even if the output power of the motor is adequate.

In a conventional EV motor design, used by all permanent magnet motors to date, there are only two options to address this issue: a more powerful motor could be used to cover the entire range, or mechanical gears could be provided for the motor. Both methods add weight to the system, which translates to higher costs.

Conventional, old technology must make a compromise between torque and efficiency, which is the main reason for limited range. In generic terms, this design has only one mode—one "sweet spot"—which, as noted above, is the operating condition where the motor delivers highest efficiency. ePropelled's technology provides multiple modes and, therefore, multiple "sweet spots".

Multiple Motor Modes

eDTS reconfigures the motor modes using hardware and software. As a result, each mode will have different characteristics including torque profile, speed range, and constant power range. This allows for very efficient delivery of optimized performance across the power curve by minimizing the losses in the magnetic material and copper windings.

The eTDS technology allows our single motor to function as if it were multiple different motors, each ideally suited to a desired "sweet spot" on the curve and each area of high efficiency being additionally expanded. This way, each mode is optimized to deliver different performance characteristics, such as high torque when starting from a stop and a seamless change to high efficiency at higher speeds. Since these needs change quickly and frequently when driving, our sophisticated software control is an essential aspect of the system.

The magnetic field pattern and other parameters of the electric machine change, giving it the flexibility to operate optimally when controlled by the adaptive power electronics drive. The control system is designed to allow the transition between the modes to take place seamlessly to deliver optimum torque/speed/efficiency characteristic in real time.

"Magnetless" vs eDTS Technology

Induction motors, universal motors, wound stator/wound rotor motors, and switch reluctance motors are all "magnetless" in that they do not use permanent magnets. However, no motor can work without a magnetic field.

In general, permanent magnet (PM) motors are more efficient than "magnetless" motors. For example, the permanent magnetization means that the rotor can run synchronously to the switching AC current (although this is also true for reluctance motors). This eliminates the slippage that is required in induction motors, for example. It also eliminates the secondary circuit rotor heat losses, meaning that heat efficiency is improved.

Even though PM motors' inherent efficiency is higher than in "magnetless" motors, not all PM motors are made equal. ePropelled's torque control technique is much more efficient than a standard PM motor propulsion system. Therefore, **eDTS** motors are not only more efficient than the "magnetless" motors, but also more efficient than other PM motors.

The Future of Electric Propulsion

Our solution produces a much more energy-efficient method of electric propulsion that increases driving range of the vehicle and life expectancy of the battery pack or allows for smaller batteries for the same range. This is a major improvement to today's capabilities, and it better meets the expectations of the market, manufacturers, and consumers.

Main benefits of the eDTS technology are undeniable:

At least 15% reduction in system-level energy consumption.

Vehicles lasting longer between charges.

Lower costs due to smaller batteries and better efficiencies.

Key takeaways

Among other advantages delivered by eDTS technology, it can:

- start the vehicle at low current compared to standard machines, increasing the driving range of the vehicle,
- offer higher starting torque and extended constant power when compared to other machines,
- take lesser current compared to standard motor,
- increase the maximum torque and maximum speed of the motor,
- select the most efficient mode based on vehicle demand, which will save the battery energy and increase driving range,
- reduce the battery size and cost, and
- implement the cruise mode in vehicle with less current.