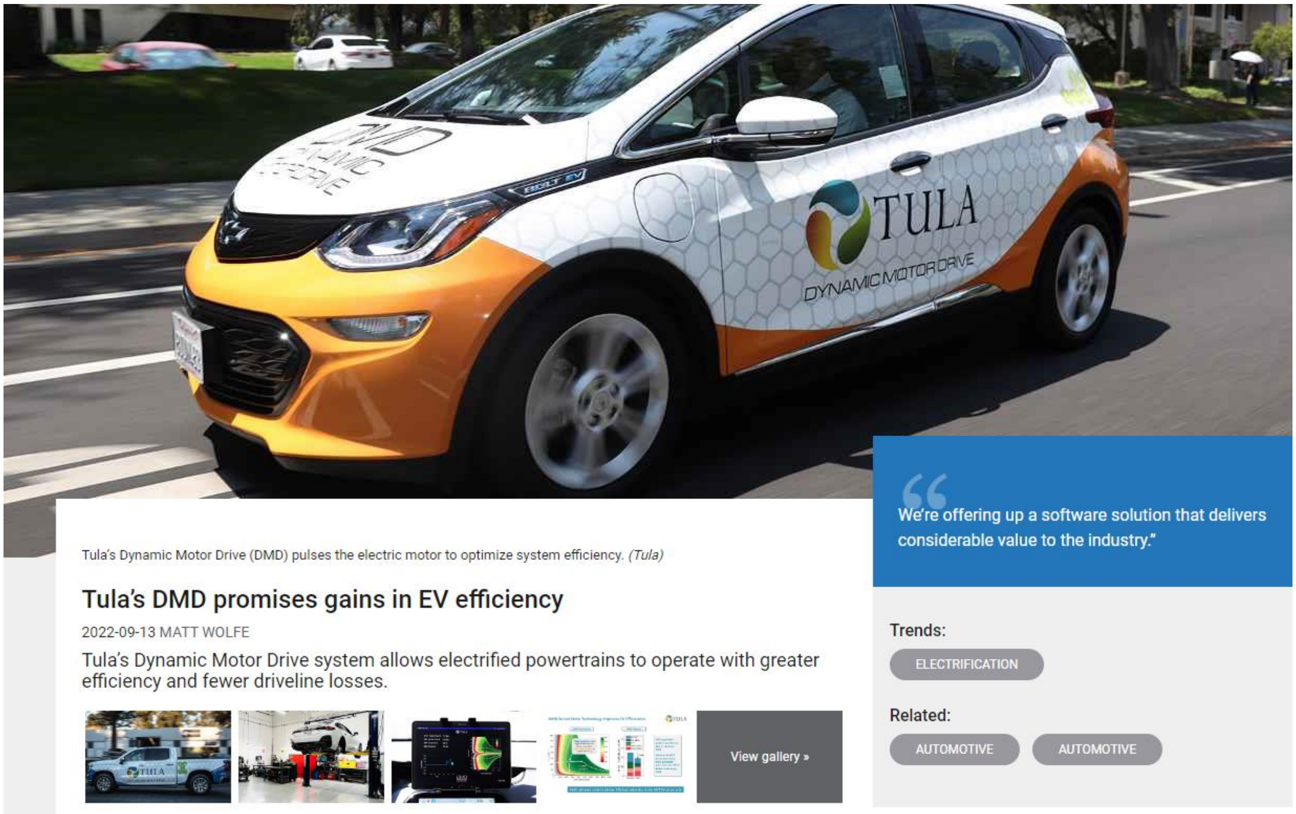

Nestled in San Jose, California just south of the San Francisco Bay, the small but mighty team at Tula Technologies continues to develop advancements for optimizing the efficiency of ICE and electrified powertrains. SAE Media recently visited their facility to speak with the engineering leadership and test drive vehicles equipped with their latest innovations.

Tula's goal is to let the motor (regardless of fuel type) "operate where efficiency is the highest and vary the frequency of operation to provide the desired output." To that end, the company already has systems in the market and in high states of development to increase the efficiency of ICE and electrified vehicles. The best known of these is Dynamic Skip Fire (DSF) which is currently in use on several production General Motors V8s.

Dynamic Skip Fire

Widely detailed in numerous SAE technical papers and articles, the DSF system first reached production in the 2019 Chevrolet Silverado. The company claims a 15%

efficiency gain over a similar V8 engine without the DSF system, along with NVH reduction benefits.

“An internal combustion engine efficiency map has an area where efficiency is the highest,” said Scott Bailey, president, and CEO of Tula. “So, the question we asked is how can we operate an ICE powertrain most efficiently? Our goal was to operate in the ‘sweet spot’ by varying the frequency of the output. The solution was skipping cylinders to get the torque that we need by firing as many or as few as we need to.”

Tula states that the transition from the system functioning to all eight cylinders firing is imperceptible. SAE Media test drove a current generation Silverado equipped with the latest DSF system around San Jose to validate the company’s claim.

From behind the wheel, the system feels seamless. Our test vehicle was outfitted with a display screen which showed what cylinders were firing and which ones were deactivating. Even with the screen demonstrating what cylinders were dropping, it was virtually impossible to tell that the 5.3-L V8 was not firing on all cylinders. The exhaust note would barely change when the system shut down half the engine’s capacity and there were no perceptible NVH quirks.

Naturally, implementing the system and refining it to the point where it did not cause NVH concerns was a challenge. “We used sigma delta controls to produce the desired torque profile,” said Bailey, “which matched what you want for output, but doing it in such a way that you had these highly efficient digital pulses that in the case of an IC engine did not create an NVH issue.”

Dynamic diesel combustion

Tula has also been developing a similar system intended for diesel engines. The company claims its diesel DSF (dDSF) system reduces pumping losses while enabling exhaust temperature control, which reduces both CO2 and NOx emissions. Cummins and Tula formed a partnership in 2020 to test this system on a Cummins X15 Efficiency Series inline six-cylinder engine.

While the system is not currently fitted to any production diesel engine, Tula executives state that the company is currently engaged in 10 different engine programs with six different OEMs globally to implement dDSF. They also stated that the partnership with Cummins has generated 66 new patents of diesel-related tech.

“dDSF enables exhaust temperature control so that we improve the overall efficiency of exhaust aftertreatment systems and SCR systems,” Bailey explained. “The impressive part is that we are getting a CO2 benefit and a dramatic NOx reduction from a single technology.” According to Tula, the dDSF system can deliver a 65-75% reduction in NOx emissions.

Dynamic Motor Drive for EVs

Tula's latest innovation in increased propulsion efficiency targets the EV sector. The company's Dynamic Motor Drive (DMD) was first covered by SAE in 2020. The system is now much further along in development, leading Tula to claim efficiency gains — a 25% reduction of losses in externally excited synchronous motor systems as well as a 3% gain in efficiency in battery and energy costs.

Tula's DMD system utilizes modulated torque or "pulses" to keep the electric motor in its most efficient operating range. The concept is remarkably similar to the tech Tula has used to increase the efficiency of IC engines.

"It was clear that our passenger car market was being disrupted," Bailey noted on what spurred DMD development. "If you added up what the global auto industry was investing into electrification in 2020, it totaled about 300 billion dollars. Two years later, that total is over 515 billion. So, the momentum in the market is continuing to shift. At that point, we knew our DSF passenger car market was going to be significantly disrupted."

Work on the DMD system began in 2018 but has accelerated significantly in the past six months. Like Tula's other systems, the goal is to keep the propulsion system, in this case the electric motor, operating in its most efficient range for longer periods of time. However, instead of turning cylinders on and off, Tula pulses the motor at the highest efficiency point for a given speed and load. There is no rotor current during DMD "off" pulse and the system operates "downstream" from the battery.

"The electric motor has the same fundamental efficiency sweet spot as an IC engine", said Bailey. "How you access that sweet spot is different, but there is an area of highest efficiency and if you can find a way to operate in that area more often, the same fundamental control philosophy applies."

The company states that DMD can deliver up to a 25% loss reduction in the MCT EV drive cycle. Tula also believes that this technology could rapidly help the market for electrically excitable synchronous motors (EESM) grow versus that for interior permanent magnet (IPM) motors. "When you're dealing with a system that is already 88% efficient, a 25% reduction is pretty significant," said Bailey. "By being able to take an EESM and make it more efficient than an IPM at a lower cost, that's where DMD becomes important. We're offering up a software solution that delivers considerable value to the industry."

On-road impressions

After SAE Media sampled the DSF in the Silverado, we drove a Chevrolet Bolt EV outfitted with a prototype of Tula's DMD system. Like the Silverado, the Bolt was equipped with a screen that demonstrated when the DMD system was active, in this case pulsing the electric motor. In low-load city driving, where the system is going to be most active, the pulsing of the motor was just as imperceptible as Tula's cylinder deactivation in the ICE truck.

The screen readout in the Bolt clearly demonstrated when the system was active and when the motor was functioning normally, but there was no clear change in perceptible NVH that would tip off the driver that the DMD system had been engaged. The readout on the screen also indicated what the overall efficiency of the system was during various loads. It showed that the DMD system did indeed keep the motor's output in the "sweet spot" for longer periods of time when it was active.

Mark Wilcutts, director of DMD Systems, discussed the process the company used to produce acceptable NVH levels in the cabin while the DMD system was active. "We've been doing NVH work on this car for about six months," he explained. "When we started, we had our inverter in place and were starting to drive the car just to validate functionality. But our initial impressions when the system was functioning were 'that's obnoxious, that's shaking my hands off the steering wheel.'"

Wilcutts uses this analogy:" You've got a bunch of big rocks and then you've got to knock the big ones into smaller ones, and then the smaller ones into pebbles. So, we started by finding the biggest problem and think about how we want to write an algorithm and create calibration for it. Then that gets better but then we notice three or four other problems that we didn't notice before. Then we have to write another set of algorithms to compensate for that. That's basically what's been going on over the last six months."

Tula has been using GMUTS (General Motors's Driveline Noise and Vibration Vehicle Level Allocatable Test) to validate their NVH testing as well as accelerometers and microphones for their own internal NVH scale. When compared to their NVH measurements with the stock Bolt motor control, company engineers feel that they are nearly within standard deviation of where they started when the DMD system is functioning. "There were some areas that there are 6.5's and sevens. I don't think anything was above a 7.75," said Wilcutts. "I would say we are 80-85% of the way there (on NVH reduction) now."

While SAE did not get to sample the Bolt in the earlier states of DMD calibration or a stock one for sake of comparison, the work that Wilcutts and the Tula team have put into the system is steadily showing progress.

Heavy-duty implications

While the DMD system does offer most of its benefits under low load, it can still offer efficiency gains on larger scale electrified vehicles. The company is working with a truck OEM to develop the DMD system for a commercial application. Bailey also stressed that "There is nothing that limits DMD application to just mobility."

John Fuerst, senior VP, DMD and Engineering, expanded on DMD's potential for commercial and off highway applications. He explained how DMD could be used in agricultural applications. "For example, a high horsepower tractor that spends a significant portion of its life driving a fairly low-load accessory drive using a small amount of the machines peak power," he said. "If you've got a significant portion of the application that's operating at low load, then the DMD can provide some real benefits." Tula is reportedly in talks with a U.S.-based ag equipment company about implementing the DMD system on their machines.

While the benefits of the DMD system on EESM systems is apparent, there are some losses that are higher as a result of the system's function. "The power dissipated across the resistor is proportional to the square in current," Fuerst told SAE Media. "In a resistor where you're having current losses, AKA copper losses, those losses are equal to the resistance of the copper multiplied by current. So, in a DMD use case at say 50% load where we're pulsing at 40%, we'll pulse at 40% for half the time and the other half of that time we're not delivering anything."

To deliver that 40% requires twice the current, he noted, but the losses are proportional to current squared. "So, you doubled the current, but you quadrupled the losses. And even though half the time there's no current, you've quadrupled it when there is," he explained. ""In total, the average is that you've doubled part of the cooper losses. You don't double the total losses compared to no DMD operation, but they do go up."

Even with the greater copper losses, the DMD cycle still demonstrates a large reduction in total losses according to Tula's testing (see chart in gallery). And the reductions in core and inverter losses more than offset the increased copper losses. In a EESM system, the gross theoretical gain over an EV MCT test was in the range of 2.7%-4.3%, the company reports. In practice, the expected gain from this system as configured is in the range of 2.0-3.2%.

What's next for Tula

In addition to developing DMD in cooperation with global OEMs, Tula has already embarked on their next project for increasing the efficiency of modern propulsion systems. Company leaders are tight lipped about what their newest project is, only indicating that they have something in the pipeline. Meantime, it is likely that Tula DMD technology will see production in several EVs, as well as other electrified drivelines, over the coming decade.

Even with the shift towards electrification, the company's business model has hardly changed. "We create IP, we patent it, and that puts us in a position to be transparent with customers about how to implement our technology and make them very comfortable that they know everything about what they're putting into production," Fuerst stated. "We're in the business of doing what's impossible, but what we've learned is that we need to demonstrate the technology."