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Inverter and Motor Efficiency Increase with FPCU Implementing Optimized Pulse Pattern Methods

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Executive Summary

This paper discusses the usage of Optimized Pulse Pattern (OPP) modulation to increase the efficiency of the inverter and the permanent magnet synchronous motor (PMSM) by reducing switching losses in the inverter together with copper and iron losses in the electric motor. It presents a unique implementation of Optimized Pulse Patterns dynamically selected upon speed/torque operating setpoints using several optimization criteria and performed by an FPCU integrated circuit. The efficiency improvement is measured on a high-voltage bench and compared to conventional SVPWM modulation, both using a comparable field-oriented control (FOC) of the drive. As a result, using OPP, loss reductions are in the range of 2% to 5% regarding motor and inverter have been achieved.

Keywords : Control System, Efficiency, EV

1 Introduction

Environmental considerations are actively pushing towards electric vehicles. Electric motors are far more energy-efficient than combustion engines. Nevertheless, the efficiency of today's electric drivetrains bears still significant improvement potentials, which will need to be leveraged to get the full benefit of electrification.

The range of an EV is strongly affected by the efficiency of its powertrain: the energy stored in the battery must be converted into vehicle motion, while losing as little as possible by conversion losses (resulting in waste heat) in the inverter and motor. While many others developments target improving the battery as main energy storage, we focus on the efficiency of the energy conversion in the electrified powertrain, which may be optimized using advanced control and modulation strategies.

The losses in the powertrain are consisting mainly of switching losses in the electronic power converters, and of copper and iron losses in the electric machine, which are dependent on higher-level harmonics of the rotating magnetic field. They are dependent on the vehicle operating conditions. Keeping the electrified powertrain in its optimal range is extremely challenging. The solution we developed proposes an advanced modulation strategy, that allows us to reduce losses in the inverter and mitigate undesired side effects such as harmonic injection of the electrical machine, improving the overall efficiency especially under challenging operating conditions.

Multiple modulation techniques have been studied in previous literature, each having different benefits and drawbacks depending on speed, torque, voltage and electrical frequency of the electric motor as developed in [10]. Until now, their implementation usually requires complex designs, using combinations of microcontrollers, DSPs and/or FPGAs/ASICs, which increase the overall complexity, the development time and the system cost. Therefore, advanced modulation techniques beyond traditional Space Vector PWM (SVPWM) have been little used so far in automotive applications.

In the following, we introduce a new control system design and implementation using a single chip, a Field Programmable Control Unit (FPCU) proposed in [1]. The control is based on a Field Oriented Control (FOC) for the current/torque regulation and an Adaptive PWM Control (APC) for the modulation. Depending on the motor's operating conditions, the FPCU may switch between different types of modulation techniques to provide the optimal modulation for the targeted set point. In addition to Space Vector PWM (SVPWM), the FPCU supports the flexible implementation of Optimized Pulse Patterns (OPP) modulations, which may be designed to generate the best e-motor/inverter behavior according to specific optimization criteria.

OPP is a modulation technique relying on a set of switching (pulse) patterns that are pre-computed offline. Its main purpose is to lean the harmonic signature of the control current to reduce iron and copper losses, based on precisely pre-calculated switching angle positions. Duration and position of pulses are determined upon voltage Modulation Ratio (m) and e-motor speed. Combined with Voltage Phase Compensation, the optimal operating range of the electric motor may be extended, reducing losses, torque ripple, total harmonic distortions (THD), and thus improving the overall system efficiency.

2 Adaptive PWM Control

The APC implements both SVPWM and OPP modulations.

2.1 SVPWM Modulation

Typically, SVPWM is based on fixed switching frequencies, where only the PWM duty cycle varies, while the number of switches per time period is fixed. To improve the quality and efficiency of an SVPWM controlled inverter, one usually tries to find an optimal switching frequency, which is a compromise between losses in the inverter and the quality of the (ideally pure sinusoidal) phase currents. Increasing the frequency of the SVPWM will increase the quality of the output currents, but at the expense of a dramatic increase of the inverter switching losses. In the following example, extracted from simulation, the electrical frequency (Fe) is at 550Hz, the SVPWM switching frequency (F_{sw}) is at 10kHz, resulting in 36,1 switches ($Ns_w = F_{sw}/F_e \times 2 = 36.1$) per electrical period.

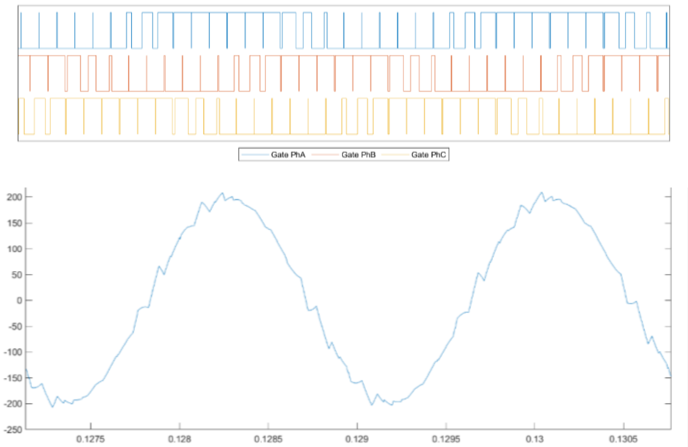

Figure 1: 10 kHz SVPWM gate switches with N_{sw} = 36 and Phase current waveform with a 4.7% THD - simulation results

In this example the SVPWM achieves a switching frequency at 10 kHz a Total Harmonic Distortion of 4.7% on the generated phase current signals.

2.2 Optimized Pulse Patterns

Instead of modulating a duty cycle at a fixed time intervals (frequency), OPP is based on periodic switching patterns that are generated as a function of the electric angle position of the electric motor.

In OPP, based on a given number of switches (N) per rotation, the switching angles may be calculated to optimize several criteria, like minimum switching (minimum losses), minimum THD, minimum current Signal/Noise ratio (SNR), the maximum percentage of power on the fundamental frequency, minimum Noise, Vibration and Harshness (NVH) generated in the e-motor. As the resulting pulse patterns are dependent on the operating points, the optimization is done for various discrete values of the modulation ratio (m = 100 x $[\ \sqrt{(Vd^2 + Vq^2)}]\ /\ [\ Vbus/\ 2\ ]$). As a result, a pattern is described by a set of angles (switching instants) α_i depending on modulation m, stored in a table.

In *figure 2*, extracted from simulation, the electrical frequency (Fe) is at 550Hz, the OPP switching frequency (F_{sw}) is at an equivalent frequency at 3.8kHz, resulting in 14 switches ($Ns_w = F_{sw}/F_e \times 2 = 14$) per electrical period. This OPP example is applied on the same SVPWM setpoint shown in *figures 1 and 2*.

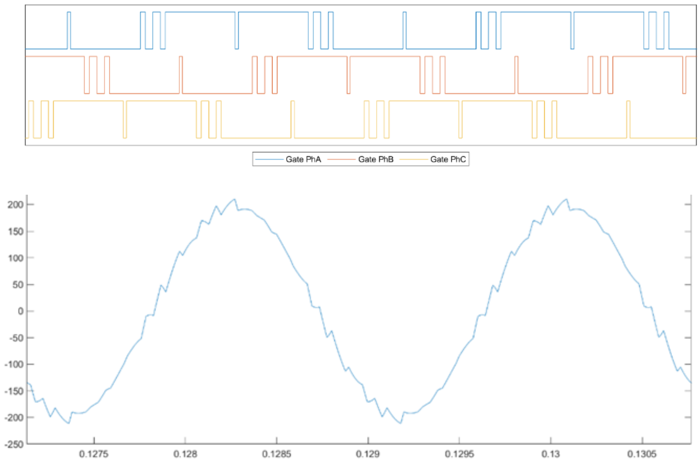

Figure 2: 3.8 kHz equivalent OPP gate switches with Nsw = 14 and phase current waveform with 4.2% THD

In this example the OPP achieves, with an equivalent switching of 3.8 kHz, a Total Harmonic Distortion of 4.2% on the generated phase current signals. This simulation example demonstrates, that for the same operating set point the OPP modulation achieves a better THD while reducing the number of switches by a factor of 2.6.

3 Algorithm architecture and design

The APC relies on offline generated (optimized) patterns, that are properly executed ("played") in real-time. To achieve the required resolution in angle-based pulse control, OPP execution demands a huge real-time processing capability. As an example, for a 6 pole pairs electric motor rotating at 20,000 rpm, controlled with modulation over 32,768 tick resolution on an electrical period, a software implementation of OPP would require 65,536,000 interrupts/s. Obviously, a CPU software-based implementation cannot properly support such a modulation. As of today, OLEA® Field Programmable Control Unit is the only automotive-qualified System-on-Chip powerful enough to run such a demanding algorithm, while also ensuring the ISO 26262 safety ASIL D level.

This chapter introduces the design architecture of the APC implemented using the OLEA T222 FPCU described in [1] and [2]. The APC algorithms are integrated into a complete motor control application described in [3].

3.1 Embedded control loops and algorithms

Figure 3 shows the functional partitioning of the APC using the computational resources of the FPCU: (1) the CPU and (2) the programmable hardware-accelerated area provided by the AMEC FLU. In general, the real-time hardware control loops and algorithms are executed within the AMEC/FLU hardware programmable unit. The resources of the CPU may be used mainly for non real-time critical (i.e. vehicle) functions.

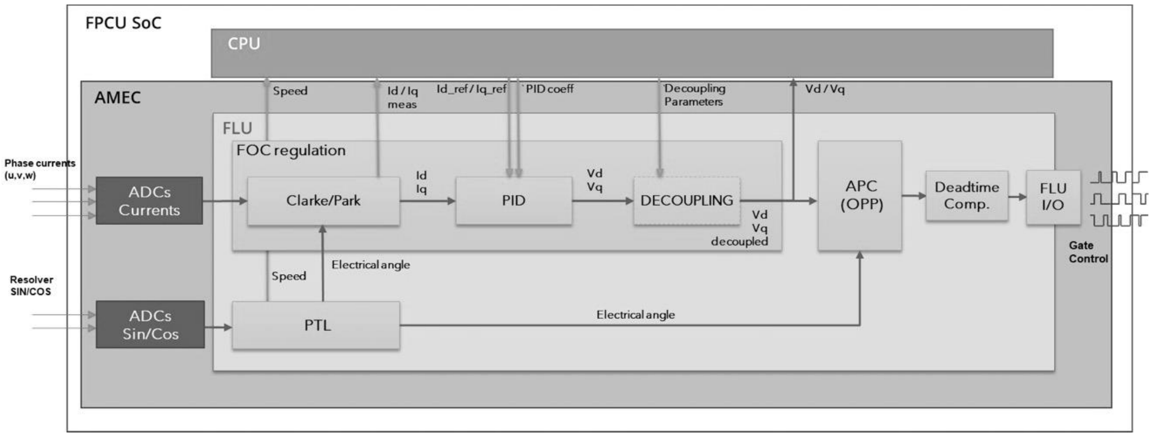

Figure 3: APC algorithms insertion into the high-level control-loop mapped into the FPCU

Regarding the implementation shown in *Figure 3*, the main control loop runs at a 200 kHz sampling ratio, including the three-phase currents (I_u, I_v, I_w) acquisition, the Clarke & Park transform, the PID control of I_d, I_q target values, up to the determination of the decoupled V_d, V_q reference values. The APC modulator, *Figure 4,* generates the pulses to be sent to the gate drivers. The electrical angle is determined using an integrated Position Tracking Loop (PTL) algorithm that processes the resolver winding SIN/COS signal at 20 kHz. A dead time compensation algorithm compensates for the delays to be introduced between the transistors high and low.

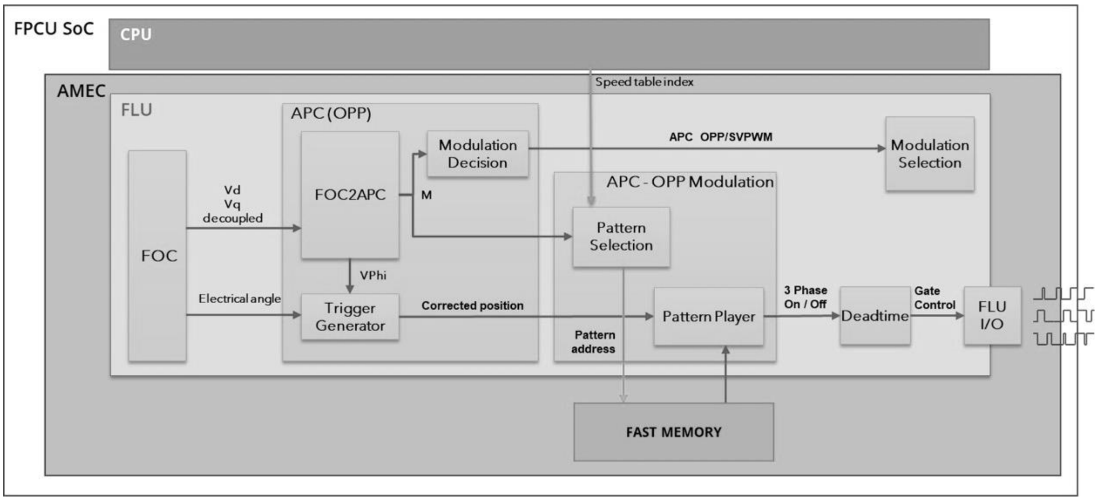

Figure 4: APC modulation block

Figure 4 shows the detailed APC modulation block. Here, the decoupled V_d, V_q commands are translated into modulation ratio *m* and phase angle V_{phi} commands

$$m = \frac{\sqrt{Vd^2 + Vq^2}}{\left(\frac{Vbus}{2}\right)} \quad (1)$$

$$Vphi = arctan\left(\frac{Vq}{Vd}\right). (2)$$

Depending on the modulation ratio *m,* the corresponding optimized pattern (stored in a table) is selected. The APC pattern is then executed using the V_{phi} dephasing according to the electrical position.

In addition to the OPP, the APC also supports SVPWM modulation. A complete set of thresholds is programmable to define all the conditions to switch from one modulation to another. It is possible to switch from an OPP modulation to an SVPWM with full flexibility and seamlessly in less than 2 µs.

In addition, the main control-loops also include flux-weakening and saturation management, which are not described in this article.

3.2 Pulse Pattern generation

Considering the periodicity of the inverter and motor state, the inverter can be used to apply a periodically recurring control of the gates, synchronized with the system period. Consequently, a pattern is the description of the given state of one phase of the inverter, for all positions of the rotor within one electrical period.

By applying the pattern to all three phases (with the appropriate phase shifts of typ. 120° per phase), 3 coherent phases can be obtained. Depending on the topology of the inverter, a pattern may have two levels (0 and 1) or more in the case of multilevel inverters (-1, 0, 1, for a 3-level example).

A pattern is composed of a constant and even number of switching events (transitions from one level to another), located at specific angular positions within an electrical turn.

As described above, pulse patterns may be optimized according to a free set of criteria (like THD, the amplitude of current harmonics, inverter and motor losses etc.). Any property that can be modeled or measured may be reflected in the optimization criteria used for pattern generation.

A numerical pattern generator is our solution to calculate the optimized pulse pattern, for the desired scenario. As a single pattern might not be sufficient to fulfill a scenario, coherent or consecutive patterns shall be generated.

To assess the quality of a pattern, the motor behavior can be measured on a bench, simulated in a test environment or analytically predicted. The fastest way to assess the quality of a pattern is an analytical prediction: every model has a representativity, directly linked to the quality of its approximations to calculate physical quantities. Even the simplest models ensure fast computations, albeit low representativity.

A standard PMSM current simulation model will provide from the inverter potentials (V_{abc}) , the phase currents (I_{abc}) from which iron & copper losses and torque may be estimated, for example using the Steinmetz motor loss equations (presented in [8]), parametrized using coefficients for the Eddy, Hysteresis and Excess losses in different frequency ranges.

Assuming the motor losses are estimated from the current harmonics, a frequency-dependent equivalent motor resistance is estimated via regression. This indicator is called RI^2 and, based on it, patterns are generated, targeting to minimize motor losses.

Generating a pattern means simultaneously finding the most appropriate switching angles α_i of an even number E of switching events within a period $0\ldots2\pi$, in ascending order.

To simplify the problem (and reduce the dimension of the search space), the inverter and motor behavior, whether considered as tensions or currents, are considered as best represented as sinusoidal quantities. Symmetry properties may be used to reduce the dimension of the search space as proposed in [7].

For any point in the search space (e.g. any pattern), the resulting phase currents and other physical quantities are estimated and used as a score, based on selected criteria according to customer-specific requirements.

Starting from an initial pattern (seed), the score can be successively improved using neighboring estimation and incremental displacements. We use a modified genetic algorithm, targeting to find the absolute maximum:

At initialization, a population of patterns (seeds) is generated either randomly or in the appropriate area of the search space.

1. Each individual of the population is assessed for survival (via the calculation of its score)
2. Only the fittest individuals (having the highest scores) are memorized as breeders.
3. New individuals are created using mutations from the breeders of the previous population.
4. New individuals are created using crossovers (recombination) from several of the breeders.

5. Repeat from step (2) until complete convergence.

One big advantage of this generation method is its agnosticism of the fitness function, making it compatible with any model and any scoring function. Also, it is possible to implement additional constraints based on the hardware (controller, inverter or motor), to ensure that some situations will be avoided altogether (minimum on-time for gate drivers, angular resolution given the rotor speed, phase-to-phase pattern interaction, controller related requirements). Depending on motor behavior and operating conditions, validation and re-optimization steps are considered in the practical implementation described in Chapter 4.

In the study reported in this paper, symmetrical patterns optimized with respect to Total Harmonic Distortions (THD), Torque Ripple and Ri2, along with asymmetrical patterns have been generated and are respectively referenced: (1) APC-THD, (2) APC-Torque-Ripple, (3) APC-Ri2, (4) APC-Asymmetric.

Considering the lack of detailed knowledge on the physical non-linearities of the e-motor, these different types of OPP allow exploring the best modulation to be applied on the inverter in order to extract the highest efficiency from the complete system.

4 Implementation framework for a targeted inverter/e-motor system

A systematic methodology is applied to define, produce and test the patterns. Throughout the development, the same set of system data is used to develop the control and the associated calibration, to generate the table of patterns, to run the simulations in the Model in the Loop (MiL) environment, and to setup the Hardware in the Loop (HiL) test benches.

For steady-state analysis, a set of stationary operating setpoints is defined to characterize the target system e-motor efficiency map, with setpoints representing MTPA (Maximum Torque per Ampere), MTPV (Maximum Torque per Voltage), constant torque or constant power conditions. Each setpoint is considered as a dedicated test case in steady-state, for which a set of patterns is generated using the optimization algorithm described in chapter 3.

Once the resulting tables of patterns have been generated, they are used first in MiL environment simulations, to compare the simulation results between the standard SVPWM modulation used as a reference and the OPP (Optimized Pulse Patterns) patterns for the chosen criteria. In the next step, HiL simulations are performed using an inverted control board embedding OLEA FPCU. The inverter and the plant model used on the HiL are calibrated with the same target system data. Each simulation runs on the HiL with the inverter control board and the different modulations, using SVPWM as a reference to compare with different OPP patterns.

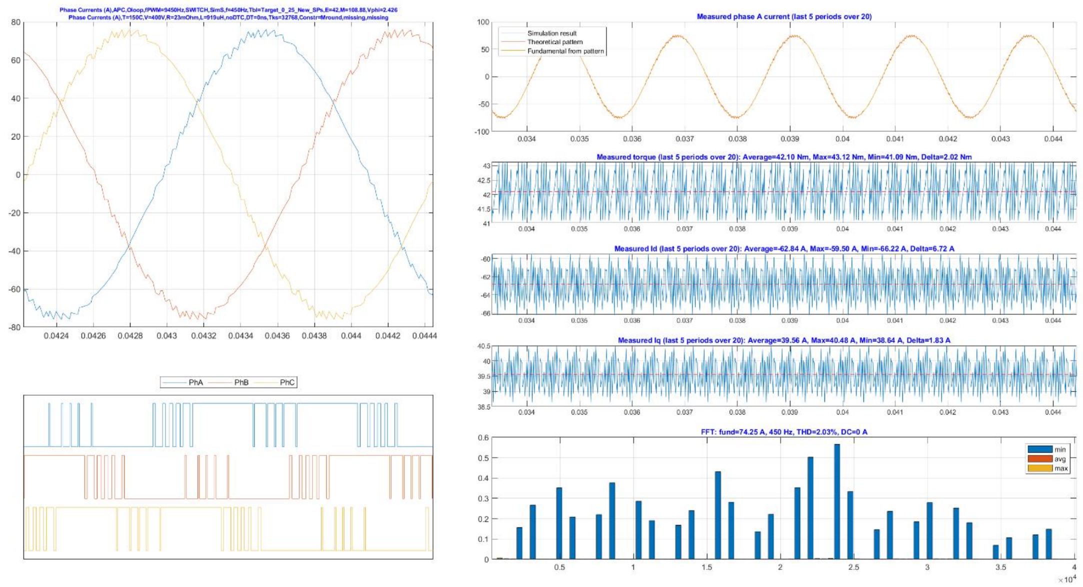

Figure 5: Example of a MiL simulation results for a dedicated setpoint

The HiL recorded measurements are then analyzed and compared with the MiL simulation results. The recorded gate and phase currents are re-injected in the MiL environment to assess the control performance and validate the target pattern player.

To assess the e-motor and inverter plant models of the MiL and HiL environment, the e-motor bench session measures are also re-injected into the MiL simulation environment.

In this way, comparison and cross-check are achieved for the control algorithm behavior in real-time versus the theoretical one in the MiL (1) and for the e-motor's plant model accuracy (2). This allows improving 1 & 2 in fast development iterations.

5 Experimental Results

This chapter reports the experimental results that have been obtained on an e-motor bench using a commercially available BorgWarner/Cascadia Motion inverter/e-motor system, which has been modified to use an OLEA FPCU controller board.

5.1 Inverter/e-motor system

The 2-level inverter is a BorgWarner/Cascadia Motion PM100DX module [4] equipped with a control board including an OLEA T222 FPCU from Silicon Mobility and based on a SEMIKRON IGBT module. The electric motor is an HVH250-090SOM product from BorgWarner [5].

	PM100 DX
Inverter level	2 levels
Topology	3-phases
IGBT module	SKiM606GD066HD
DC Voltage – operating	50-400 Volts
DC Overvoltage trip	420 Volts
Maximum DC Voltage – nonoperating	500 Volts
Motor Continous current	300 Arms
Motor current peak	350 Arms
Output power peak	120 KW
DC-Bus capacitance	440 µF
Coolant water flow rate	8-10 LPM
Operating Temperature range	[-40 : +80] °C
Volume	5,5 Liters
Weight	7.5 Kg

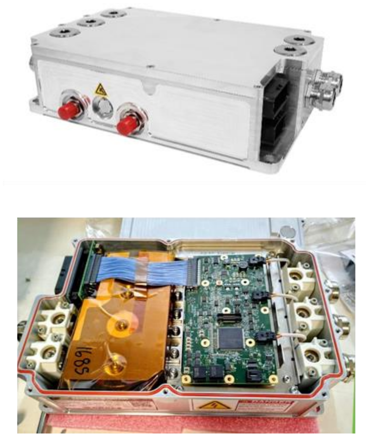

Figure 6: PM100DX inverter with integrated OLEA T222 FPCU based control board

	HVH250-090-SOM
Motor type	PMSM
Number of pole pairs	5
Number of phases	3
Max Current	350 Arms
Max Speed Max	12000 RPM
Max Power	120 KW
Max Torque (peak)	311 Nm at 300 Arms
Rated Torque	208 Nm
Rated Speed	2500 RPM @320V
Coolant oil flow rate	5-30 LPM
Position sensor	Resolver winding (SIN/COS)

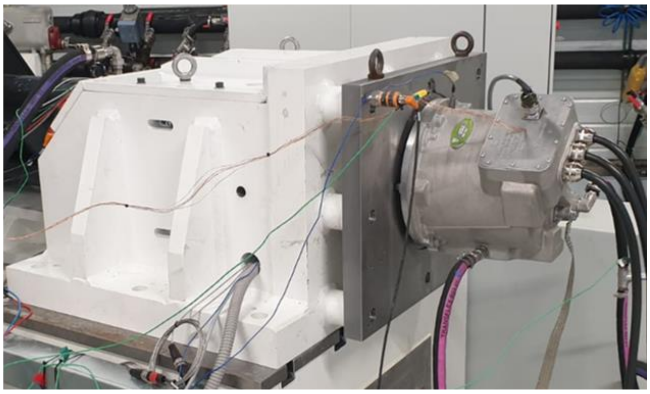

Figure 7: HVH250-090-SOM mounted on an emotor bench from EMC [9]

5.2 Measurements

All the efficiency measurements have been executed in torque control mode and close loop. The torque control mode relies on i_d, i_q Look-Up Tables (LUT) implementing the Maximum Torque Per Ampere (MTPA) and Maximum Torque Per Voltage (MTPV) under the electric motor design data. Consequently, the electric motor load of the bench has been controlled in speed. As the physics of the motor has not yet been fully characterized concerning the effect of the modulation on the electric motor losses, different APC pulse pattern types have been used for the measurements including the patterns described in section 3.2.3 (APC-THD, APC-Ri2, APC-Torque-Ripple, APC-Asymmetric). They are compared with a reference SVPWM modulation at 10 kHz, which represents the best compromise balancing inverter and electric motor losses. Both APC and SVPWM modulations implement a dead time compensation.

All the measurements have been realized using the same OLEA T222 FPCU control board in current close-loop operating mode and steady-state conditions, using the same torque/speed operating set points and on the same temperatures averages for the electric motor and inverter. This measurement method guarantees, that the different modulations are strictly comparable using the same operating and environmental conditions.

The measurement has been achieved on 8 operating setpoints as defined in the table below. These operating setpoints have been selected to be representative of a real-driving cycle test.

		DC BUS [V]	Speed [RPM]	Speed [Hz]	Torque [Nm]	Power [kW]
Operating Set points	**1**	400	1800	150	-10	-1.88
	2	400	6900	575	20	14.45
	3	400	3600	300	30	11.31
	4	400	5400	450	-20	-11.31
	5	400	8400	700	50	43.98
	6	400	8400	700	20	17.59
	7	400	10200	850	40	42.73
	8	400	9500	792	50	49.74

Table 1: Operating Set Points

Different types of APC patterns have been executed and compared with the SVPMW modulation on several criteria including the overall system efficiency, the Total Harmonic Distortion (THD), the Torque Ripple, the motor losses and inverter losses. As an example, *Figures 8-11* show an extract of these criteria for operating setpoint #3.

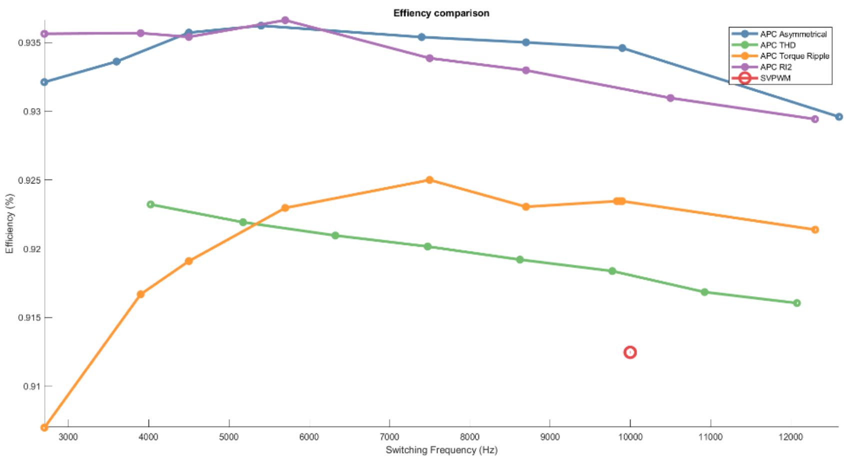

Figure 8: Overall system efficiency comparison on operating setpoint #3

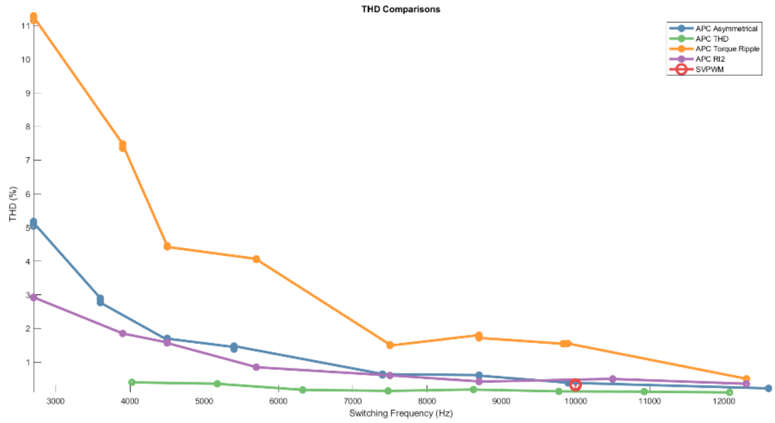

Figure 9: THD comparison on operating setpoint #3

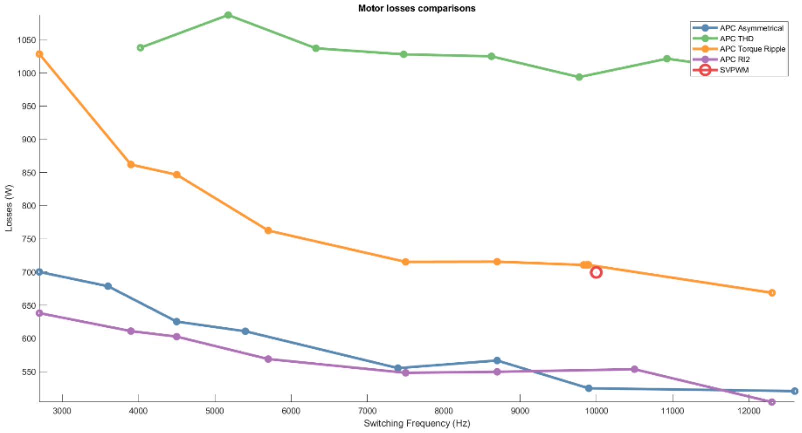

Figure 10: Motor losses comparison on operating setpoint #3

The table below summarizes the results for the selected APC pulse patterns that provide the optimal performances in matters of efficiency, THD and torque ripples. As it can be observed, compared with SVPWM, the overall inverter plus e-motor efficiency at the 8 operating points is improved in the range of 2 to 4.6%, by choosing the appropriate APC pulse-type (OPP pattern). On average, the THD is at 0.6%, and torque ripple at 0.2 Nm.

		DC BUS [V]	Speed [RPM]	Speed [Hz]	Torque [Nm]	Power [kW]	Avg Temp [°C]	APC Efficiency [%]	SVPWM Efficiency [%]	Efficiency Increase [%]	APC Pulse type	Eq Fsw [Hz]	Loss Reduction [W]
Operating Set points	1	400	1800	150	-10	-1.88	25	87.22%	82.59%	4.64%	THD	3750	87
	2	400	6900	575	20	14.45	32	92.48%	90.30%	2.18%	Ri2	6325	315
	3	400	3600	300	30	11.31	27	93.66%	91.25%	2.42%	Ri2	5700	273
	4	400	5400	450	-20	-11.31	28	93.58%	89.81%	3.77%	TRIPPLE	8800	426
	5	400	8400	700	50	43.98	30	93.42%	91.39%	2.03%	THD	7400	894
	6	400	8400	700	20	17.59	31	91.47%	88.70%	2.77%	TRIPPLE	7500	488
	7	400	10200	850	40	42.73	43	91.41%	88.53%	2.88%	THD	9300	1230
	8	400	9500	792	50	49.74	39	92.35%	90.30%	2.05%	THD	8700	1018

Table 2: Experimental results table

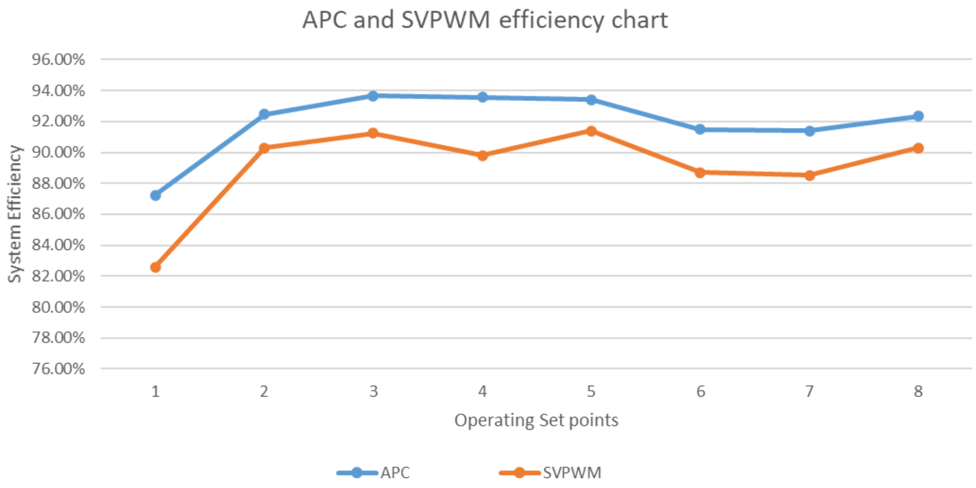

Figure 11: Final results

Summarizing the results:

- All 8 operating-set-points show efficiency improvements using APC OPP-based modulation versus SVPWM from 2.05% up to 4.64%.
- Combined e-motor + inverter Losses reduction varies from 87 W up to 1230W (average), which besides the better energy efficiency may also allow for further cost savings regarding cooling and dimensioning of components.

6 Usage in Cascadia Motion Inverter Products

Cascadia has several inverter product lines that are sold in low-volume specialty vehicle markets where functional safety certification or standards compliance is not required. These vehicle propulsion inverters cover the 100 – 500kW power range. Cascadia products are generally used in very high-performance vehicles where size, weight, and performance are more important than cost. As the company moves to integrate the inverter directly on the motor, both inverter and machine performance improvements become more important to differentiate our products in the market.

6.1 Expected Benefits

Any improvement in propulsion system (motor + inverter) efficiency is good as improving motor and inverter efficiency allows a lower cooling system demand and better vehicle range. Since a typical vehicle spends a lot more time at light load and commute-level speeds, efficiency improvements at low power are much more important from a range improvement perspective. This is one of the many reasons for the interest from the market in SiC inverters – they have superior light load efficiency than IGBT-based inverters – but they are much too expensive currently for mainstream vehicle applications. Today SiC power devices are ~4x the cost of automotive-qualified Si IGBT in the same package.

The results from this work indicate a sufficient improvement in new motor + inverter efficiency to make this attractive to our new and existing customers. It makes an IGBT-based inverter more competitive compared to a SiC inverter – without the added cost.

The novel PWM methods used here appear to generate a bit more voltage at the inverter terminals in the field weakening without degrading motor efficiency. Standard overmodulation tends to add harmonic content to the output current that degrades motor efficiency, so even if one could get to the same net fundamental voltage the peak power would need to be derated or the duration reduced. Race cars don't need peak power for more than a few seconds at a time, so not that important – but in a commercial vehicle these peaks may need to be sustained for much longer periods and even small improvements are significant.

Safety Compliance to ISO26262 is mandatory for "production" vehicle platforms, but generally not in all applications or for low-volume niches. Clearly, as time goes by, the competitive landscape will change and ASIL compliance will "trickle-down" to even Cascadia's low-volume market based on the SEooC (Safety

Element out of Context) approach. Customers are expecting this change over the next few years. The OLEA approach to Functional Safety is a much less invasive one than is typically required for the standard automotive controllers to develop and validate a Propulsion inverter.

6.2 Impact on BoM

The change in product BoM cost is negligible. The OLEA is not significantly more expensive than its ASIL-D capable competition, and while different the support circuits are also not significantly different in material cost. Component package and solder assembly processes to support the OLEA are also no different. Cascadia does not expect a product cost change if/when this processor is moved into one or more of our products.

6.3 Projection of usage on Cascadia Inverter Roadmap

This project started as a safety delta-design effort to evaluate the capability of the OLEA controller and toolchain in a high-performance automotive inverter. The performance improvements are a (very) welcome result of the work and add significant impetus to the program and would make the new inverter more competitive, especially in the performance end of the market where Cascadia lives.

Cascadia needs a safety-compliant inverter product that is flexible enough to be used in many low-volume applications as a SEooC component. The OLEA and associated toolchain appear to be the best path forward for a small engineering team to tackle this large effort.

7 Conclusion

This paper describes the importance of advanced modulation techniques which, applied to the sub-system inverter/e-Motor of electric powertrains, are delivering significant efficiency improvements.

The work shown here is to be considered supporting the same targets as adjacent work on new power transistor technologies (GaN, SiC), advanced inverter system architecture (multi-stage, multi-level), and even advanced speed, current and magnetic flux control strategies (i.e. Model Predictive Control, AI-based control). They all target to produce a better energy efficiency for the EV/HEV drivetrain. And as the physical approach for improvements is different, their practical benefits of each will mostly add on.

What is common for all those new technologies: they all will need, besides a precise understanding of the system to allow its optimization, much better and faster handling of the critical real-time constraints of the system. To make this possible by providing significantly higher computing performance, while fulfilling the highest standards in terms of safety, at competitive bill-of-material costs: that's the challenge we at Silicon Mobility tackle with our OLEA FPCU product line since day one.

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Presenter Biography

Khaled Douzane has 21 years of experience in the semiconductor industry with an automotive focus. As VP Products of Silicon Mobility, he is defining and driving all semiconductor and software product lines for HEV/EV powertrain applications. Khaled is at the origin of the major patented technologies of the company. Khaled Douzane is graduated from Nice Sophia-Antipolis POLYTECH engineering school in electronics.

Lary Rinehart has 46 years of experience in power electronics, power semiconductor packaging, and motor drives, the past 20 years focused on automotive and heavy vehicle propulsion electrification. As a founder of Rinehart Motion, and now Director of Advanced Engineering for Cascadia Motion (RMS was acquired in January 2019 by BorgWarner), Larry has developed Silicon IGBT, Silicon Carbide and GaN inverters for electrified propulsion in myriad applications, ground sea and air.

Christophe Keraudren has 20 years of experience in software research and development at Siemens VDO and Continental. As VP System and Software of Silcion Mobility, he is leading the system and software development for HEV/EV applications. Christophe received his Engineering Degree in Computer Science from École Nationale Supérieure d'Electrotechnique, d'Electronique, d'Informatique, d'Hydraulique et des Télécommunications (ENSEEIHT) in Toulouse.

Sylvain Rodhain has 13 years of experience in embedded systems engineering, 8 years in the automotive industry at Viveris, Renault and Bosch. He works as a product application expert at Silicon Mobility, focusing on advanced product development for HEV/EV. Sylvain holds a MSc in Engineering from Centrale-Supélec Paris and a MSc in Computer Science, Autonomous Systems from KTH Sweden.

Farid Tahiri has 16 years of experience in embedded system engineering in the automotive industry and in particular at PSA Peugeot Citroën. As a principal product application expert at Silicon Mobility, he drives advanced product development for HEV/EV and support customers in integrating OLEA technologies. Farid hold a Master of Engineering (MEng), Embedded electronics from Polytech Orléans.