R3-PowerUP – the Driver for key European BCD Technologies Development focused on Smart Power and Power Discretes ICs

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ABSTRACT

Numerous, growing number of power electronic applications operate below 1kV. The "*300mm Pilot Line for Smart Power and Power Discretes*" ECSEL project [1] (acronym *R3-PowerUP*) is focused on volume up-scaling of a set of 90nm and 110nm BCD technologies operated by STMicroelectronics. High volume FABs capable to produce relatively cheap power electronic components are necessary to lower power electronics hardware cost. R3-PowerUp project supports technology migration from 200mm diameter substrates size used in existing BCD technologies to 300mm wafers to be processed in European pilot line facility oriented on Smart Power IC fabrication [2]. This paper focuses on power electronics hardware solutions applicable for brushless, direct current (BLDC) motors driver development pursued by the authors' team and R3-PowerUP project partners. Available BLDC driving modes have been presented. Hardware implementation scenarios available for fully integrated and for hybrid solutions are also discussed.

Keywords: Power electronics, BLDC Driver, BCD technology, brushless motor, UAV demo, R3PowerUP, ECSEL, Łukasiewicz Research Network in Poland.

1. R&D TRANSFORMATION CONTEXT IN POLAND

ITE [3] is a major Polish R&D Centre in the field of semiconductor electronics and physics research with a focus on development of innovative micro and nano-technologies and systems. Since 1.04.2019 ITE is the member of the Łukasiewicz Research Network [4] in Poland. The network is focused to conduct critical research and commercialize research results essential for national and international economy. The network joins 38 national research institutes located in 11 cities in Poland, employing around 8,000 employees. The creation of the Łukasiewicz Research Network is intended to achieve and profit "*economies of scale*" and enable the creation of comprehensive research services for entrepreneurs based on their shared potential. The Łukasiewicz Research Network will be an effective technological and intellectual background of public administration, but above all a real bridge between science and the economy. Its creation will positively affect the activity of micro, medium and small enterprises, which gaining simplified and more effective access to the results of scientific research and know-how, enabling them for more effective development.

2. R3-POWERUP PROJECT

Growing number of power electronic applications needs high volume FABs capable to produce relatively cheap power electronic components. One can identify power-electronics market demand in area of power management and power supply. White goods such as cookers, vacuum cleaners, washing machines also incorporate power electronic controllers and drivers. Computer peripherals (HDD, printers, fans, optic-readers), home and building automation for lighting, climate (HVAC), entertainment, security and appliances form another field of power electronics application. The set of 90nm and 110nm BCD technologies by STMicroelectronics, the clue of the R3-PowerUP project, have been selected for migration from 200mm to 300mm substrates expected to be run on the European pilot line facility for Smart Power technology in Agrate (Italy). High volume scaled up technology is expected to lower chip fabrication costs. The R3-PowerUP project joins 35 partners from 14 countries. There are two partners from Poland: Instytut Technologii Elektronowej (research institute) and Automatix (SME). The overarching goal of the project is to enable the largest European industrial base to keep the leadership on Smart Power technology and the related product platforms. It positions itself mainly towards the higher technology readiness levels mainly TRL5 – TRL8. Efficient design and optimization of Intelligent Power Modules (IPM) for various application fields are addressed by 10 test-vehicle designs (technology demonstrators) to be pre-validated at 200mm substrates and selectively adopted for qualification on the 300mm wafers in the European FAB line. The migration to 300mm wafer size shall involve both: power discrete and advanced smart power, logic and PCM (non-volatile memories). It is highly innovative feature for power semiconductor IC electronics.

Power electronics hardware and software solutions development of a driver (the controller with electronic commutator) for brushless direct current (BLDC) motors are pursued by the authors' team and R3-PowerUP project partners. Various BLDC control modes are available for implementation to achieve operation in controlled power or torque modes assuring precise rotation speed control. Available BLDC driving modes have been presented in details along with hardware implementation scenarios available for integrated and for hybrid solutions. Preliminary applications and electro-mechanical parameters are discussed.

3. BLDC DRIVE CONTROLLER

BLDC's are electronically commutated, synchronous DC motors. The permanent magnet of the BLDC is rotor-attached, so the coils are outside. There is no need to supply rotor it with current, so it is purely the brushless structure. On the one hand, BLDC motors are more difficult to drive than brushed motors. On the other hand significant profits of BLDC drives open new application areas. The most significant advantages over the brushed drives are reduced dimensions for comparable mechanical performance, reduced price, improved power efficiency, electrical performance, lower acoustic noise and higher durability, electronically controlled rotation speed, power, torque, good power to weight ratio and high mechanical reliability. It makes BLDCs more and more useful and popular. Design and technology used to develop the electronic controller for BLDC drive remain the technical challenge. Real time adaptive control algorithm, BLDC state feedback to the controller and operation mode switching are a bit challenging.

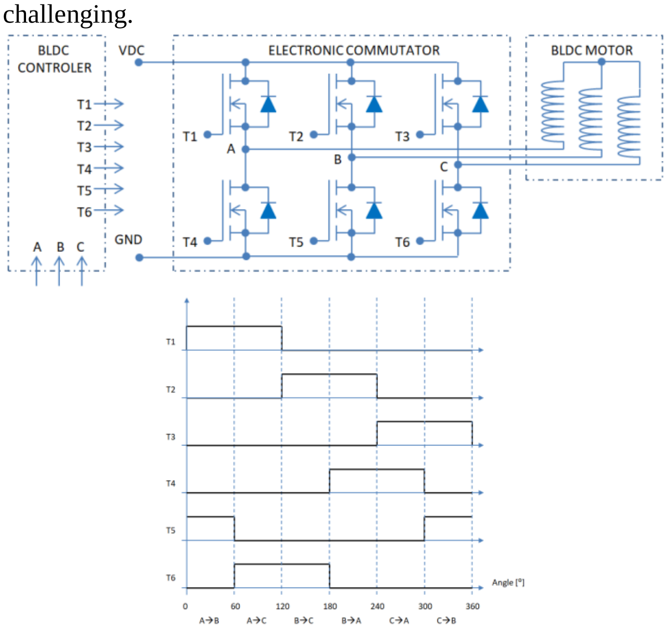

Figure 1: The general diagram and driving phases of the BLDC driver and driving signals for 3-phase BLDC control module (controller, commutator, drive).

There are six signals and six respective transistors for three-phase BLDC controller forming an electronic commutator. As one can observe there are no phase overlaps for transistors T1-T2-T3 and T4-T5-T6 timing respectively (Fig. 1). Three-phase BLDC drive with respective of poles uses three-phase driver uses 6 independently driven MOS or bipolar power transistors. Each one of the switching transistors is enabled for 120º.

BLDC drive controllers use microprocessor driven pulse power supply solutions like IGBT / HEMT / PowerMOSFET transistors fabricated in SiC, GaN or BCD technology variants. The dedicated BLDC controller discussed here produces phased AC electric signals driving phase transistors grouped for three-phase BLDC drive signal. Number of drive poles affects rotation speed and can be object of speed control switching.

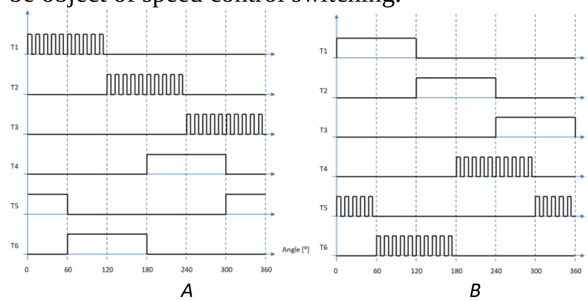

Figure 2: Asymmetric (T1/T4, T2/T5, T3/T6) 50% PWM phase regulation schemes for three-phase BLCD drive controller.

There are various multiple-phase BLDC controller configurations in practice. There are several phase control algorithms applicable for upper (Fig. 2A), lower (Fig. 2B) and complementary (Fig. 3) switching transistor phase driving schemes. The BLDC driver switching transistors T1-T5/T6, T2-T6/T4 and T3-T4/T5 are switched every 60º with phase overlaps respectively. General timing of phase switching algorithm, A, B and C PWM signals by T1-T6 gate drivers and supply voltage of phased signal (signals A, B and C) imposed to the stator coils determine the BLDC rotation parameters. Asymmetric PWM driver strategy on switching transistors (Fig. 2) drawback is unbalanced load and exploitation conditions of transistors T1, T2, T3 vs. T4, T5 and T6. The better concept is the balanced drive solution (Fig. 3) with symmetric PWM = 50% signals for T1/T4, T2/T5 and T3/T6 respectively.

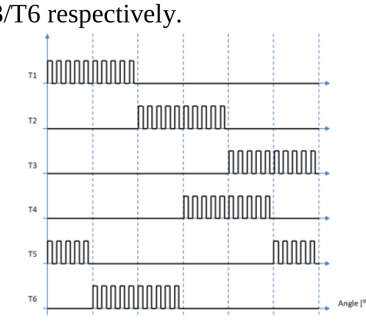

Figure 3: Balanced (T1/T4, T2/T5, T3/T6) 50% PWM phase regulation schemes for three-phase BLCD drive controller

Various types of BLDC drive state feedback are available: static sensing by rotor position sensors like Hall sensors, photodiodes or dynamic sensing of rotation like back electromotive force (back EMF) measured by fast ADC converter or conditioned by a simple comparator integrated with a controller and processed by microprocessor according the control algorithm implemented. Real time drive feedback is necessary on drive starting phase and working stage. For correct engine operation during start-up, it is necessary to know the position of the rotor dependent on number of phases and poles. For 3-phase 2-pole the desired accuracy of the configuration is 60 deg. It is determined by pre-positioning of the rotor, by position sensors or by determination of the position based on a series of current pulses used in sensorless BLDC systems. On the starting phase, the initial positioning of the rotor is the most common practice in case of sensorless BLDC systems.

It consists in sequential switching on all phases of the winding for a specified time. With no detection of the initial position, the rotor movement can be clockwise or counterclockwise, which is not always acceptable.

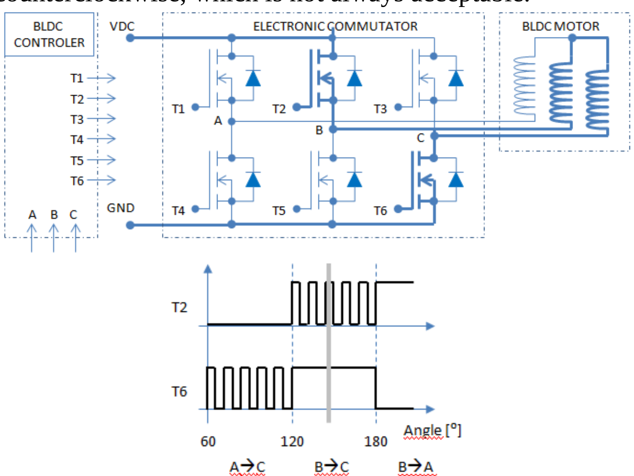

Figure 4: The BLDC driver diagram and two driving phases on transistors T2 and T6 for 3-phase BLDC drive (controller, commutator, drive). T1, T3, T4, T5 transistors turned-off. Current path in bold. Coil "A" winding available for back-EMF detection. T2 phase ON for 50% PWM.

It is necessary to control the supply current when determining the position of the rotor. Due to steady state of the BLDC in the beginning of starting phase, (no initial rotation) short-circuit occurs on coils' windings. The BLDC drive starts up with no control of the rotor position by successive switching on driving transistors (T1-T6 bridge valves), forcing subsequent magnetic responses of the stator magnetic field vector: when the stator and rotor streams added – magnetic circuit saturates. When stator and rotor streams subtract – the magnetic circuit is on linear part. Finally, the current response to voltage pulses varies at different rotor positions. Highest currents appear if the rotor position corresponds to the nearest stator field vector subsequently processed by the control unit.

The variable mechanic load of the BLDC drive requires real time feedback to the BLDC controller on rotor status. The real time positioning detection is necessary to keep rotation synchronism, control rotation speed, power and torque. Closed loop (feedback) on actual rotor position is necessary to keep the BLDC drive in state of BLDC rotation and rotor position synchronic with driving signals regardless the rotation speed or variable load. According the BLDC controller configuration constant power / speed / torque modes are available. Stator currents amplitude, phase and frequency control is sensitive to rotor flux by current monitoring and speed deviation / position / rotor phase sensing. There are various hardware solutions available for rotor state monitoring like simple optical encoders, Hall sensors, current / voltage sensors like voltage monitoring of the central point of stator 3-phase coils (if available), comparators and by software algorithms challenging from high data processing resources necessary for high-speed solutions. Driving phases of switching-transistors chop adaptively.

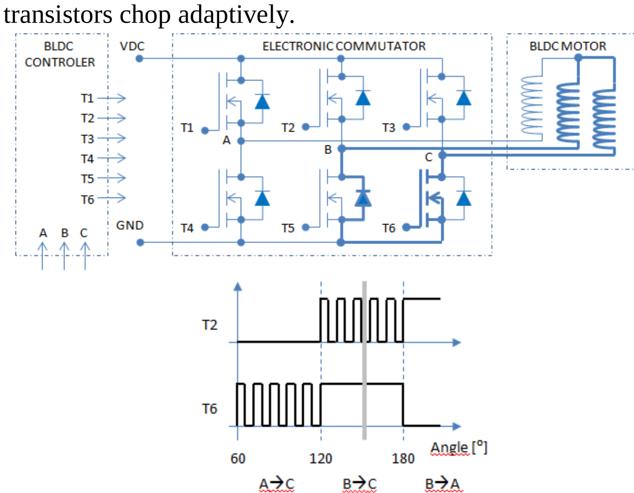

Figure 5: The BLDC driver diagram and two driving phases on transistors T2 and T6 for 3-phase BLDC drive (controller, commutator, drive). T1, T3, T4, T5 transistors turned-off. Coil "A" winding available for back-EMF detection. T2 phase OFF for 50% PWM. Current loop closes by T5 parallel diode. Current path in bold.

Current path for sample T2-T6 driving phase between serial coils B and C for the basic case of 50% PWM driving phase switching closes through T2 and T6 (Fig.4).

Current path for subsequent T2 signal switching-off results in T5 transistor only to remain tuned-on. In such a case the coil winding "A" remain (Fig. 4 and Fig. 5) available for back-EMF detection, whereas the current loop closes through T5 parallel diode (Fig. 5). The pulse width modulation (PWM) control is applied for driving phases for precise torque regulation and power control (Fig. 6 PWM=25%) and can be adapted for any scheme of phase regulation. Varying BLDC mechanical load (typical for real BLDC applications) results in an extended, real time PWM regulation. PWM control is necessary to control rotation speed. Therefore, the rotor positioning system is necessary to correct real-time rotation phase shifts that cannot let the drive to loose of rotation synchronism leading the drive definitely to stop. The PWM phase regulation leads the controller to regulate BLDC torque and power. There are several implementations of the feedback loop. Hall sensors application covers the rotation speed range from the rotor stopped. It is simplest but most prone to failures and EM interferences. Optical methods require additional piece of detection hardware. Pure electric methods like electromotive force detection (back-EMF) are the most reliable but due to fundamental physics applicable over some threshold rotation speed of the about 10% of the rated speed.

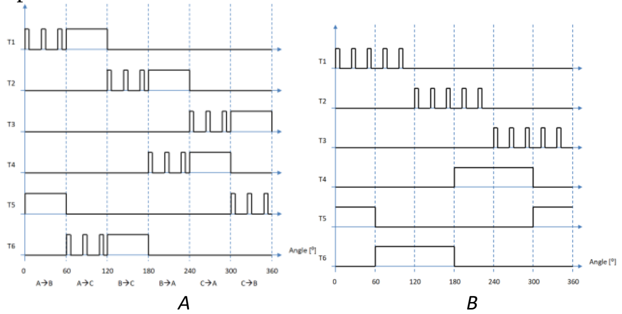

Figure 6: The 25% PWM phase-signal regulation schemes for three-phase BLDC drive controller in balanced and unbalanced driving strategies..

4. THE CURRENT STATUS

In frame of the R3-PowerUP project ITE steps through the design, verification and testing of the BLDC driver in the BCD9 technology by STMicroelectronics. Current research activities by the ITE [5] lead to the full module integration scheme (Fig. 7a) of the driver with control electronics. Such an integration scheme would be beneficial for limited weight, volume, high reliability applications if the chip price would not be the dominating factor.

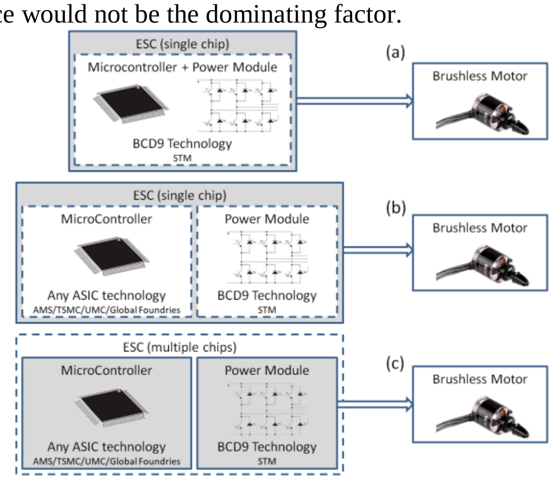

Figure 7: Available BLDC controller partitioning setups: a) full integration, single chip; b) partial split, heterogeneous integration; c) total split, two and more chips assembled on PCB.

The development strategy consists on application of discrete elements as presented on Fig. 7c. Option depicted on Fig. 7b will be feasible if separation mechanisms available will not satisfy control module protection requirements. The most promising and target solution should implement Fig. 7a strategy. Current activities are focused on reprogrammable solution with flexibility of algorithm testing development before the fully integrated design will become technically available. The design staff implements and develops the BLDC control algorithm running on D32PRO microcontroller IP owned by ITE, synthesized on FPGA assisted by external application elements (buffers, transoptors, protection diodes etc.).

5. NEXT STEPS

The estimation is that fully integrated solution incorporating D32PRO microcontroller assisted by application elements and programming interface the IC module should require not less than 40pins. Available current density and optional need for external elements can slightly change this value. Preliminary modeling and simulation activities have been performed using TCAD, CoventorWare and Comsol to test voltage stress aware exploitation along preliminary estimations for power dissipation. Multidomain, thermo-electro-mechanical modelling are scheduled along with future IC design tasks.

6. CONCLUSIONS

The interest in drives with brushless DC motors is constantly growing. In the case of engines equipped with position sensors, the engine control system is simple, reliable and cheap. Sensorless drives in comparison with drives equipped with sensors advantage is higher reliability. The relative disadvantage of such solutions is higher complexity of the control system and obligatory start-up procedure – not important in case of fully integrated driver solution with BCD technology operated by STMicroelectronics. The BLDC driver development aim is mainly to participation in broad BCD9 technology validation after up-scaling to 300mm substrate wafers.

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