RISC-V Microcontroller MD6605 for Power Electronics Control

Takanaga Yamazaki* Hitomi Shishido**

Abstract

Sanken Electric has developed the microcontroller MD6605 for advanced power electronics control systems such as power supplies and motors. MD6605 is built on a cutting-edge 22nm ultra-low-leakage process and incorporates a RISC-V CPU core along with non-volatile ReRAM memory. In addition to the RISC-V CPU core, MD6605 features a heterogeneous multi-core architecture consisting of a DSP for digital filter computation and an EPU (Event Processing Unit) capable of high-speed task switching, enabling high efficiency and functionality in power electronics control systems. Sanken Electric plans to actively deploy products utilizing MD6605 for various power electronics control applications.

1. Introduction

In recent years, the promotion of GX (Green Transformation) initiatives aimed at achieving a decarbonized society has driven increasingly stringent requirements for energy-saving performance in electronic devices. In particular, data centers, which are expanding due to the proliferation of generative AI, consume large amounts of electricity and demand significant improvements in power delivery efficiency.

Moreover, power supply systems used in widely adopted consumer electronics and industrial equipment are also subject to ongoing efficiency improvements. Recent AI processors and high-performance SoCs (System on a Chip), which utilize ultra-fine process technologies and operate at higher clock frequencies, require low-voltage and high-current power supplies under demanding conditions, necessitating high-precision power control.

To address these challenges, Sanken Electric has long pursued digital control methods for power supplies and has developed the advanced microcontroller MD6605 to meet increasingly stringent requirements. MD6605 is not only suitable for power supply control but also for brushless DC (BLDC) motor control used in home appliances and industrial equipment. It contributes to improved efficiency and offers automatic parameter adjustment functions to simplify development.

2. Digital Power Control and Its Advantages

Traditionally, power supplies have been controlled using analog methods, as shown in Figure 1. These methods are well-established and can be implemented with relatively simple hardware. However, analog control using resistors and capacitors for linear phase compensation has limitations in parameter adjustment range, resulting in fixed converter topologies. Efficiency improvements through optimal control require complex hardware, and noise countermeasures rely solely on hardware, necessitating many additional components. Communication with external systems and implementation of intelligent functions are also difficult. In high-output power supplies, reducing losses across the full load range is challenging, often requiring large heat sinks and increasing system costs.

* Engineering Development Headquarters, Power Device Development Division, System Development Department

** Engineering Development Headquarters, Power Device Development Division, System Development Department, Digital Development Section

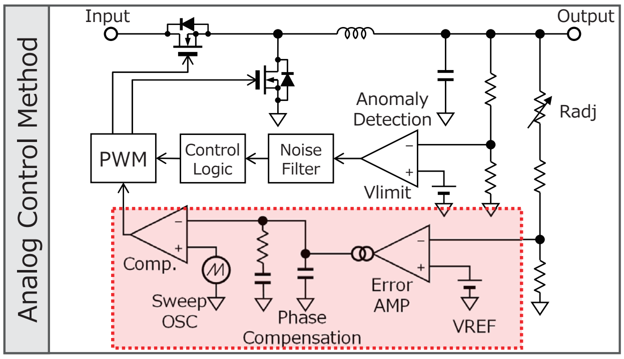

Figure 1. Example of Analog Control Method for a Power Supply (Buck Converter)

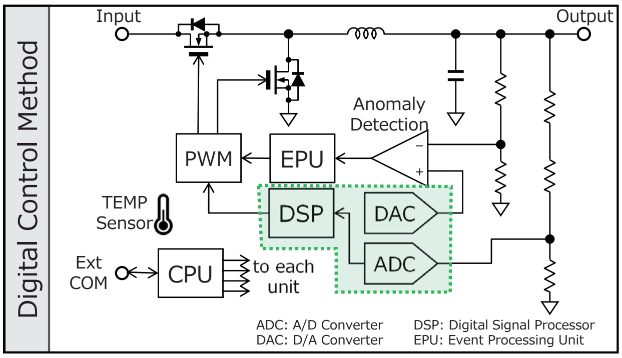

Figure 2. Example of Digital Control Method for a Power Supply (Buck Converter)

Figure 2 illustrates a digitally controlled power supply. Digital control enables flexible linear and nonlinear control through numerical computation, which is not possible with analog methods. Although digital control requires more hardware, such as DSPs (Digital Signal Processors), it offers numerous advantages:

- Capable of supporting any power converter topologies
- High-precision and fast response through advanced control algorithms
- High efficiency through optimized control tailored to load conditions and other operating factors
- Flexible noise countermeasures via software
- Implementation of communication and intelligent functions
- Reduction of heat sinks and noise countermeasure components due to improved efficiency
- Lower system costs, especially in high-output, high-precision power supplies

As a result, digital control is widely adopted in high-output power supplies for server centers, high-end AV equipment, and low-voltage, high-current power supplies for high-performance AI processors.

The following sections detail specific advantages of digital control.

(1) Compatibility with Various Converter Topologies

Digital control is primarily software-based, enabling adaptation to various converter topologies, such as the buck converter in Figure 2 and other types shown in Figure 3, without requiring any changes to the controller hardware.

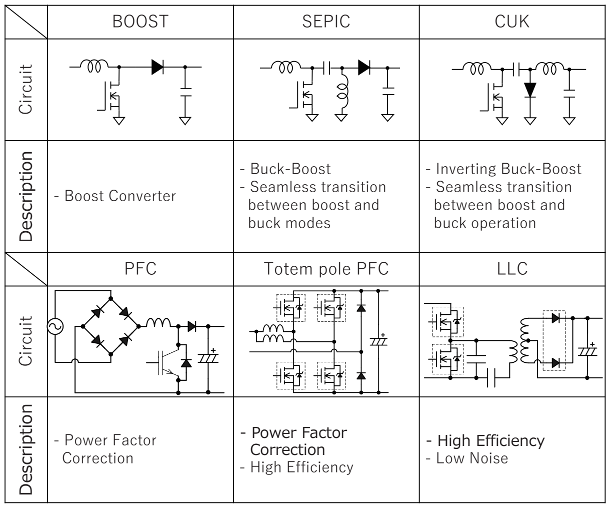

Figure 3. Various Power Converter Topologies Supported by Digital Power Supplies

(2) High-Precision Output Voltage

By detecting ambient temperature in real time using temperature sensors and applying compensation, power supplies with minimal temperature variation characteristics, as shown in Figure 4, can be achieved.

(3) Efficiency Improvement Across Full Load Range

Power supplies typically exhibit reduced efficiency under light-load conditions. Digital control enables fine-tuned optimal control based on load conditions, improving efficiency across the entire load range. For example, the switching frequency can be reduced under light loads. Figure 5 shows an example of efficiency in a digitally controlled high-efficiency DC-DC intermediate bus converter.

(4) Implementation of Advanced Modern Control

Figure 6 shows a block diagram of PID control (classical control), commonly used in analog systems. It performs feedback control to match the output voltage with the target value. However, in high-power systems with large load fluctuations and high precision requirements, this method struggles to meet targets.

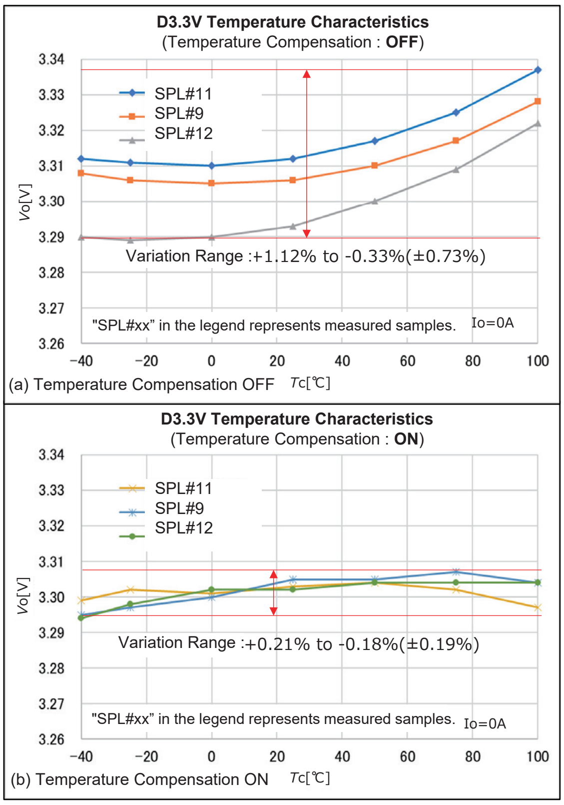

Figure 4. Effect of Temperature Compensation by Digital Control

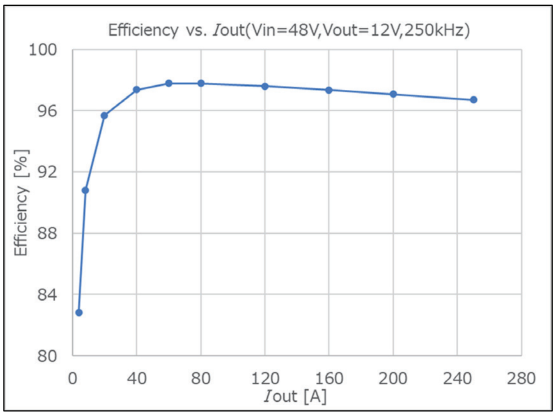

Figure 5. Efficiency of a High-Performance DC-DC Power Supply with Digital Control

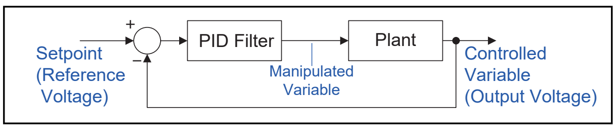

Figure 6. Typical PID Control (Classical Control)

Figure 7 presents an approximate two-degree-of-freedom control (modern control) method that adds a disturbance estimate to the target value to cancel out disturbances. This method requires numerical computation and can only be implemented through digital control.

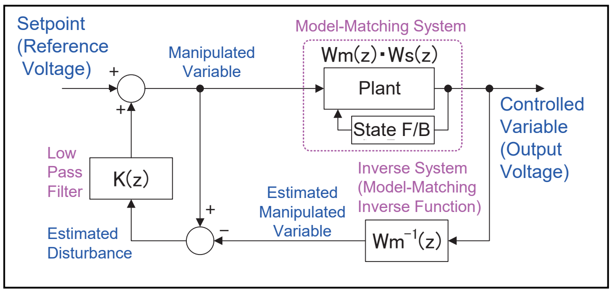

Figure 7. Approximate Two-Degree-of-Freedom Control (Modern Control)

Figure 8 demonstrates the effectiveness of two-degree-of-freedom control, showing simultaneous improvement in target response and disturbance rejection. This method is effective for controlling power supplies for large-scale AI processors requiring low voltage (0.5V–0.9V), high precision (±20mV), and high current (100A or more).

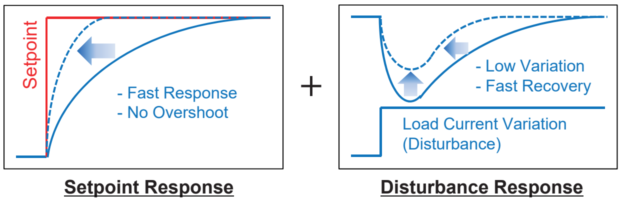

Figure 8. Effectiveness of Approximate Two-Degree-of-Freedom Control

(5) Fault Detection and Prediction

Digital control enables early detection of signs of power supply abnormalities.

- FFT Processing: Output voltage waveforms sampled via A/D converters are analyzed using FFT to detect changes in frequency components indicating potential faults.
- Edge AI: Real-time duty cycle command patterns are analyzed by edge AI using learned data to detect signs of abnormalities (Figure 9).

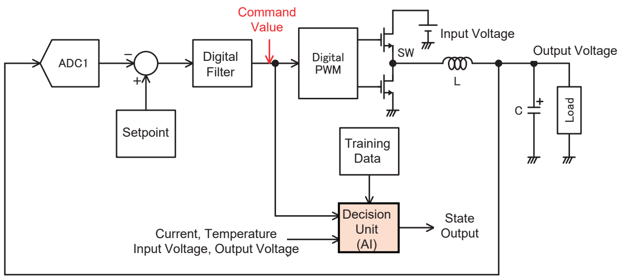

Figure 9. Fault Prediction Using Edge AI

(6) Realization of Intelligent Power Supplies

Digital control using microcontrollers (CPUs) allows complex system processing.

- Multi-output power sequencing: Arbitrary configuration of power-up and power-down sequences for multiple output rails
- Communication control: External communication enables voltage adjustment, ON/OFF control, current limit changes, and monitoring of power operation status (PMBUS, AVSBUS)
- Operation log management: Logging of power operation and fault detection status in non-volatile memory
- Self-diagnosis: Self-diagnosis of the microcontroller chip and the entire power system, with automatic shutdown or external reporting in case of abnormalities

3. Required Functions for Power Control Microcontrollers

To flexibly implement the digital control described above, a dedicated microcontroller is essential (Figure 10). Power control involves fast-responding electrical circuits, requiring much shorter control cycles than motor control. Therefore, high-speed DSPs and A/D converters are indispensable.

Additionally, higher PWM carrier frequencies require high-resolution PWM timers. Power systems also require rapid response to events such as overvoltage/overcurrent, zero-crossing of voltage/current, and fault detection. While simple operations can be handled by hardware, complex cases requiring flexibility cannot be efficiently managed through CPU interrupt processing due to latency. Thus, a specialized high-speed response processor is needed.

Consequently, power control microcontrollers must adopt a heterogeneous multi-core system comprising not only a CPU core but also DSP cores and high-speed response processors.

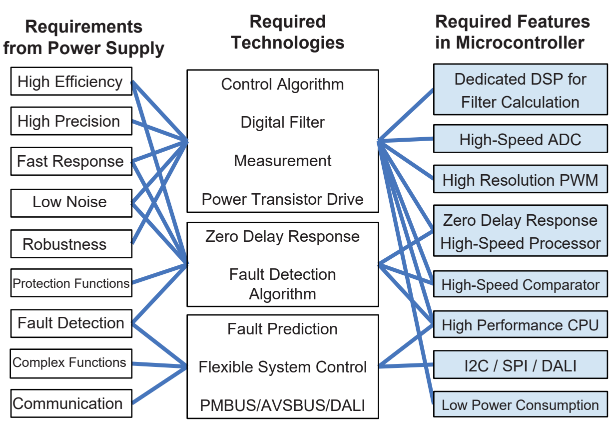

Figure 10. Required Functions for Power Control Microcontrollers

4. MD6605 Microcontroller for Power Electronics Control

Sanken Electric has developed MD6605 as the next-generation microcontroller for power supply control. Considering applications that require simultaneous control of motors and power supplies, MD6605 is equipped with functions necessary for motor control and is designed as a comprehensive microcontroller for power electronics control.

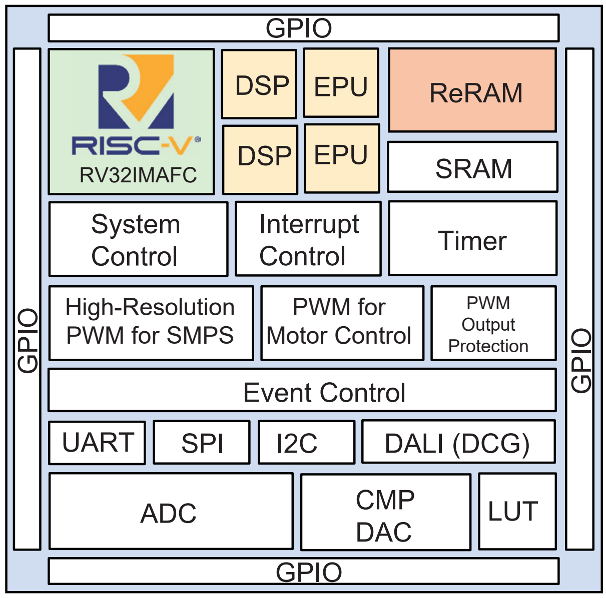

Figure 11. Block Diagram of MD6605

Table 1. Summary of MD6605 Specifications

Item	Specification
RISC-V CPU	ISA=RV32IMAFC, Debugger I/F=cJTAG
DSP	x2units Floating Point Operations
EPU	x2units Zero-Delay Task Switching
ROM	ReRAM(Resistive Memory) 128KB+ECC
RAM	8KB+ECC
Interrupt	x64inputs x16prioritys Dedicated Timer
System Control	OSC PLL Low-Power Functional-Safety
Timer	16bit Timer, Low Power Timer, WDT etc.
HPWM(SMPS)	High-Resolution PWM x8 outputs
MPWM(Motor)	Complementary PWM x6 outputs
Event Control	Event Network Switches & Event Handling
Serial COMM	UARTx3ch SPIx1ch I2Cx1ch DALI(DCG)
ADC	x3units 12bits 3MSPS x8inputs/unit
Comparator	x6units with 10bit DAC, Logical Operations
GPIO	Any Functions can be assigned in each Pin.
Operating Cond.	66.6MHz, VDD=3.3V (Single Voltage)
Process	TSMC 22nm ULL Process integrating ReRAM

Figure 11 shows the block diagram of MD6605, and Table 1 summarizes its specifications. The following sections describe the key features of MD6605.

5. Heterogeneous Multi-Core Architecture

As previously mentioned, MD6605 adopts a heterogeneous multi-core architecture that enables parallel processing using three types of cores with distinct characteristics to achieve high-efficiency and high-precision power electronics control.

(1) CPU (Central Processing Unit)

Responsible for system-wide control tasks such as communication, operation logging, fault diagnosis, and control during non-steady states. Due to increasing program complexity, a high-performance 32-bit CPU is required. For digital filter processing and motor vector control, floating-point arithmetic is preferred over fixed-point to avoid issues such as limited dynamic range, overflow, and underflow. Therefore, the CPU must support floating-point instructions.

(2) DSP (Digital Signal Processor)

Handles digital filter computations for power electronics control. As control sampling frequency increases, high-speed arithmetic processing becomes essential. The DSP must be capable of executing multiply-accumulate operations in a single cycle using both integer and floating-point arithmetic.

(3) EPU (Event Processing Unit)

Handles rapid responses to various events such as comparator inversion at zero-crossing of current or voltage, completion of A/D conversion, and timing events from PWM timers. These operations require high-speed responsiveness, which cannot be achieved with conventional CPU interrupt handling due to latency from register saving and restoring. Therefore, a dedicated processor capable of zero-latency task switching is necessary.

Figure 12 illustrates the heterogeneous multi-core configuration of MD6605. Since DSP and EPU frequently interact with A/D converters and PWM timers, they are connected via dedicated buses. With two DSP units and two EPU units, MD6605 performs parallel processing using a total of five cores including the CPU. This parallelism enhances system performance without increasing operating frequency.

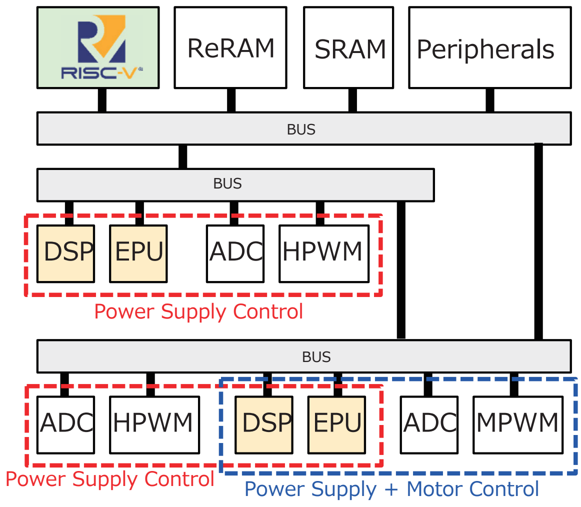

Figure 12. Configuration of MD6605 Heterogeneous Multi-Core Architecture

MD6605 operates at 66.6 MHz, but its heterogeneous architecture delivers floating-point performance of 400 MFLOPS and integer performance of 600 MOPS.

6. Integration of 32-bit RISC-V CPU Core

MD6605 employs the latest RISC-V*** architecture as its main CPU. RISC-V is an open instruction set architecture that allows anyone to design freely. Although commercial IP cores are available, Sanken Electric has developed its own implementation.

RISC-V features a simple instruction set, high processing performance, and efficient code density. Its surrounding ecosystem, including development environments, is rapidly maturing, and widespread adoption is anticipated.

Table 2 presents the specifications of the RISC-V CPU core integrated in MD6605.

Table 2. Specifications of the RISC-V CPU Core Integrated in MD6605

Item	Specification
Instruction Set Architecture	RV32IMAFC (Multiplication, Floating Point)
Pipeline	Integer:3 to 5stages Floating:5 to 6stages
Integer MUL	1cyc
Floating Point	Add/Sub/Mul/Mul&Add : 1cyc
Debugger	2-wire cJTAG x4 Hardware Breakpoints
Interrupt	x3 RISC-V standard x64 Expanded Inputs (x16 priorities)
Dhrystone 2.1	1.6 DMIPS/MHz
Coremark 1.0	3.30 Coremark/MHz
Development Environment	・MD Studio (based on Eclipse) ・3rd Party IDE (planning)

*** RISC-V is a registered trademark of RISC-V International and Mr. Krste Asanović.

7. Enhanced DSP and EPU Cores

MD6605 includes two units each of proprietary DSP and EPU cores. Table 3 summarizes their specifications.

Table 3. Specifications of DSP and EPU

Item	DSP	EPU
Purpose	High-speed computation independent of CPU	High-speed response to power control events
Number of cores	2 cores	2 cores
Number of threads	1 thread	2 threads
Instruction set	Fixed 16-bit	
Pipeline	3-5 stages	
Event response	Event wait, timer wait, event output (real-time application capability)	
Thread control	None	Zero-time thread switching
32-bit fixed-point arithmetic	Add/Sub/Mul/Mul&Add : 1cyc Div : 8 cyc (Newton-Raphson)	
32-bit floating-point arithmetic	Add/Sub/Mul/Mul&Add : 1cyc Div : 8 cyc (Newton-Raphson)	None
Debugger	Step execution / PC break / Data break / Software break	

The DSP is a processor equipped with 32-bit floating-point and fixed-point arithmetic units. Figure 13 shows its block diagram. The DSP can perform arithmetic, logic operations, and data transfers in response to events without CPU intervention. It supports single-cycle execution of addition, subtraction, multiplication, and multiply-accumulate operations for both floating-point and fixed-point data, enabling high-precision control such as phase compensation and vector control. Division using the Newton-Raphson method can be completed in eight cycles.

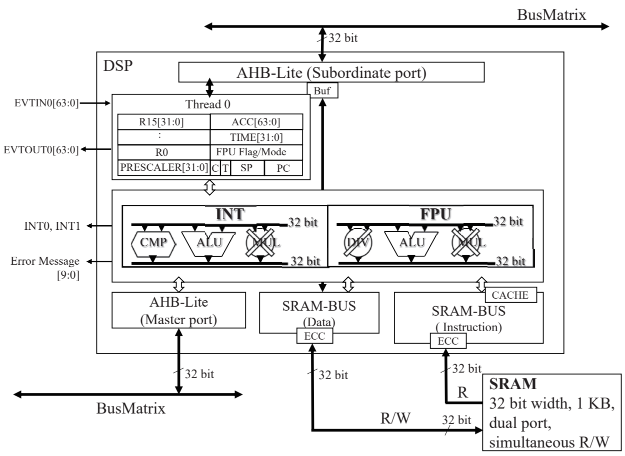

Figure 13. Block Diagram of DSP

The EPU differs from the DSP in terms of floating-point support and thread count. Each EPU has two threads and one fixed-point arithmetic unit. Each Thread has its own general-purpose registers, timer, and program counter. The EPU executes tasks assigned to threads sequentially based on priority.

In power electronics control, rapid response to numerous events is essential. Upon receiving an event signal, the EPU immediately executes the corresponding task.

During task switching, thread-specific resources such as registers are retained, eliminating the need for data saving and restoring. Unlike CPU interrupt handling, the EPU enables zero-latency task switching.

Figure 14 illustrates an example of zero-latency task switching using fixed priority (Thread 0 > Thread 1). When Thread 0 is inactive or waiting for an event, Thread 1 executes instructions. Upon receiving an event, Thread 0 immediately takes over execution.

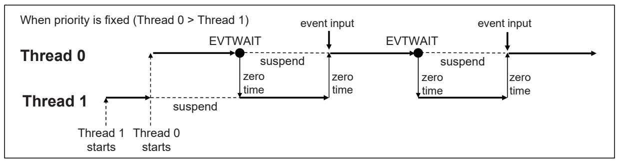

Figure 14. Zero-Latency Task Switching

A key feature of the EPU is its ability to control event input/output via instructions. MD6605 also supports internal event routing. In power electronics control, synchronized operation among modules is required, which is achieved through event signals exchanged between modules.

As shown in Figure 15, MD6605 handles various internal event signals such as A/D conversion completion and comparator inversion. Event routing is configurable via the Event Controller (EVC), enabling synchronized operation across modules.

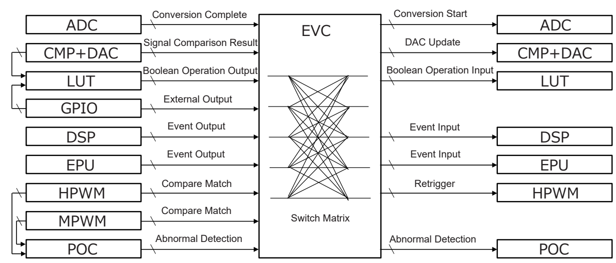

Figure 15. Event Connections in MD6605

8. Peripheral Functions and Their Features

This section describes the main peripheral functions integrated in MD6605.

(1) HPWM: High-Resolution PWM

HPWM is a high-resolution PWM designed for power supply control. Since power control requires short control cycles and high PWM carrier frequencies, high resolution is essential. The HPWM in MD6605 offers sub-nanosecond resolution, enabling fine adjustment of duty cycles. It features a 16-bit counter that determines the PWM period and duty cycle by comparing counter and reference values. Both up-count and up-down count modes are supported.

Additionally, HPWM includes a retrigger function that enables real-time changes to counter behavior in response to events such as overvoltage, overcurrent, or zero-crossing of voltage/current. This allows immediate execution of operations such as PWM stop, duty cut, or cycle skip operations.

(2) MPWM: PWM for Motor Control

MPWM is a PWM module for motor control. It features a 32-bit up-down counter and can generate six PWM signals (three complementary pairs). As shown in Figure 16, MPWM adopts a center-aligned mode, which offers high noise immunity and precise control for motor applications. The duty cycle is adjustable from 0% to 100%, and a dead-time function prevents simultaneous switching of paired transistors.

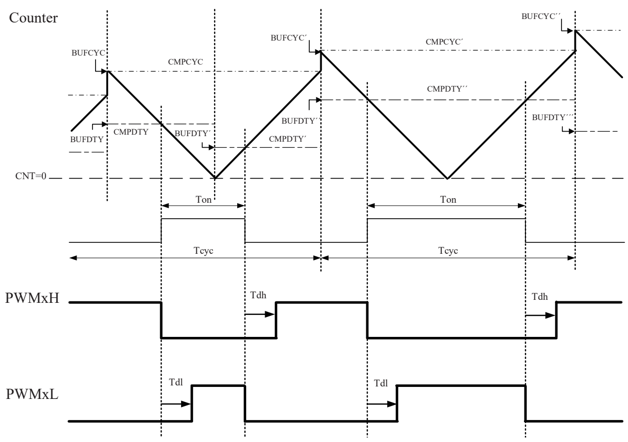

Figure 16. MPWM Counter and Output Waveforms

(3) POC (PWM Output Controller)

POC controls the output state of PWM terminals based on changes in comparator or LUT outputs, or events from the EVC. In abnormal power conditions, POC can override PWM control and immediately fix the output state, enabling rapid protection. MD6605 includes two POC units: POC0 for HPWM and POC1 for MPWM.

(4) A/D Converters

MD6605 integrates three 12-bit successive approximation A/D converters. In power control, they enable simultaneous control of three converters; in motor control, they allow concurrent sampling of three-phase currents. These converters are compact, fast, and energy-efficient. At a 66 MHz clock, the maximum conversion rate is 3 MSPS.

(5) LPTMR: Low-Power Timer

LPTMR is used to wake the microcontroller from low-power modes. In power electronics control, the system may enter low-power mode under specific conditions, such as idle states. MD6605 supports the following low-power modes and wake-up sources:

- Sleep Mode: Wake-up via interrupt
- Standby Mode: Wake-up via GPIO interrupt, comparator level interrupt, LPTMR, or DCG (DALI Control Gear)
    - Normal Standby: GPIO, comparator
    - LPTMR Standby: GPIO, comparator, LPTMR
    - DCG Standby: GPIO, comparator, DCG

LPTMR is suitable for periodic wake-up from low-power modes to execute scheduled tasks.

9. Adoption of TSMC 22nm Process and ReRAM

MD6605 is manufactured by TSMC using a cutting-edge 22nm ULL (Ultra Low Leak) process and incorporates ReRAM (Resistive RAM) as non-volatile memory.

The 22nm process was selected for the following reasons:

1. Reduced chip size and lower cost
2. Lower power consumption using ULL process and HVT (High Vt) transistors
3. As the final generation of planar processes, it ensures long-term supply stability

For non-volatile memory, ReRAM was chosen over FLASH due to implementation challenges in 22nm nodes. ReRAM has a simpler structure, built in the interconnect layers, and offers the following advantages:

- Fewer additional masks, resulting in lower cost
- Column-level overwrite without block erasure, improving usability
- Reliability (data retention) equal to or better than FLASH

Although MRAM (Magnetoresistive RAM) is another option for fine-process non-volatile memory, ReRAM is increasingly adopted in automotive and other applications due to its cost advantages.

10. Deployment in AC-DC Power IC Products

MD6605 is offered as an integrated one-package solution designed to enhance system integration. By combining high-voltage gate drivers and other key components, it significantly improves usability and efficiency. It will not be released as a standalone microcontroller.

Figure 17 shows the MD67xx product series for AC-DC power supply units (PSUs). MD67xx integrates MD6605 and supports simultaneous control of a totem-pole PFC and two-channel LLC resonant converters.

Key benefits of MD67xx in PSU applications include:

1. High efficiency (>98%) across all load ranges enabled by bridgeless totem-pole PFC, zero-cross switching, and load-adaptive control
2. Low THD achieved through high-speed optimal control of PFC
3. Fast transient response enabled by advanced current-mode control of LLC
4. Compact heat sinks and platforms made possible by the use of GaN/SiC devices
5. Enhanced functionality, including communication control, operation logging, and fault diagnosis

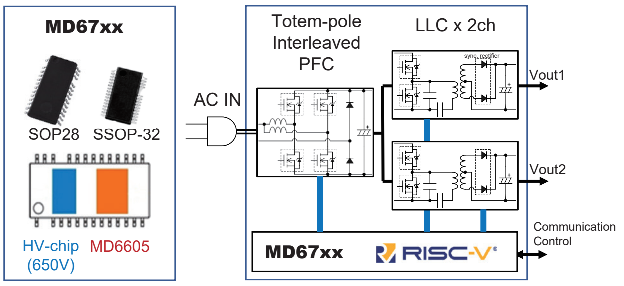

Figure 17. Application Example of MD6605 in PSUs

11. Deployment in DC-DC Power IC Products

Figure 18 shows the MD77xx product series designed for intermediate bus converters (IBC) in DC-DC power systems. MD770x integrates MD6605 and controls multiple high-efficiency hybrid converters in parallel.

Key benefits of MD77xx in IBC applications include:

1. High efficiency (>98%) even at large step-down ratios enabled by advanced hybrid converters
2. Output current exceeding 200A achieved through parallel multi-phase operation and precise current balancing
3. Flexible control of multiple converter types with a single MD770x (e.g., dual IBC or one IBC plus six POL channels)
4. Power management via PMBUS/AVBUS communication

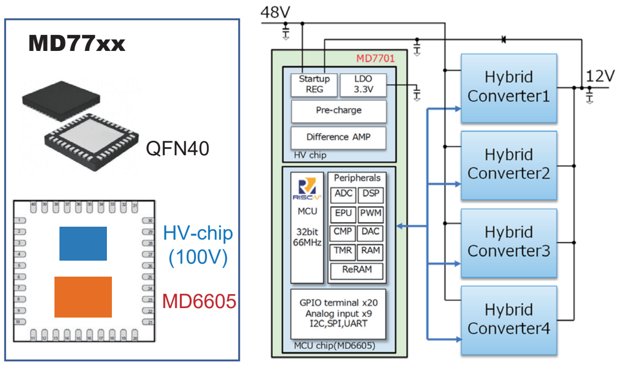

Figure 18. Application Example of MD6605 in IBCs

12. Deployment in Motor Control Products

Figure 19 illustrates the application of MD6605 in BLDC motor control for industrial and home appliance sectors. While conventional IPMs (Intelligent Power Modules) integrate power devices and gate drivers, the digital IPM with MD6605 adds advanced motor control capabilities such as speed and torque regulation.

Thanks to its high processing performance, MD6605 enables simultaneous motor and power control (e.g., PFC control).

Key features of the digital IPM with MD6605 include:

1. Sensorless vector control and auto self-alignment function for automatic motor parameter extraction and optimal control
2. Adjustable dv/dt of gate-drive waveforms for noise reduction
3. Reduced component count and PCB size through integrated motor and power control

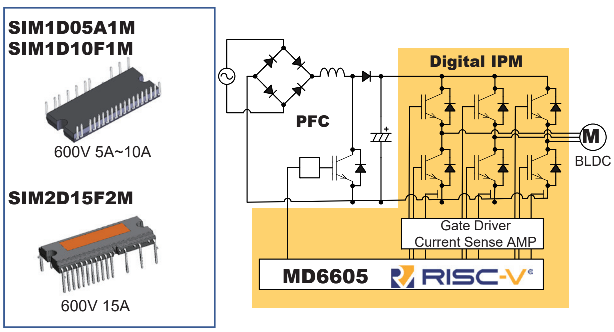

Figure 19. Application Example of MD6605 in Motor Control

4. GUI-based application for automatic motor parameter tuning, improving development efficiency
5. Intelligent features, including communication, fault detection, and fault prediction

13. Conclusion

Sanken Electric has developed the MD6605 microcontroller for advanced power electronics control systems, featuring a RISC-V CPU core and ReRAM non-volatile memory technology built on a 22nm ultra-low-leakage process. Its heterogeneous multi-core architecture, comprising CPU, DSP, and EPU cores, delivers exceptional processing performance.

Looking ahead, Sanken will continue to expand its lineup of high-efficiency IC products based on MD6605, contributing to GX (Green Transformation) initiatives aimed at achieving a decarbonized society.

References

1. *The RISC-V Instruction Set Manual Volume I: Unprivileged Architecture*, May 2025, RISC-V International.
2. *The RISC-V Instruction Set Manual Volume II: Privileged Architecture,* May 2025, RISC-V International.