RX Family

Digital Power Conversion (UPS (CCM Interleaved PFC, Chopper DC-DC Converter))

Summary

This application note uses a RX66T or RX26T group. It is intended to explain how to drive and control AC-DC converters, DC-DC converters, and DC-AC inverters for uninterruptible Power System (UPSs), and how to use motor control development support tool [RMW]*1.

These sample programs are only to be used as reference and Renesas Electronics Corporation does not guarantee the operations. Please use them after carrying out a thorough evaluation in a suitable environment.

Note   1: RMW is an abbreviation for Renesas Motor Workbench.

Operation check device

Operations of the sample programs have been checked by using the following device.
RX family RX66T Group (R5F566TEADFH)
RX family RX26T Group (R5F526TFDGFP)

It is also applicable to RX family that has the resources described in this application note or equivalent peripheral functions. (RX72T, RX24T, RX24U, RX660, etc)

Target sample program

The target sample programs of this application note are as follows.

· RX66T_P13178_UPS_CSP_RV100 (IDE: CS+)
· RX66T_P13178_UPS_E2S_RV100 (IDE: e^{2}studio)
· RX26T_P13178_UPS_CSP_RV100 (IDE: CS+)
· RX26T_P13178_UPS_E2S_RV100 (IDE: e^{2}studio)

Reference Materials

· RX66T Group User's Manual: Hardware (R01UH0749)
· RX26T Group User's Manual: Hardware (R01UH0979)
· Renesas Motor Workbench User's Manual (R21UZ0004)
· Digital Power Conversion (Totem Pole Interleaved PFC (AC-DC Converter)) (R01AN6877)
· Digital Power Conversion (LLC Resonant Converter (DC-DC Converter)) (R01AN7118)

Contents

RENESAS

1. Overview

This application note outlines the digital control power supply and explains how to control and implement uninterruptible power supplies (UPSs) as examples of driving and controlling digitally controlled power supply [1] using RX66T/RX26T group. It also explains how to use motor control development support tool [RMW].

Notes: 1. The digitally controlled power supply refers to AC-DC converters, DC-DC converters, and DC-AC inverters.

1.1 Development environment

Table 1 and Table 2 show the development environments for the software subject to this application note.

Table 1 Hardware development environment

Microcomputer	Evaluation Board (50Hz 100V 100W Power Board Kit [1])	
	Board name	Model
RX66T (R5F566TEADFH) OR RX26T (R5F526TFDGFP)	RX66T CPU Card OR RX26T CPU Card	P05701-C0-038 OR P05701-C0-068
	Base Board	P13178-C0-001
	AC-DC Board	P13178-C0-002
	DC-DC Board	P13178-C0-003
	DC-AC Board	P13178-C0-004

Table 2 Software development environment

Device	IDE Version	RX Smart Configurator [3]	Toolchain version [2]
RX66T	CS+: V8.07.00	Version 2.11.0	CC-RX: V3.04.00
	e^{2}studio:2022-01	e^{2}studio plug-in version	
RX26T	CS+:V8.10.00	Version 2.19.0	CC-RX: V3.05.00
	e^{2}studio:2023-10	e^{2}studio plug-in version	

Note 1: 50Hz 100V 100W power board kit is made by Desk Top Laboratories Inc. If you have any questions about the solution, please contact Desk Top Laboratories Inc.
2: If the same version as the toolchain (C compiler) specified in the project does not exist in the import destination, the toolchain is not selected and an error occurs. Check the toolchain selection status in the project settings screen.
Refer to FAQ 3000404 for the selection procedure.
(https://en-support.renesas.com/knowledgeBase/18398339)
3: This project does not use the generated code by this tool.

2. Digital control power supply overview

The digitally controlled power supply described in this application note refers to the switching power supply method (including AC-DC converter, DC-DC converter, and DC-AC inverter). Switching power supplies use system LSIs such as MCUs and switching device to smooth the input power supply and enable efficient output to match the load. The application of the harmonic current regulation system (IEC 61000-3-2 or in japan JIS C 61000-3-2) is mandatory for equipment using AC power supply, power factor correction circuit (PFC*1) is required to suppress the harmonic current. RX66T/RX26T is equipped function (PWM timer (MTU3d,GPTW) + FPU) for switching control (bridged system capable of handling large power supply) and PFC control, enabling control with 1MCU. 1MCU design eliminates the specialized components, thus reducing costs.

Notes:　1. PFCs are abbreviations of Power Factor Correction and are used in general equipment that uses AC power (industrial fields such as machine tools, consumer products represented by home appliances, etc.).

2.1　Outline of AC-DC converter circuit

AC-DC converter circuit can be broadly divided into the linear system and the switching system. The linear system uses a transformer for the AC input stage (a system in which the primary and secondary power supplies are completely separated and the current loop is closed by each), and is used for heavy-weight large-size AC adapters, etc. The switching method uses MCUs such as RX66T/RX26T and switching device and does not use a transformer for the input stage (a method in which the primary power supply and the secondary power supply are not separated and the current loop is common), and it is used for light-weight small-size AC adapters, etc. This application note uses a switching method. Figure 1 shows an example of the circuit configuration of the linear system, and Figure 2 shows the circuit configuration of the switching system.
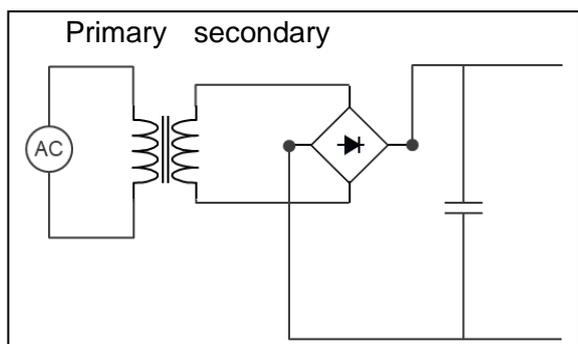
Figure 1 Linear circuit configuration example　　Figure 2　Switching circuit configuration example
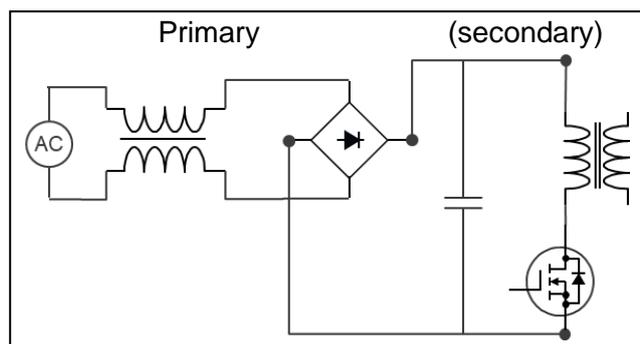
The linear system enables stable output with low noise, but when the potential difference is large, the consumption due to heat increases proportionally, resulting in poor efficiency. In addition, since a transformer that matches the maximum power supply load is inserted into the input stage, the weight and area are increased. The switching system has higher power supply efficiency than the linear system and can handle step-up, step-down, and step-up/step-down. However, as a disadvantage, noise suppression (LC filter, pass capacitor addition, etc.) is generally required. A comparison table between the linear system and the switching system is shown below.

Table 3 Comparison of switching system and linear system

	Linear system (Transformer system)	Switching system
Step-up	Impossible	Possible
Step-down	Possible	Possible
Step-up and Step-down	Impossible	Possible
Efficiency	Output ÷ Input	High (about 95%)
Noise	Small	Large
Number of parts	Few	Many
Cost	Low	High

2.1.1　Power factor correction circuit (PFC)

The power factor correction circuit used in AC-DC converters is a switching circuit to be added to the converter. This circuit eliminates the phase difference between voltage and current and makes the power factor of the power supply close to unity by making it sinusoidal. The reasons for requiring a power factor correction circuit are to reduce reactive power and to avoid harmonic current regulations. Harmonic current regulations are IEC61000-3-2 formulated by the International Electrotechnical Commission (in Japan, a JIS C 61000-3-2 of Japanese Industrial Standards formulated based on IEC) aimed at reducing harmonic currents generated by power supply circuits (switching power supplies) installed in equipment to below the regulatory limits. Failure to comply with this standard will cause harmonic currents to flow out to the commercial power supply side, resulting in problems such as damaging power transmission and distribution facilities (phase advance capacitors, etc.), and therefore must be applied to commercialization. Please confirm the specifications of each country for details.

■Cause of harmonic current generation

The cause of harmonic current generation in the switching power supply is generated by the smoothing capacitor located at the subsequent stage of the diode bridge. When the input AC voltage is lower than the terminal voltage of the smoothing capacitor, no current flows. When the input AC voltage rises and exceeds the terminal voltage, charging starts to the smoothing capacitor and current flows. As a result, the waveform of the input current is distorted with respect to the sine wave, resulting in harmonic currents. In addition, since a phase difference with the voltage occurs, the power factor deteriorates. Figure 3 shows the waveform image of voltage and current by the smoothing capacitor.
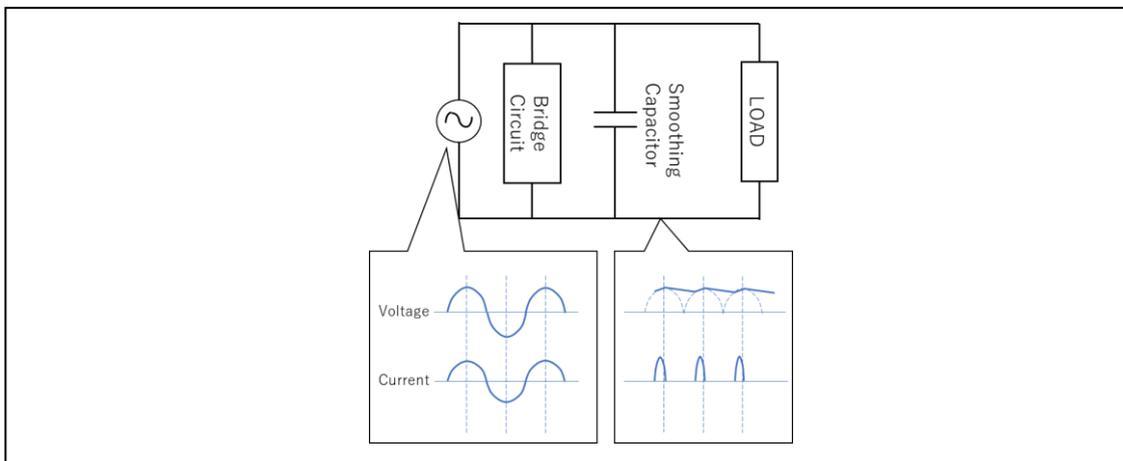
Figure 3 Waveform image of voltage current by smoothing capacitor

2.1.2　Type of power factor correction circuit (PFC)

There are various circuit methods to realize PFC, and broadly speaking, they are passive type, partial switch type, and active type. The passive type requires a large reactor and a capacitor, so it is used for a power supply with a relatively small capacity. The partial switch method is a method in which a switch is added to the reactor insertion section of the passive method, and current can be passed through the section where no current flows in the passive method. The active method is used for a relatively large capacity power supply, and the active method using an MCU or a dedicated IC is used in recent power supply boards. This document describes the active method. The active method has three switching modes and two configurations each. Table 4 lists the switching modes of the active method. The details of the configuration are shown in 2.1.4, and the overview of each switching mode is shown in 2.1.5 to 2.1.7.

Table 4 Active switching mode

Mode	Current continuous mode		Current discontinuous mode		Current critical mode	
Composition	Single	Interleaved	Single	Interleaved	Single	Interleaved
Symbol	CCM	ICCM	DCM	IDCM	CRM	ICRM
Output power	200W or more	400W or more	300W or less	600W or less	400W or less	1000W or less

2.1.3　Applications of various PFC circuits

Current discontinuous mode is used for relatively small power supplies (e.g. LED bulbs). The current critical mode is used for medium-class power supply equipment (e.g. office automation equipment). Current continuous mode is used for relatively large power supply equipment (e.g. air conditioners). Table 5 shows the magnitudes of output power according to PFC mode differences. The main PFCs used under the Harmonic Current Regulatory System (IEC 61000-3-2) are shown in Table 6.

Table 5 Output power images of various PFCs

Mode	Mode	Output power (w)															
		~10	30	50	100	200	300	400	500	600	700	800	900	1k	2k	3k	4k~
Current discontinuity Mode	Single	■	■	■	■	■	■										
	Interleaved				■	■	■	■	■	■							
Current criticality Mode	Single			■	■	■	■	■									
	Interleaved						■	■	■	■	■	■	■	■			
Current continuity Mode	Single					■	■	■	■	■	■	■	■	■	■		
	Interleaved						■	■	■	■	■	■	■	■	■	■	■

Table 6 Types of PFCs used for IEC61000-3-2 standards

Class	Applications	Main PFC Circuits
A	Balanced three-phase equipment (industrial motors, etc.)	Current continuity
	Power tools (stationary electric saws, etc.)	Current criticality, Current continuity
	Sound equipment (sound amplifiers, etc.)	Current criticality
	Independent phase control dimmer (e.g. chandelier)	Current discontinuity
	Vacuum cleaners (commercial vacuum cleaners, etc.)	Current continuity
	Professional lighting equipment for stage lighting and studio (e.g. spotlights)	Current discontinuity
	High-pressure washers (compressed pumps, etc.)	Current continuity
	Device not belonging to other classes	Current continuity, Current discontinuity, Current criticality
B	Hand-held power tool (e.g. grinder)	Current discontinuity
	Arc welders that are not for commercial use (e.g., welders for 100V power supply DIY)	Current continuity
C	Lighting equipment (inverter fluorescent lamps, etc.)	Current discontinuity
D	Refrigerators and freezers containing variable speed drives for control of compressor motors of 600 W or less	Current continuity
	TVs, PCs, PC monitors	Current discontinuity, Current criticality

RENESAS

2.1.4　Single and interleaved configurations

A single configuration consists of one switching circuit and an interleaved configuration consists of two or more switching circuits. In the single configuration, the fluctuation width of the inductor current increases and the switching noise increases. Since the interleaved configuration switches between the two switching circuits, the inductor current varies in T/2 time. Therefore, the inductor current ripple is reduced, the size of the input filter can be reduced, and the output can be increased. It is suitable for relatively large-capacity power supply applications. Figure 4 shows a comparison between a single configuration and an interleaved configuration.
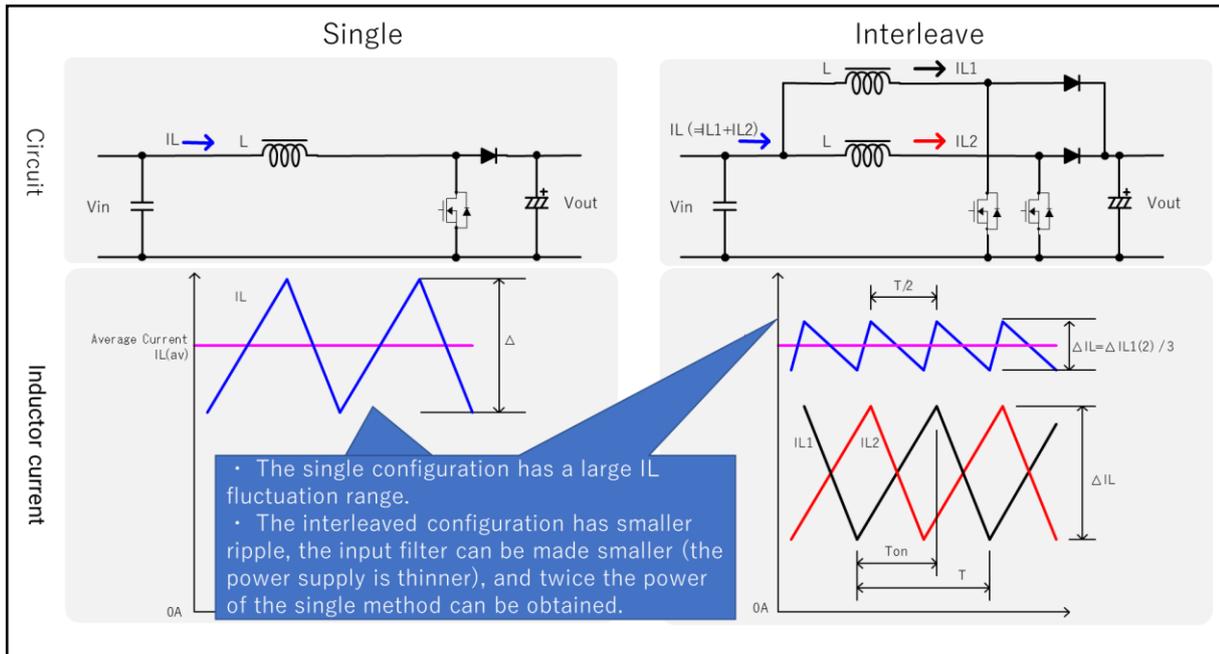
Figure 4 Differences between single and interleaved configurations

2.1.5   Active PFC current continuous mode

Current continuous mode is a mode in which current flows continuously to the reactor. The switching device is turned on before the reactor current becomes zero, so the reverse current of the diode is superimposed on the reactor current, resulting in a large on-loss of the switching device and a large switching noise. Since this mode has a relatively large output power, there are many opportunities to use this mode for power control, motor control, etc. The UPS in this application note adopts an interleaved configuration in current continuous mode. Table 7 shows the current continuous mode, Figure 5 shows the circuit configuration, and Figure 6 shows the reactor and diode current changes.

Table 7 Overview of current continuous mode

Mode	Current continuous mode	
Composition	Single	Interleaved
Symbol	CCM	ICCM
Inductor current	Inductor current does not turn 0A	
Inductor value	Small	
Ripple	Small	
Output power	200W or more	400W or more
Switching frequency	Fixed	
Control method	PWM control (Duty0% to 100%)	
Efficiency (switching loss)	Bad	Slightly worse
Noise	Large	Slightly larger
Main converters	Boost type	
Cost	Slightly higher	High
MCU calculation (difficulty)	Fair	Slightly higher
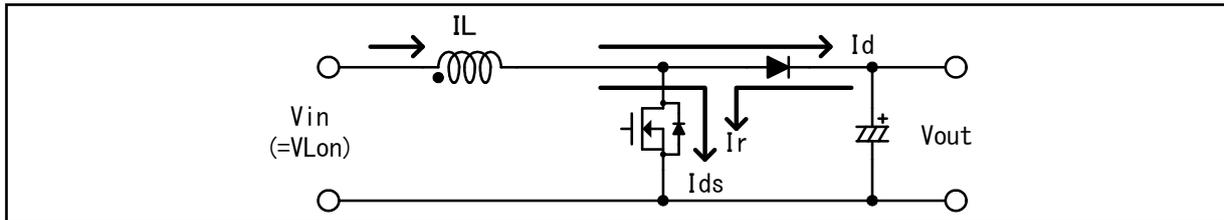
Figure 5 Circuit configuration in current continuous Mode
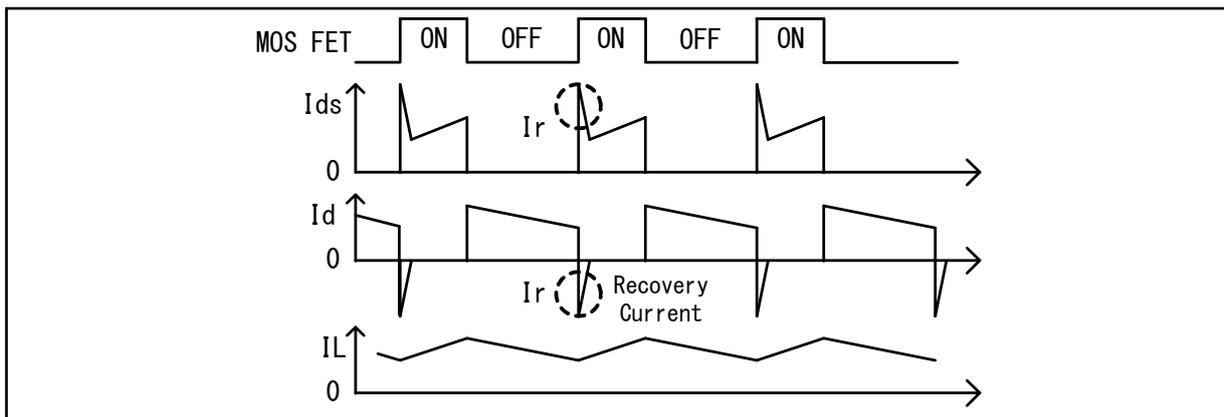
Figure 6 Current change of reactor and diode in current continuous mode

2.1.6　Active PFC current discontinuous mode

The current discontinuous mode has a period in which the reactor current becomes zero. Since the switching device is turned on when the reactor current is zero, there is no reverse current of the diode and the on-loss of the switching device is reduced. Switching noise is also reduced. In this mode, the peak current of the coil increases because the switching frequency is constant during the switching device on-time, resulting in poor efficiency. This mode is often used for applications where the output power is relatively small. The current discontinuous mode is outlined in Table 8, the circuit configuration is shown in Figure 7, and the current changes in the reactor and diode are shown in Figure 8.

Table 8 Overview of Current discontinuous mode

Mode	Current discontinuous mode	
Composition	Single	Interleaved
Symbol	DCM	IDCM
Inductor current	Duration in which inductor current becomes 0A occurs	
Inductor value	Large	
Ripple	Large	
Output power	300W or less	600W or less
Switching frequency	Fixed	
Control method	PWM output (fixed ON time)	
Efficiency (switching loss)	Fair	Slightly better
Noise	Fair	Slightly lower
Main converters	Inverted RCC (Ringing Choke Converter)	
Cost	Fair	Slightly higher
MCU calculation (difficulty)	Low	Fair
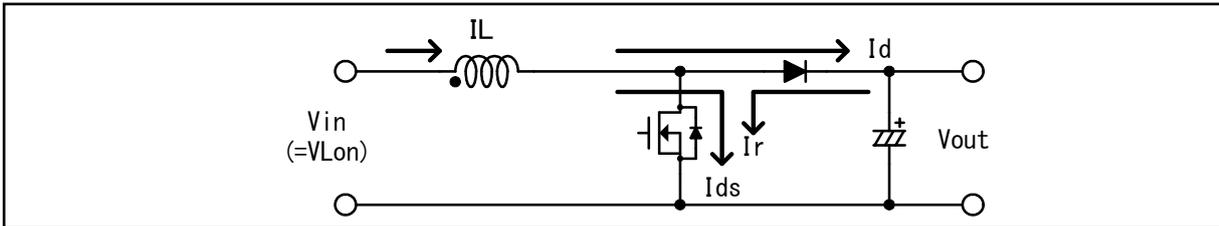
Figure 7 Circuit configuration in current discontinuous mode
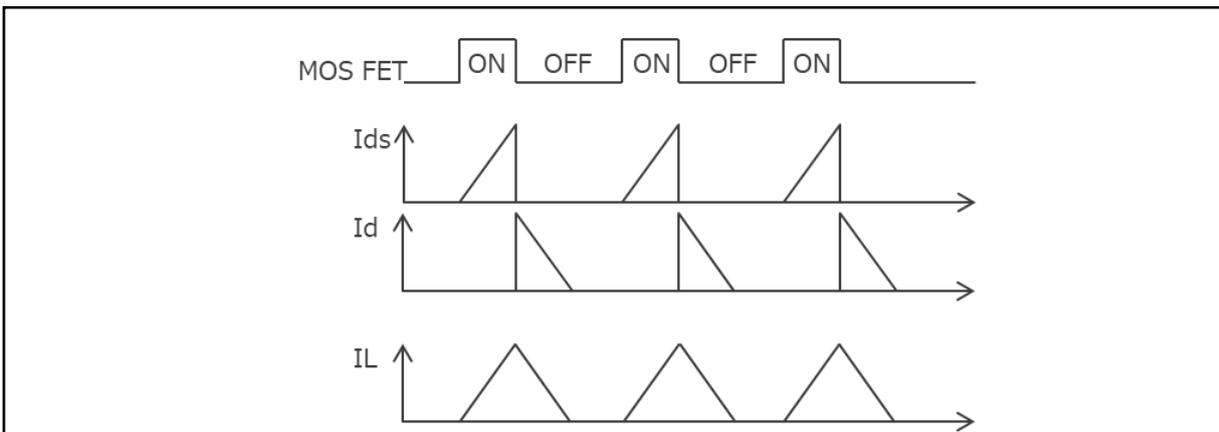
Figure 8 Current change of reactor and diode in current discontinuous mode

2.1.7   Active PFC current critical mode

The current critical mode monitors the point where the reactor current becomes zero and turns on the switching device. Since the switching device is turned on when the reactor current is zero, there is no reverse current of the diode and the on-loss of the switching device is reduced. Switching noise is also reduced. In this mode, the switching device's on-time is constant, but the switching frequency varies constantly depending on the input and output voltages. This mode is often used for medium-scale applications with output power. The overview of the current critical modes is shown in Table 9, the circuit configuration in Figure 9, and the current changes in the reactors and diodes in Figure 10.

Table 9 Overview of current critical mode

Mode	Current critical mode	
Composition	Single	Interleaved
Symbol	CRM	ICRM
Inductor current	Inductor current becomes 0A momentarily	
Inductor value	Large	
Ripple	Large	
Output power	400W or less	1000W or less
Switching frequency	Always change	
Control method	PWM output (fixed ON time)	
Efficiency (switching loss)	Slightly better	Good
Noise	Slightly lower	Low
Main converters	Boost type	
Cost	Slightly higher	High
MCU calculation (difficulty)	Slightly higher	High
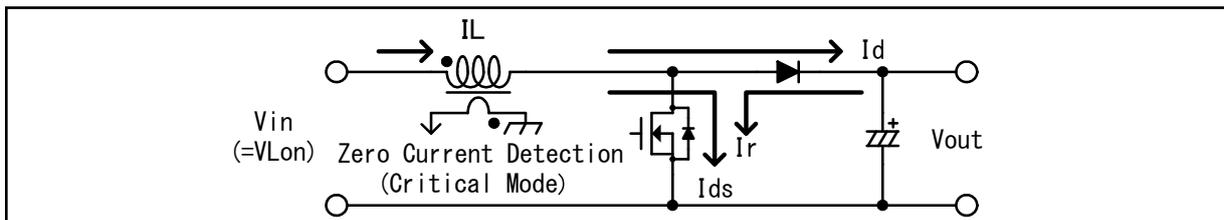
Figure 9 Circuit configuration in current critical mode
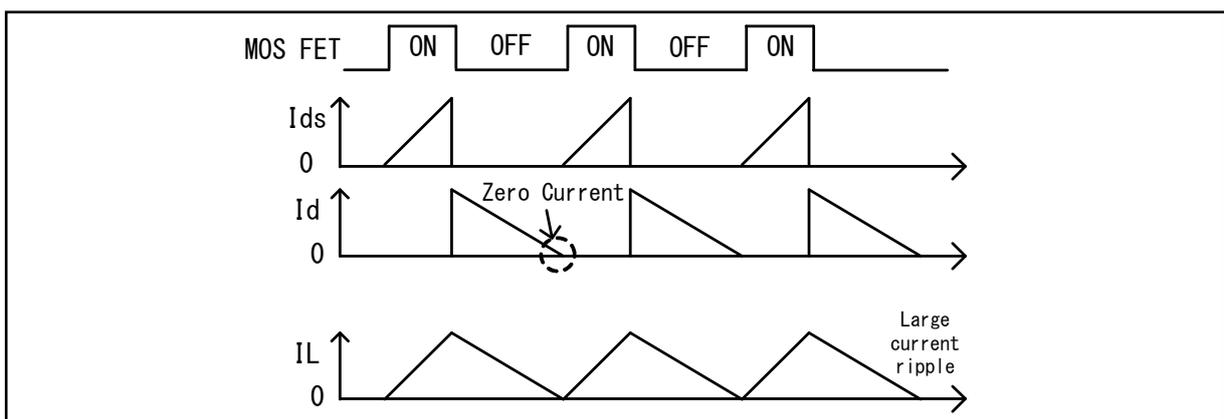
Figure 10 Current changes of reactor and diode in current critical mode

RENESAS

2.2 Outline of DC-DC converter circuit

DC-DC converters convert incoming DC power supplies (such as the output power supply of AC-DC converters) to DC power supplies with different voltages. DC-DC converter has a step-down converter in which the output voltage is lower than the input voltage and a step-up converter in which the output voltage is higher than the input voltage. In addition, there are isolation type, non-isolation type, and various circuit methods. This application note uses a non-isolation chopper circuit. Table 10 shows the rough classification.

Table 10 DC-DC converter rough classification

No	Mode	Main Voltage Conversion Methods (step-up/step-down)	Main Circuit Methods (isolation/ Non-isolation)
①	Forward	Step-down	Isolation
②	Flyback	Step-up/step-down	Isolation
③	Push-pull	Step-up/step-down	Isolation
④	Bridge	Step-up/step-down	Isolation/Non-isolation
⑤	Chopper	Step-up/step-down	Non- Isolation

2.2.1   DC-DC converter circuit system

DC-DC converters include step-up, step-down, step-up and step-down circuits, and various circuit methods. This application note is roughly classified into five types. The categories are shown in Table 11.

Table 11 Types of DC-DC converter circuit methods

Type	Description	Main applications	Advantages	Disadvantages
① Forward	It is a circuit system in which power is transmitted from the primary side to the secondary side by switching device on, and it can be used in a wide range of applications from small power output to large power output. This is an isolated circuit mainly used in the step-down. It has high power conversion efficiency, but noise countermeasures in the MHz band may be required. Refer to 0 for details of operation.	Step-down circuit	・Available from small output to large output ・Be stable in control	Excessive noise
② Flyback (Other Excitation Type)	It is a circuit system which stores electric power in an inductor by switching device on, and outputs electric power stored in an inductor by off, and it is used for the application of small power output. Though the input voltage range is wide, large peak current flows to switching devices and inductors. It used for step-up and step-down in isolation circuit. Refer to 2.2.3 for details of operation	Step-down circuit/ Step-up circuit	・Have fewer parts ・Wide input voltage range	Not suitable for large capacity output
③ Push-pull	A circuit system in which two transformers are driven alternately by two switching devices. Because of the high efficiency of transformer use, it is used for applications with large power output. Mainly It used for step-up and step-down in isolation circuit. Refer to 2.2.4 for details of operation.	Step-down circuit/ Step-up circuit	Available at high output	Magnetization of transformer must be carefully monitored.
④ Bridge	Switching devices with low withstand voltage can be used because the transformer applied voltage is half of the input voltage. Though the full bridge makes the circuit configuration and control more complicated than the half bridge, the power conversion efficiency is high. The operating principle is the same as that of the push-pull method, and it is used for the application of large power output. Mainly it used for step-up, step-down, step-up and step-down in isolation circuit. Refer to 2.2.5 for details of operation.	Step-down circuit/ Step-up circuit/ Step-up/down circuit	・Available at large output ・Be highly efficient	Be difficult to control
⑤ Chopper	No transformer is required for non-isolation circuit. There is a step-down chopper method which converts to Low-Voltage and a step-up chopper method which converts to High-Voltage. There is single drive, interleaved drive, current continuous, discontinuous, and critical modes. Refer to 2.1.2 Power Factor Correction Circuit (PFC) for details. The method used in this application note. In the case of AC power path, step-down operation is performed to charge the battery. In the case of the battery power path, boosting operation is performed for power supply from the battery (battery discharge). Refer to 2.2.6 for details of operation.	Step-down circuit/ Step-up circuit/ Step-up/down circuit	・Available from small output to large output ・There are various control methods.	Control is relatively cumbersome

2.2.2　DC-DC converter forward system

Figure 11 shows the circuit configuration and current flow.
・Excitation current (A) is generated in the primary coil when the switching device is turned on, and current flows through the secondary coil and through the diode.
・Inverting voltage (B) is generated when the switching device is turned off, and current flows through the diode.
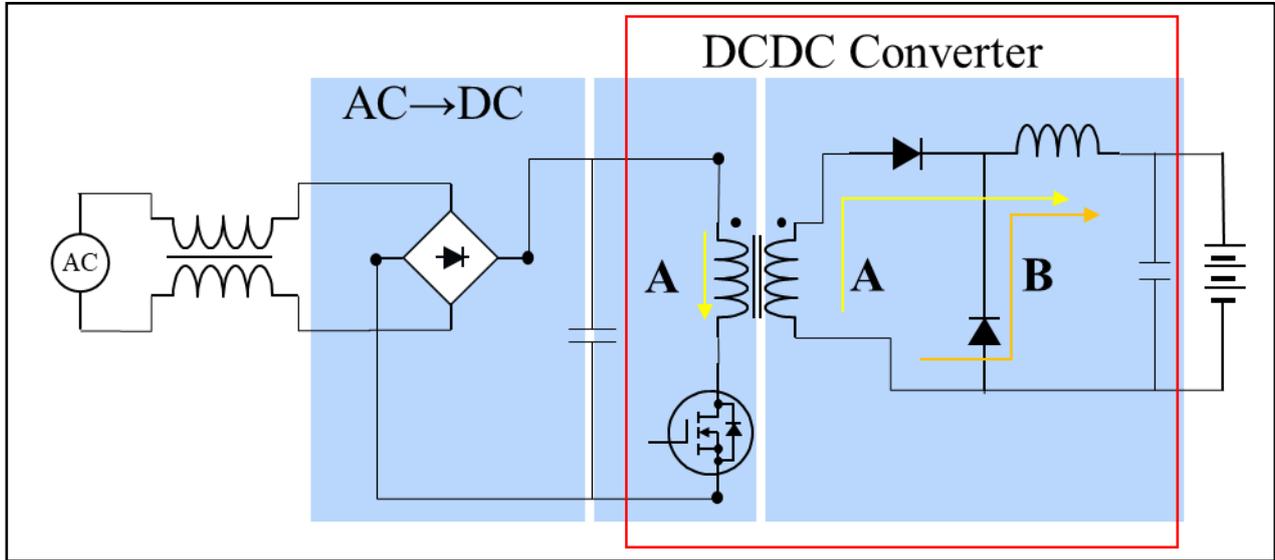
Figure 11 Image of DC-DC converter Forward system

2.2.3　DC-DC converter flyback system

Figure 12 shows the circuit configuration and current flow.
・Excitation current (A) is generated in the primary coil when the switching device is turned on, and energy is accumulated in the primary coil.
・Inverting voltage (B) is generated in the secondary coil when the switching device is turned off, and current flows through the diode.
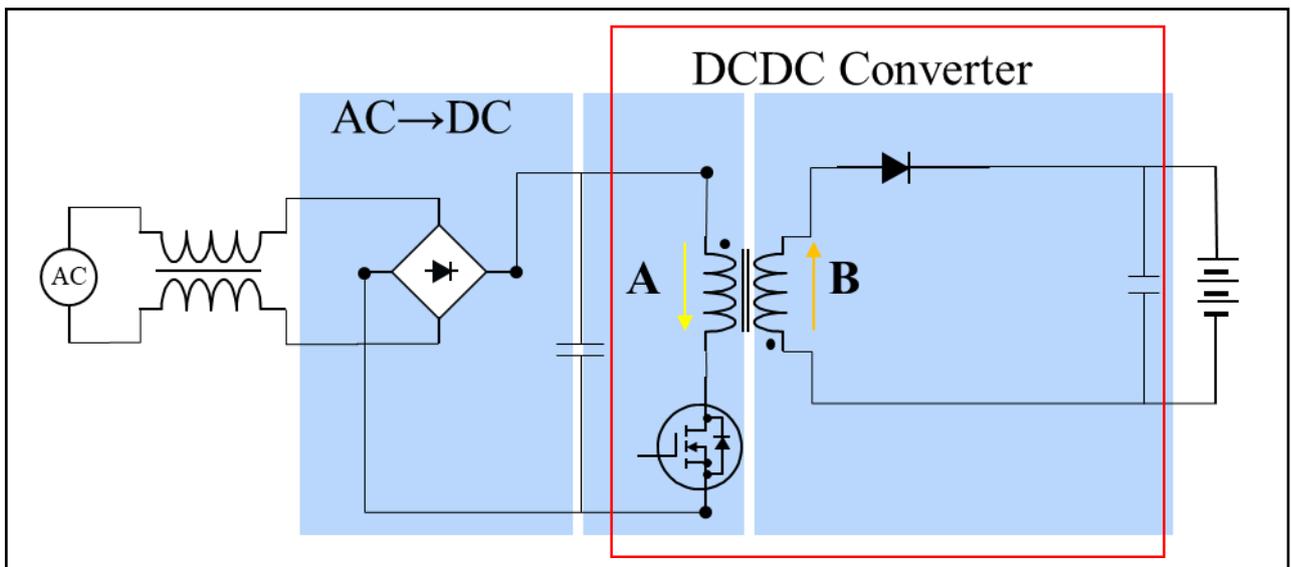
Figure 12 Image of DC-DC converter Flyback system

2.2.4 DC-DC converter push-pull system

Figure 13 shows the circuit configuration and current flow.

・When the left switching device is turned on (the right switching device is turned off), excitation current (A) is generated in the upper primary coil, and current flows through the diode through the upper secondary coil.

・When the right-side switching device is turned on (the left-side switching device is turned off), an excitation current (B) is generated in the low-side primary coil and current flows through the low-side secondary coil through the diode.
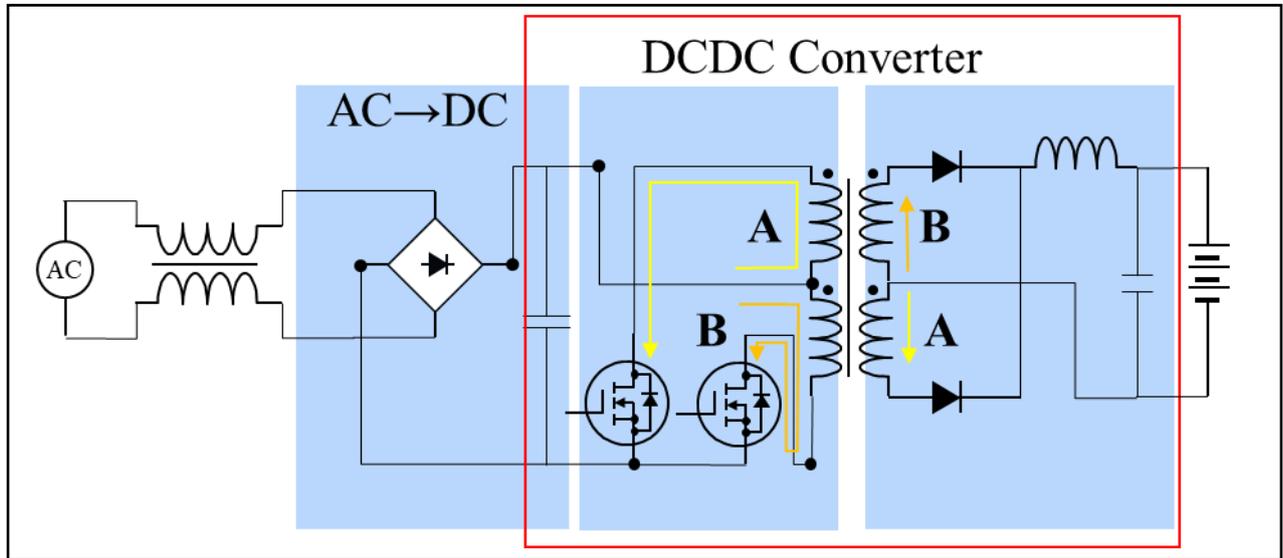
Figure 13 Image of DC-DC converter Push-Pull system

2.2.5 DC-DC converter full-bridge system

Figure 14 shows the circuit configuration and current flow.

・When the upper left switching device and the lower right switching device are turned on (the upper right switching device and the lower left switching device are turned off), an exciting current (A) is generated in the primary coil and current flows through the secondary coil.

・When the upper right-side switching device and the lower left-side switching device are turned on (the upper left-side switching device and the lower right-side switching device are turned off), exciting current (B) is generated in the primary coil and current flows through the secondary coil.
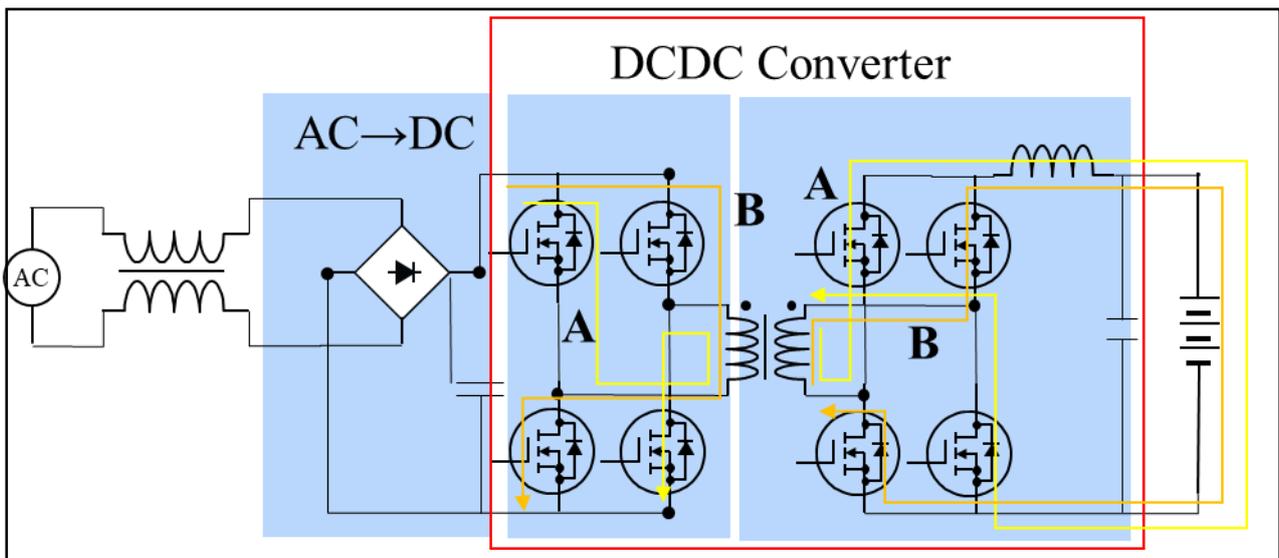
Figure 14 Image of DC-DC converter full-bridge system

2.2.6　DC-DC converter chopper system

■　Step-up system

Figure 15 shows the circuit configuration and current flow. Excitation current is generated in the coil when the switching device is turned on, and the coil excitation current flows to the output side when the switching device is turned off. Step-up is performed by repetitive operation. This method is used in this application note.
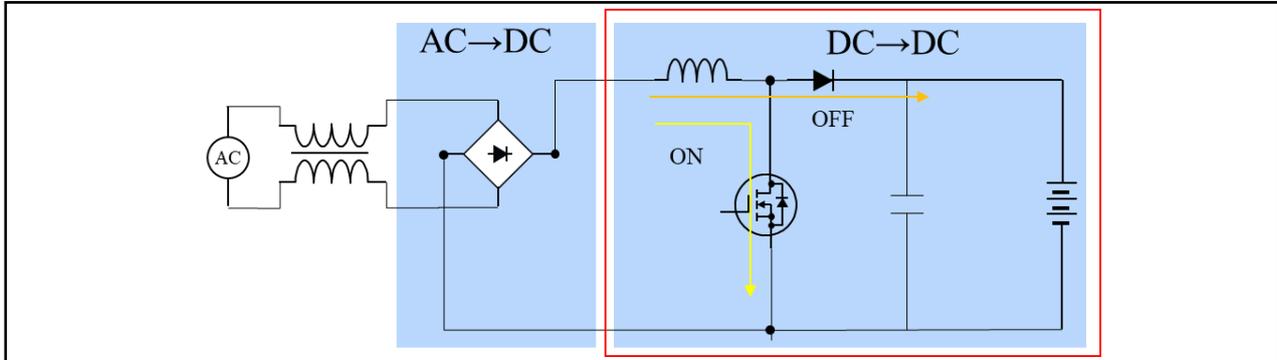
Figure 15 Image of DC-DC converter chopper (Boost) system

■　Step-down system

Figure 16 shows the circuit configuration and current flow. Excitation current is generated in the coil when the switching device is on, and excitation current flows to the output side by turning off the switching device. Step down by repetitive operation. This method is used in this application note.
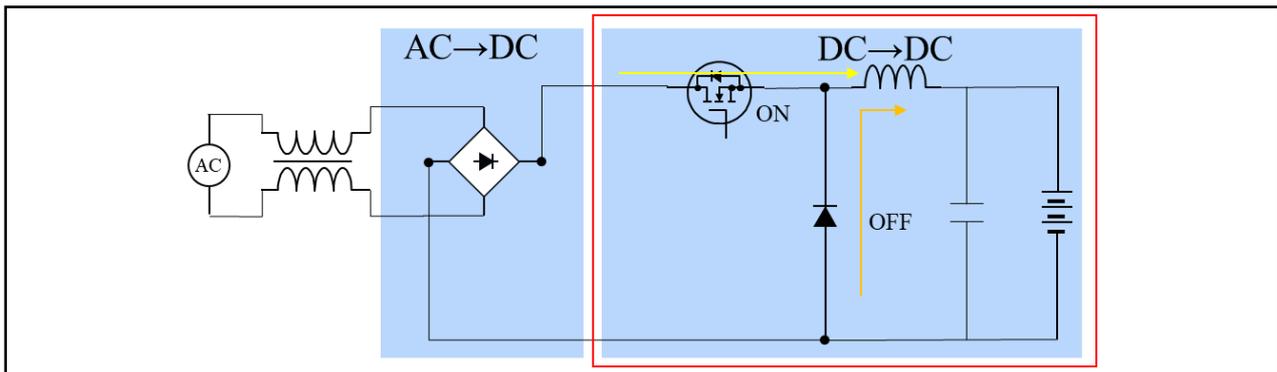
Figure 16 Image of DC-DC converter chopper (Step-Down) system

■　Step-up/Step-down system

Figure 17 shows the circuit configuration and current flow. A circuit that combines step-up and step-down methods provides both step-up and step-down operations.
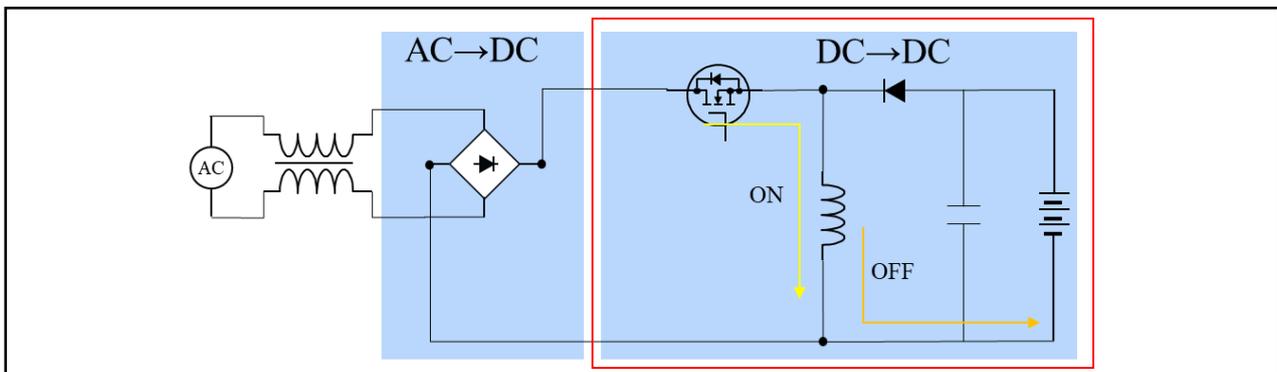
Figure 17 Image of DC-DC converter chopper (Step-Up/Down) system

3.　Digital power conversion (UPS) system overview

As shown in Figure 18, UPS is classified into two types: "continuous inverter system" and "continuous commercial power supply system". The continuous inverter system always supplies power to the connected equipment through the inverter. The continuous commercial power supply system is a method in which the commercial power supply is supplied during normal times and the battery power is supplied via an inverter during a power outage. This application note is a UPS-system using "continuous inverter system" *1.

[NOTE] 1: This application note does not include system error handling. If necessary, this can be achieved by adding Switch control to the AC-output stage.
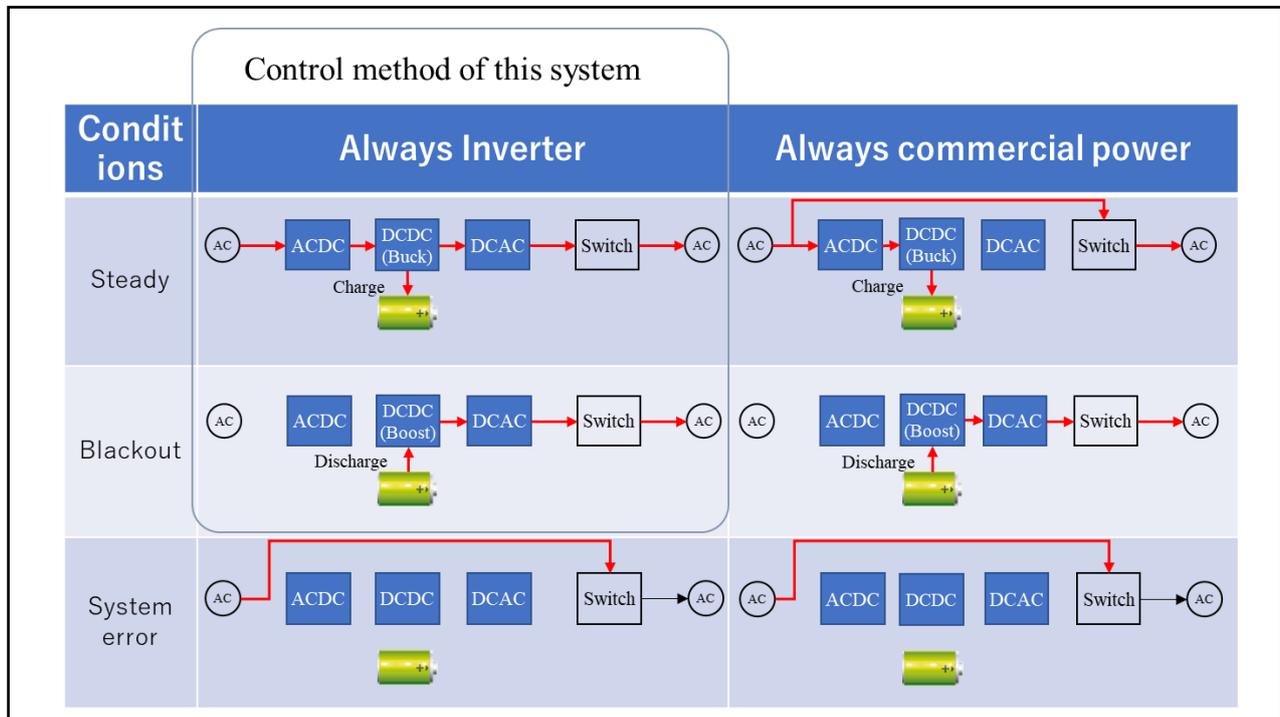
Figure 18 UPS control method for this system

3.1　System configuration

This system consists of five boards as shown in Table 12 as a 50Hz 100V 100W power supply board kit. Base Board is a board for inserting various converters (AC-DC, DC-DC) and inverter boards (DC-AC). Each board is controlled by a RX66T CPU Card or RX26T CPU Card. Figure 19 shows a configuration diagram, Figure 20 shows a board connection diagram, and Figure 21 to Figure 25 show external views of each board.

Table 12 List of used boards

No.	Board name	Model name	Remarks
1	CPU Card (Select from the right)	P05701-C0-038	R5F566TEADFH CPU-Evaluation Board
		P05701-C0-068	R5F526TFDGFP CPU-Evaluation Board
2	Base Board	P13178-C0-001	Power supply board that serves as a base for inserting various power supply boards
3	AC-DC Board	P13178-C0-002	AC-DC converter board
4	DC-DC Board	P13178-C0-003	DC-DC converter board
5	DC-AC Board	P13178-C0-004	DC-AC inverter board
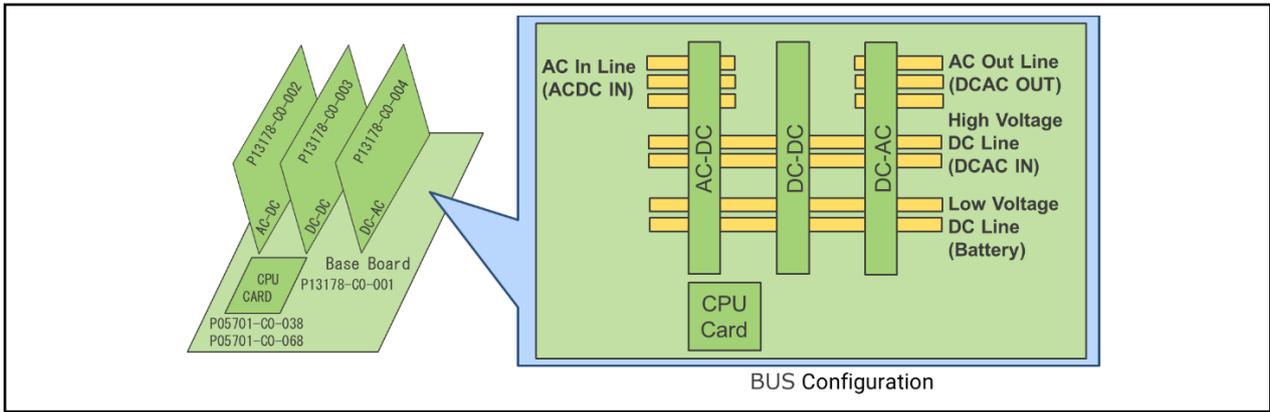
Figure 19 Board configuration diagram
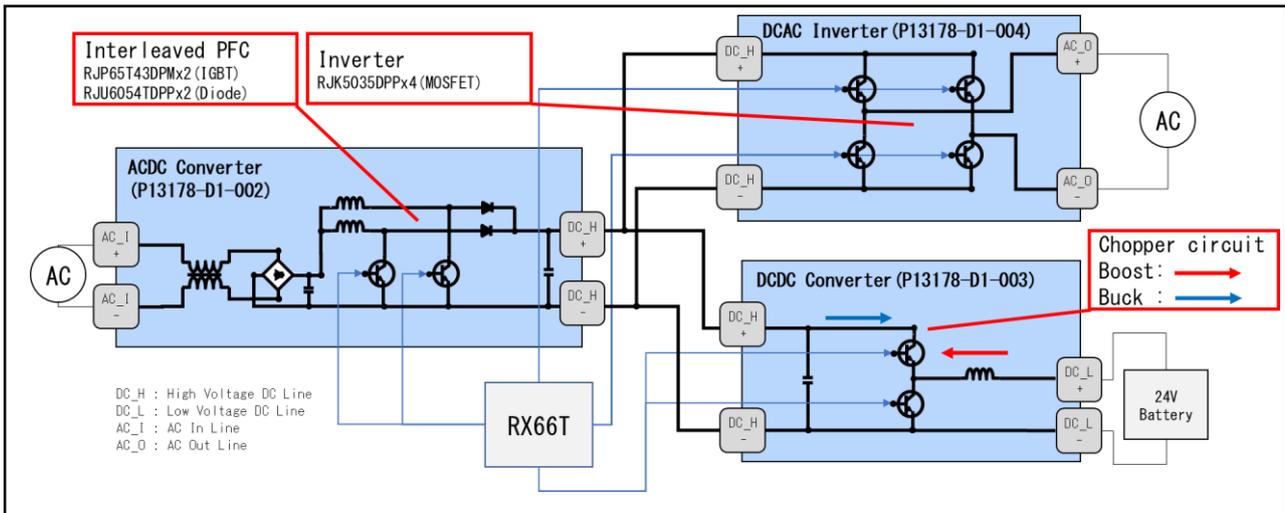
Figure 20 Schematic circuit configuration (Board connection diagram)
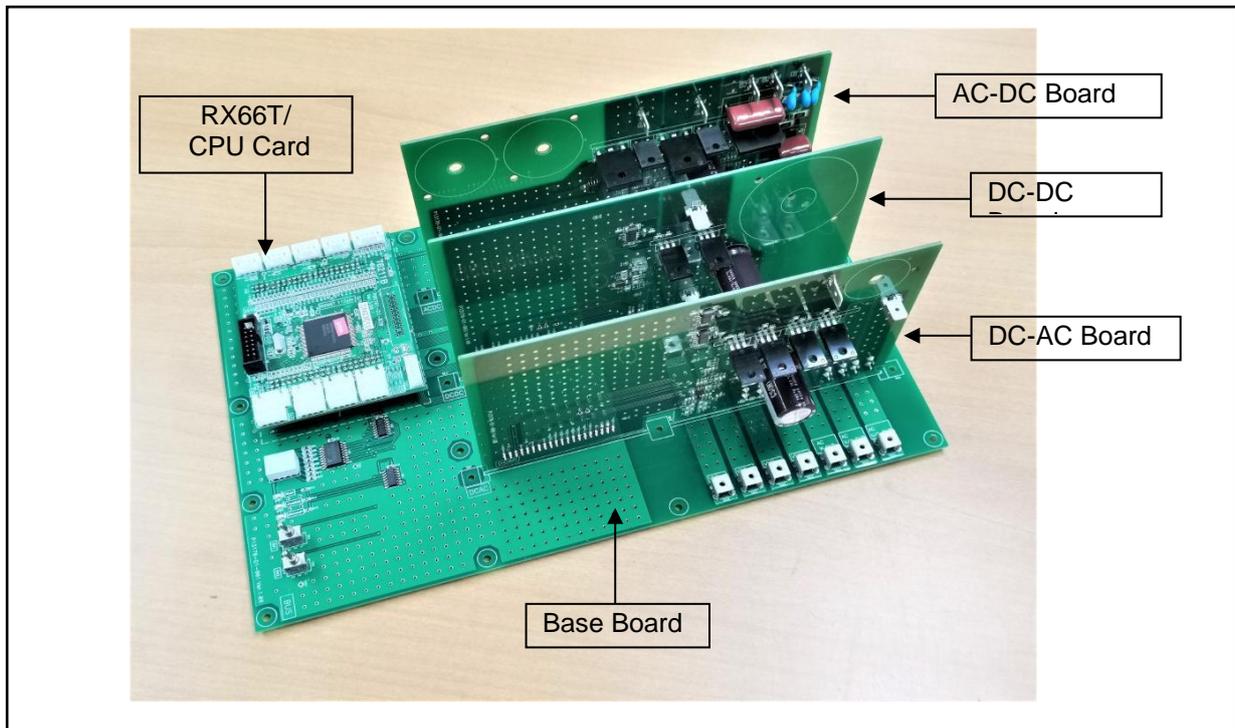
Figure 21 External view of the overall configuration
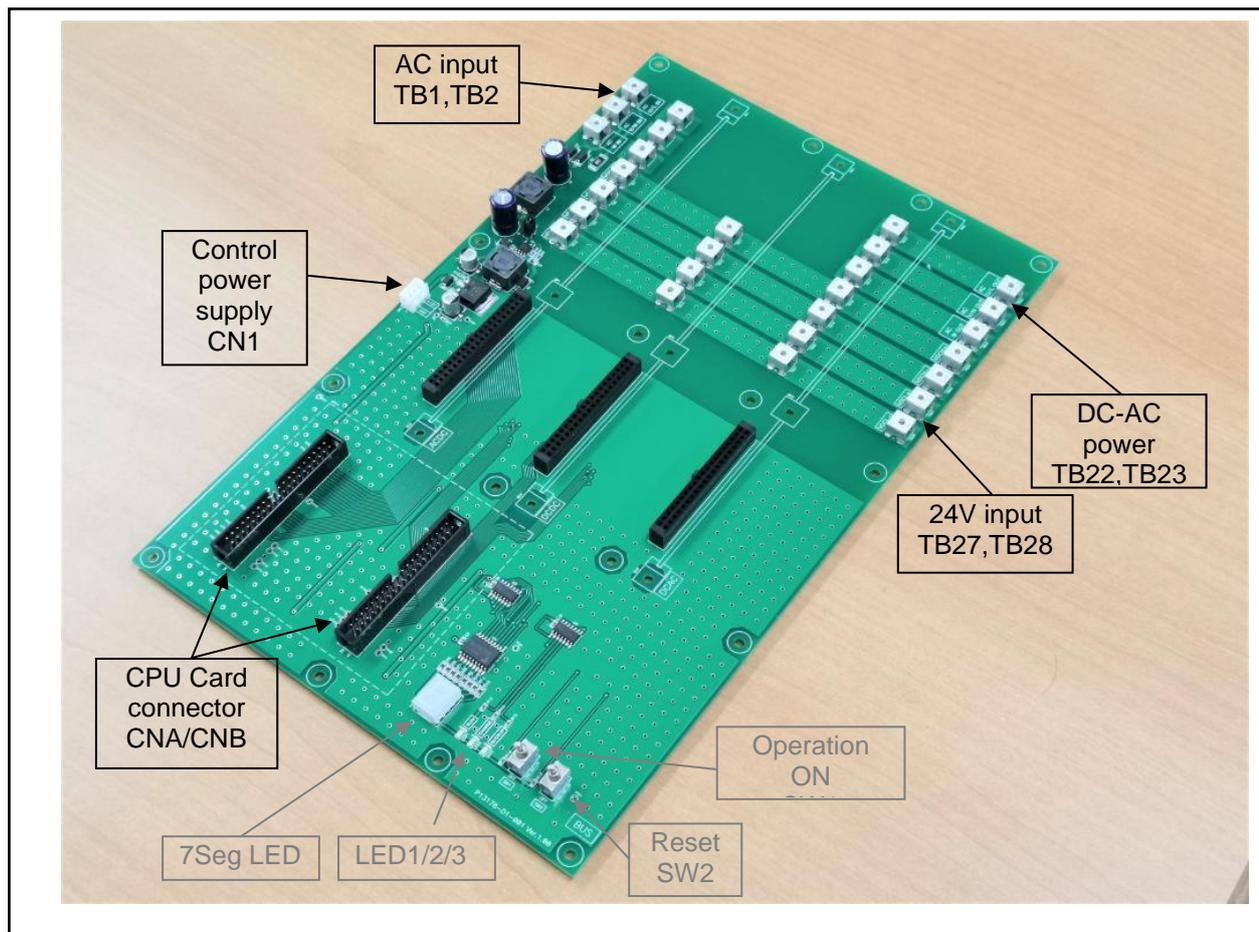
Figure 22 Baseboard external view

Table 13 Baseboard connectors

Terminal name	Definitions	Remarks
TB1	AC_U/P_IN	AC input
TB2	AC_V/N_IN	AC input
TB27	Battery P	24V input
TB28	Battery N	GND
TB22	DC-AC power	100Vrms
TB23	DC-AC power	100Vrms
CN1	CN1:1 12V CN1:3 GND	Control power, supplied from battery, always enabled
CNA/CNB	CPU Card connector	RX66T (P05701-C0-038) OR RX26T (P05701-C0-068)

Interleaved PFC circuit
IGBTx2
(RJP65T43DPM)
Diodex2
(RJU6054TDPP)
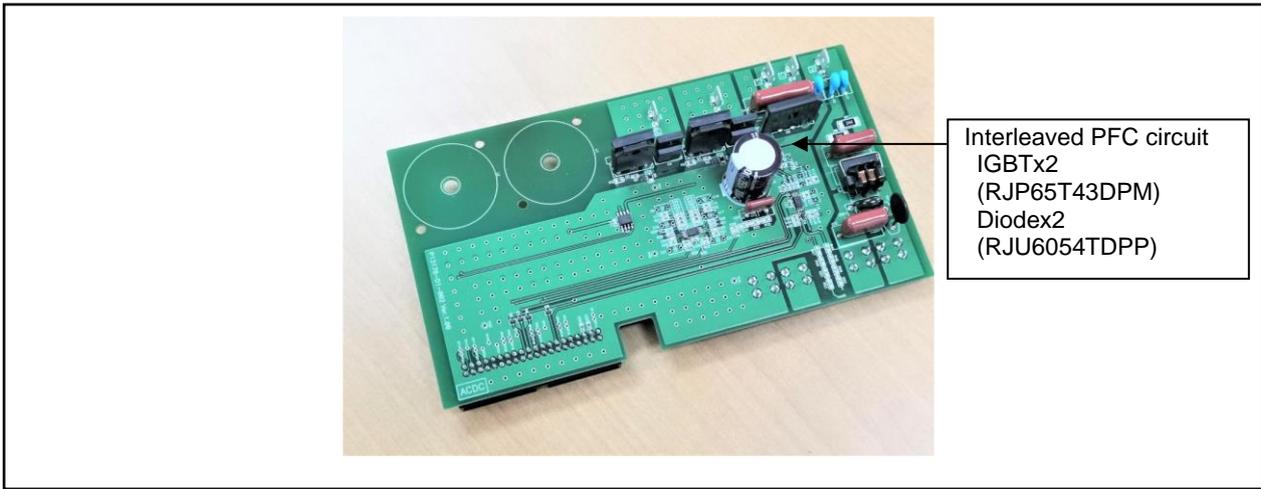
Figure 23 External view of AC-DC board

Step-up/step-down
chopper circuit
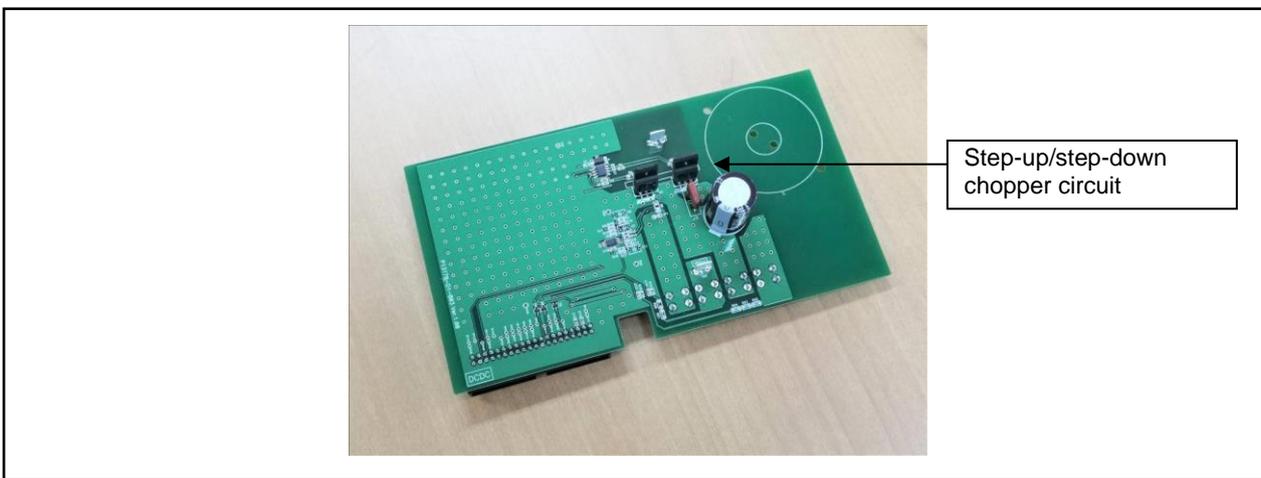
Figure 24 External view of DC-DC board

Inverter full bridge circuit
MOSFETx4
(RJK5035DPP)
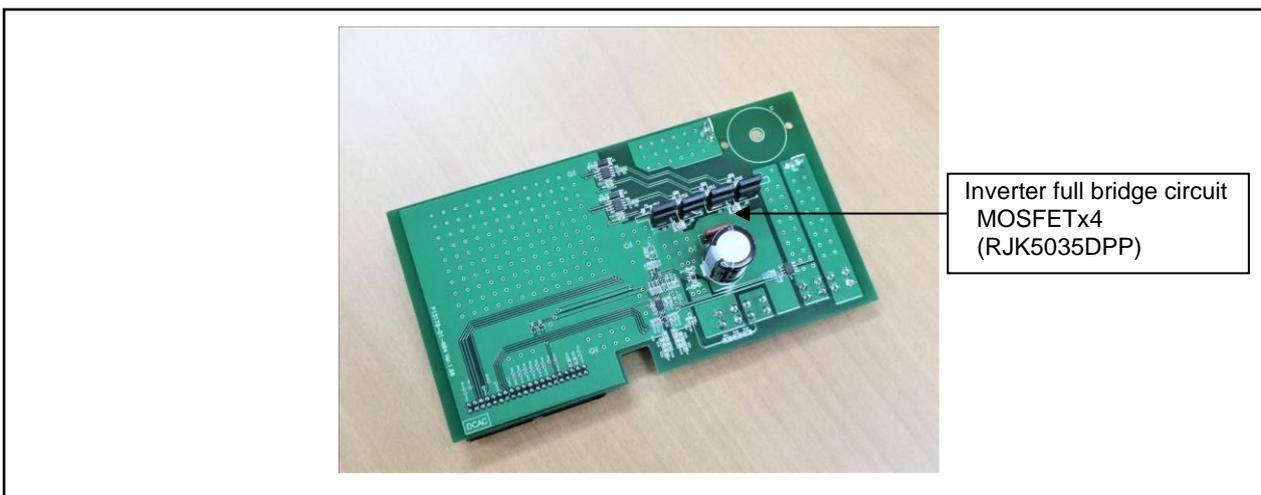
Figure 25 External view of DC-AC board

3.2　System specifications

Table 14 shows the system specifications of this system, and Figure 26 shows the operation image.

Table 14 System specifications

Item	Specifications		Remarks
AC-DC input voltage	100Vrms		Grid voltage
AC-DC output voltage	170V		DC, step-up output
AC-DC PFC method	Interleaved system		Current continuous mode
AC-DC PFC switching frequency	60kHz		Interleaved (1 PFC=60kHz))
AC-DC power factor	90% or more		When 20W or more
AC-DC shunt resistor	100mΩ		
DC-DC Low voltage	Rating 24 V		12Vx2 battery use
DC-DC high voltage	150V		
DC-DC switching frequency	40kHz		Step up and down system
DC-DC shunt resistor	10mΩ		
DC-AC output voltage	100Vrms/50Hz		Same level as the grid
DC-AC power	100W Max		
DC-AC switching frequency	20kHz		
Protection	PFC output voltage overvoltage protection	220V	
	PFC overcurrent protection (Software)	4A	
	PFC overcurrent Protection (Hardware)	4.5A (POE protected)	
	Battery voltage overvoltage protection	30V	
	Battery voltage undervoltage protection	22V	
	Battery current discharge current protection	10A	
	Battery current charge current protection	5A	
Status display	7Seg method + LEDs		Error information, operation status display
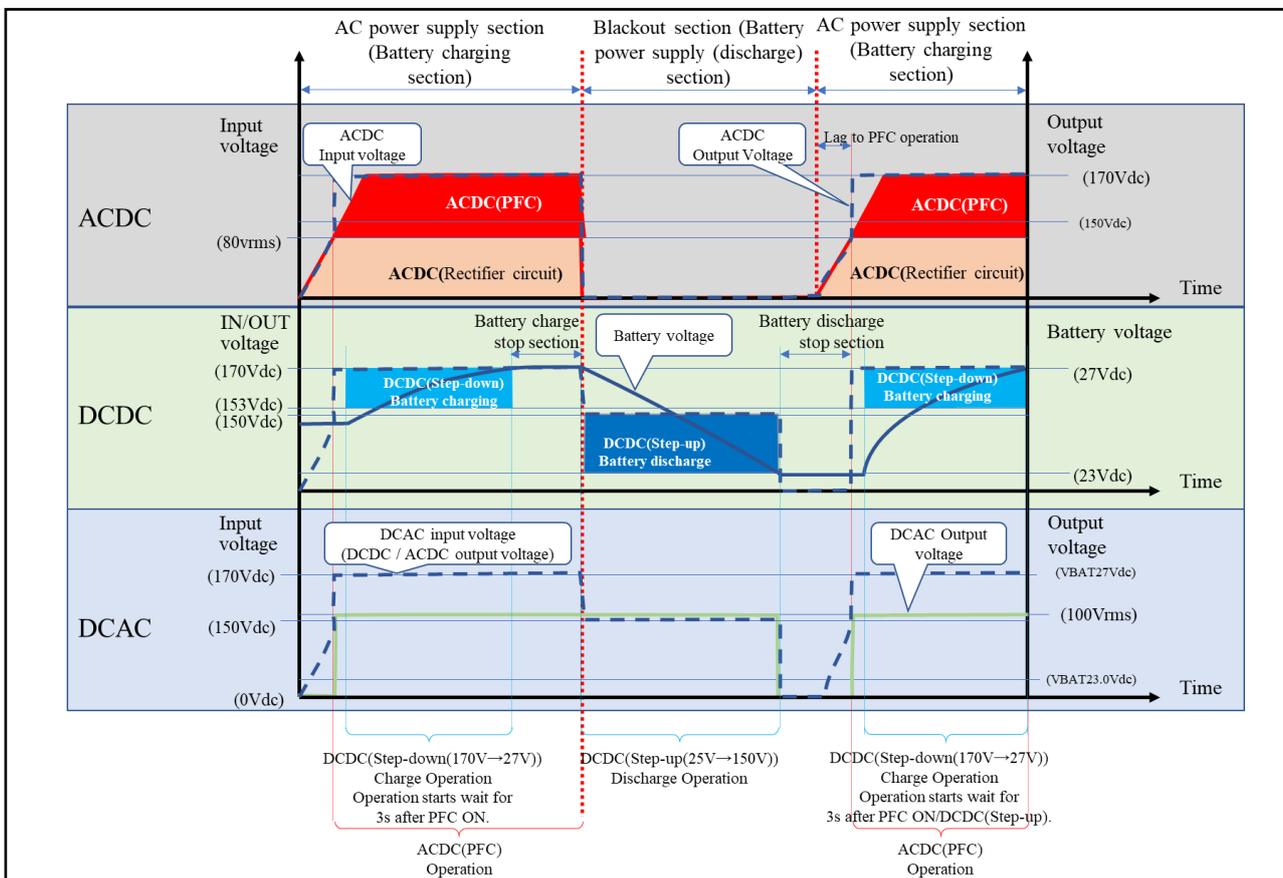
Figure 26 System operation image diagram

3.3　Hardware specification

3.3.1　Hardware configuration

The hardware configuration is shown in Figure 27.
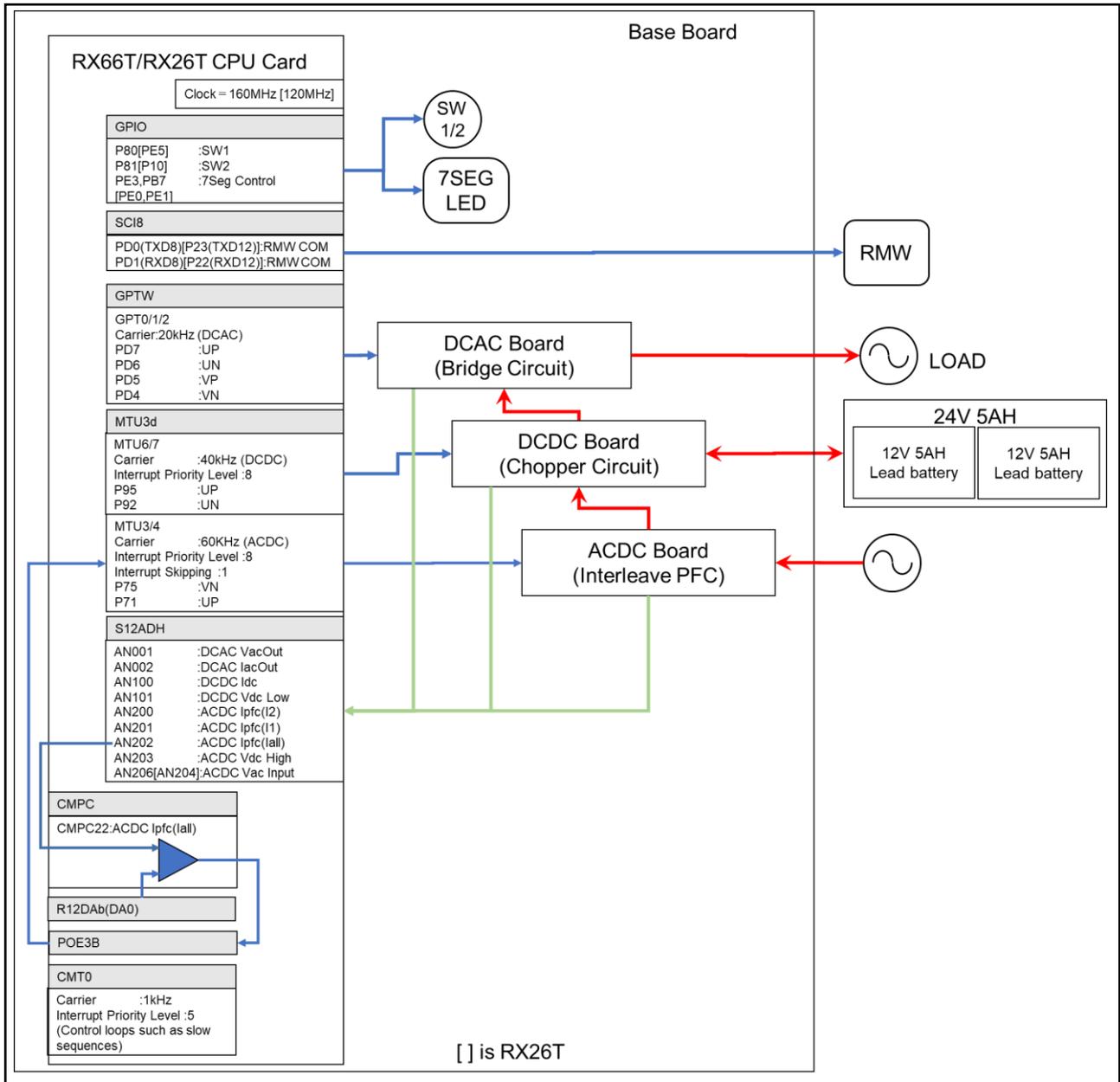
Figure 27 Hardware configuration diagram

3.3.2   User interface

Table 15 lists the user interfaces of this system, and Table 16 lists the error details.

Table 15 List of user Interfaces

Item	Interface components	Function
Operation switch	Toggle switch (SW1)	Command to start/stop operation ON : Operation start OFF: Operation stop
Reset switch	Toggle switch (SW2)	Reset input OFF⇒ON : Reset input
Operation display	Red LED1	Display of running/stopping or error Lit: Running Off: Stop or error
Battery charge indicator	Red LED2	Battery charge/discharge display LED2: Lit: Battery is being charged (170V⇒24V step-down operation in progress) LED2: Off: Battery fully charged (Battery charge stopped)
Battery discharge indicator	Green LED3	Battery charge/discharge display LED3: On: Battery is discharging (24V⇒150V boosting operation in progress) LED3: Off: Battery not discharged
Error status display	7Seg LED	Displays the error flag (1 to 255) in 5-digit increments of 1 digit per second. Refer to Table 16 for error flags. (Example) For error 032 (0x0020) 0 display/sec →3 display/sec →2 display/sec →blank display/sec →blank display/sec

Table 16 List of error flags

Error flag display	Error description	Set value	Error flag (hex)
0 0 1 □ □	PFC output voltage overvoltage protection	220V	0x0001
0 0 2 □ □	PFC overcurrent protection (Software)	4A	0x0002
0 1 0 □ □	PFC overcurrent Protection (Hardware)	4.5A (POE protected)	0x0010
0 0 4 □ □	Battery voltage overvoltage protection	30V	0x0004
0 0 8 □ □	Battery voltage undervoltage protection	22V	0x0008
0 6 4 □ □	Battery current discharge current protection	10A	0x0040
0 3 2 □ □	Battery current charge current protection	5A	0x0020

□:Blank display

RENESAS

3.3.3   MCU peripheral functions

Table 17 lists RX66T/RX26T peripheral functions used for this system.

Table 17 Peripheral function correspondence table

12-bit A/D converter (S12ADH)		Interval timer (CMT)	PWM-output timer (GPTW)	PWM-output timer (MTU3d)
· AC-DC PFC1/2 current detection (S12AD2-AN200, AN201, AN202) · AC-DC output voltage detection (S12AD2-AN203) · AC-DC input voltage detection (S12AD2-AN206 [RX26T:AN204]) · DC-DC low voltage sensing (S12AD1-AN101) · DC-DC high voltage sensing (S12AD2-AN203) · DC-DC current detection (S12AD1-AN100) · DC-AC output voltage detection (S12AD-AN001) · DC-AC current detection (S12AD-AN002)		1 [ms] Interval timer (CMT0)	Complementary PWM output -DC-AC inverter control (GPTW0/1/2)	Complementary PWM output -AC-DC PFC control (MTU3/4) -DC-DC Converter Control (MTU6/7)
Comparators (CMPC)		12-bit D/A converter (R12DAb)	Port output enable (POE3B)	
Compare AN202 (Ipfc) of S12AD2 with R12DAb (DA0) of the reference voltage, and if the reference value is exceeded, the event signal is output to POE3b (CMPC22).		CMPC reference generation (DA0)	AC-DC PFC drive (MTU3/4 of MTU3d) is stopped by CMPC event-signal (when the PFC limit current is exceeded).	

3.3.4   Pin interface

Table 18 lists the pin interfaces of RX66T/RX26T used for this system.

Table 18 RX66T/RX26T pin interfaces

Module name	Used resources	RX66T Port name	RX26T Port name	Function
GPIO		P80	PE5	SW1
		P81	P10	SW2
		PE3, PB7	PE1, PE0	7Seg Control
SCI	SCI8 [SCI12]	PD0 (TXD8)	P23 (TXD12)	RMW communication (transmission)
		PD1 (RXD8)	P22 (RXD12)	RMW communication (reception)
GPTW	GPTW0, GPTW1, GPTW2	PD2 (GTIOC2B)		DC-AC WN (not used)
		PD3 (GTIOC2A)		DC-AC WP (not used)
		PD4 (GTIOC1B)		DC-AC VN
		PD5 (GTIOC1A)		DC-AC VP
		PD6 (GTIOC0B)		DC-AC UN
		PD7 (GTIOC0A)		DC-AC UP
MTU3d	MTU6, MTU7	P90 (MTIOC7D)		DC-DC WN (not used)
		P91 (MTIOC7C)		DC-DC VN (not used)
		P92 (MTIOC6D)		DC-DC UN
		P93 (MTIOC7B)		DC-DC WP (not used)
		P94 (MTIOC7A)		DC-DC VP (not used)
		P95 (MTIOC6B)		DC-DC UP (not used when boosting)
	MTU3, MTU4	P71 (MTIOC3B)		AC-DC (PFC2) UP
		P72 (MTIOC4A)		AC-DC VP (not used)
		P73 (MTIOC4B)		AC-DC WP (not used)
		P74 (MTIOC3D)		AC-DC UN (not used)
		P75 (MTIOC4C)		AC-DC (PFC1) VN
		P76 (MTIOC4D)		AC-DC WN (not used)

S12ADH	S12AD	P40 (AN000)		(not used)
		P41 (AN001)		DC-AC VacOut
		P42 (AN002)		DC-AC IacOut
		P43 (AN003)		(not used)
	S12AD1	P44 (AN100)		DC-DC Idc (low voltage (battery))
		P45 (AN101)		DC-DC Vdc (low voltage (battery))
		P46 (AN102)		(not used)
		P47 (AN103)		(not used)
	S12AD2	P52 (AN200)		AC-DC Ipfc (I2)
		P53 (AN201)		AC-DC Ipfc (I1)
		P54 (AN202/CMPC22)		AC-DC Ipfc (Iall)
		P55 (AN203)		AC-DC Vdc (high voltage)
		P60 (AN206)	P50 (AN204)	AC-DC Vac (AC input voltage)
		P61 (AN207)		(not used)
		P62 (AN208)		(not used)
		P63 (AN209)		(not used)
		P64 (AN210)		(not used)
		P65 (AN211)		(not used)
		P20 (AN216)		(not used)
		P21 (AN217)		(not used)

3.4   Software specifications

3.4.1   Module configuration

Figure 28 shows the module configuration of the sample program.
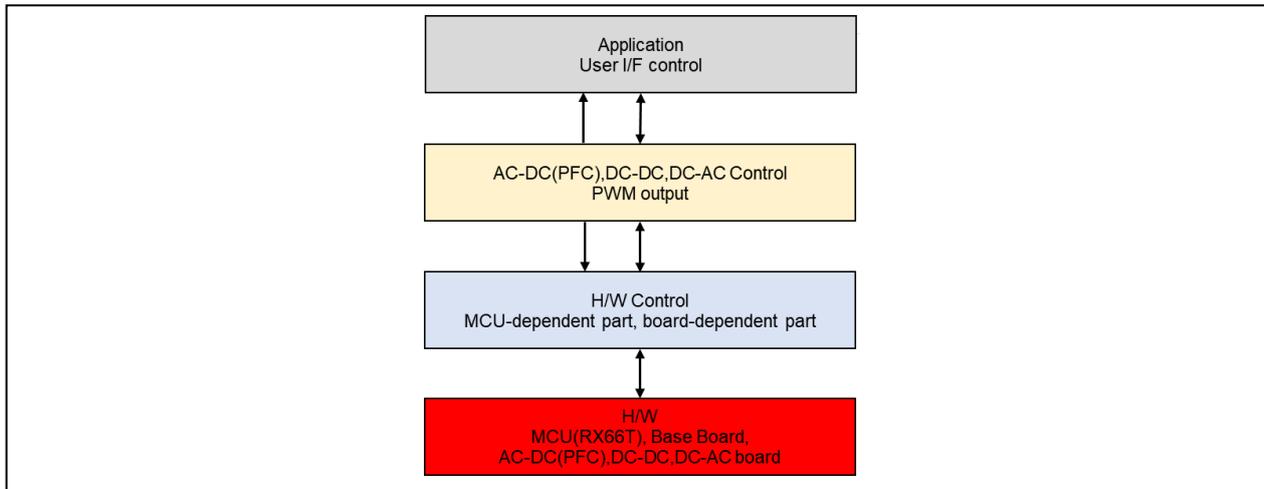
Figure 28 Module configuration

3.4.2 Software file configuration

The software folders and file configurations are shown in Table 19.

Table 19 Folder and file configuration

Folder name	File name	Description
src	main.c	Main function, user interface control
	intprg.c	Interrupt handler
	r_pwr_control.c	Initializing process
	r_pwr_interrupt.c	Interrupt process
	r_pwr_pfc_ctrl.c	AC-DC (PFC), DC-DC, DC-AC control
	r_pwr_Sequence.c	Sequential control
	r_pwr_control.h	Error parameter relation definition
	r_pwr_interrupt.h	Other control parameter definition
	r_pwr_pfc_ctrl.h	AC-DC (PFC), DC-DC, DC-AC control parameter relation definition
	r_pwr_Sequence.h	Sequence parameter relation definition
src\REL_src	resetprg.c	Power-on process
	dbsct.c	B, R section setting
	sbrk.c	Memory allocation process
	vecttbl.c	Vector table initialization process
	iodefine.h	IO register definition
	sbrk.h	Allocation size definition
	stacksct.h	Stack area size definition
	typedefine.h	Type definition
	vect.h	Vector definition
src\PWR_IOLIB	r_pwr_IOLIB_AD.c	S12ADH relation process
	r_pwr_IOLIB_CLOCK.c	Operation clock setting process
	r_pwr_IOLIB_CMT.c	CMT relation process
	r_pwr_IOLIB_INV_MTU_AD.c	MTU3d, GPTW relation process
	r_pwr_IOLIB_IO.c	I/O relation process [Only RX26T version]
	r_pwr_IOLIB_IWDT.c	IWDT relation process
	r_pwr_IOLIB_POE.c	POE3B relation process
	r_pwr_MATHLIB.c	Arithmetic process
	r_pwr_MATHLIB.h	Arithmetic operation relation definition
	r_pwr_IOLIB.h	MCU dependent part definition
src\ICS_Lib	ICS2_RX66T.h [ICS2_RX26T.h]	Communication relation definition for RMW tools
	ICS2_RX66T.lib [ICS2_RX26T.lib]	Communication library for RMW tools

RENESAS

4. Control software description

Software handling of this application note is classified into AC-DC converter control (interleaved PFC circuit), DC-DC converter control (step-up/step-down chopper circuit), and DC-AC inverter control (full-bridge circuit). Each control is performed within the "RUN Mode" shown in 4.1 State transition. The control contents are described in 4.2 Details of control.

4.1 State transition

Figure 29 shows a state transition diagram for the software subject to this application note. In this application note target software, the system status is managed in three modes: "STOP Mode", "ERROR Mode" and "RUN Mode". The operation details are shown below.

■Normal operation
(1) When the power is turned on, the unit transitions to "STOP Mode" via "Power On Reset" and enters standby status.
(2) Transits to "RUN Mode" by SW1 ON and executes "DC-AC Operation" of "AC-DC (PFC) Operation", "DC-DC Boost Operation" of DC-DC converter control (step-up/step-down chopper circuit), "DC-DC Buck Operation" and "DC-AC inverter control (full-bridge circuit) according to the respective conditions.
(3) SW1 OFF completes all processes and enters the "STOP Mode" state. Then, the system enters the standby state.

■When an error occurs
(1) When an error occurs, it transits to "ERROR Mode" and enters the standby status with "ERROR Mode". Refer to Table 16 Error Flag List for details on the error.

(2) Resetting by SW2 causes the IC to change to STOP Mode and enter standby.
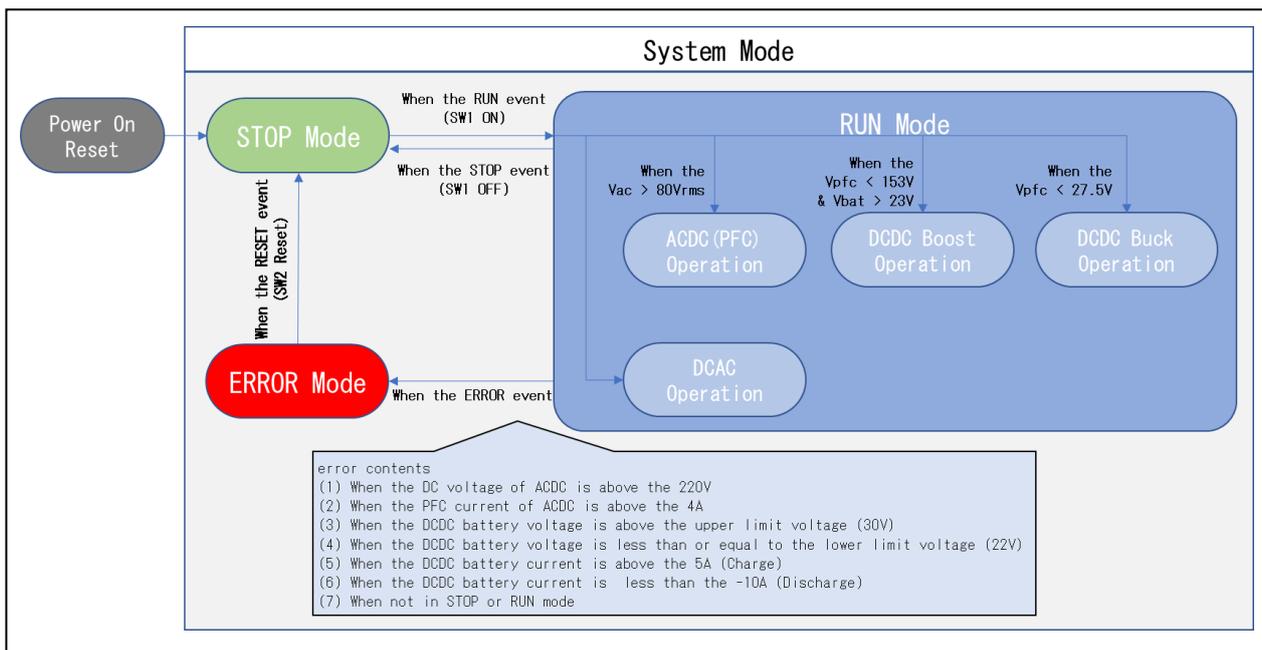
Figure 29 State transition diagram

4.2 Details of control

This section describes the software-processed AC-DC converter control (interleaved PFC), DC-DC converter control (step-up/step-down chopper circuit), and DC-AC inverter control (full-bridge circuit) of this application note.

4.2.1   AC-DC converters (PFCs) control

MTU3/4 of RX66T/RX26T MTU3d is set to complementary PWM mode, and U/V/W phase is outputted. By using the negative U and V phases, a PWM waveform with a phase difference of 180 degrees can be obtained, driving the interleaved PFC. The PFC is driven by digital control, and the duty is calculated by combining feed-forward control and PI control.
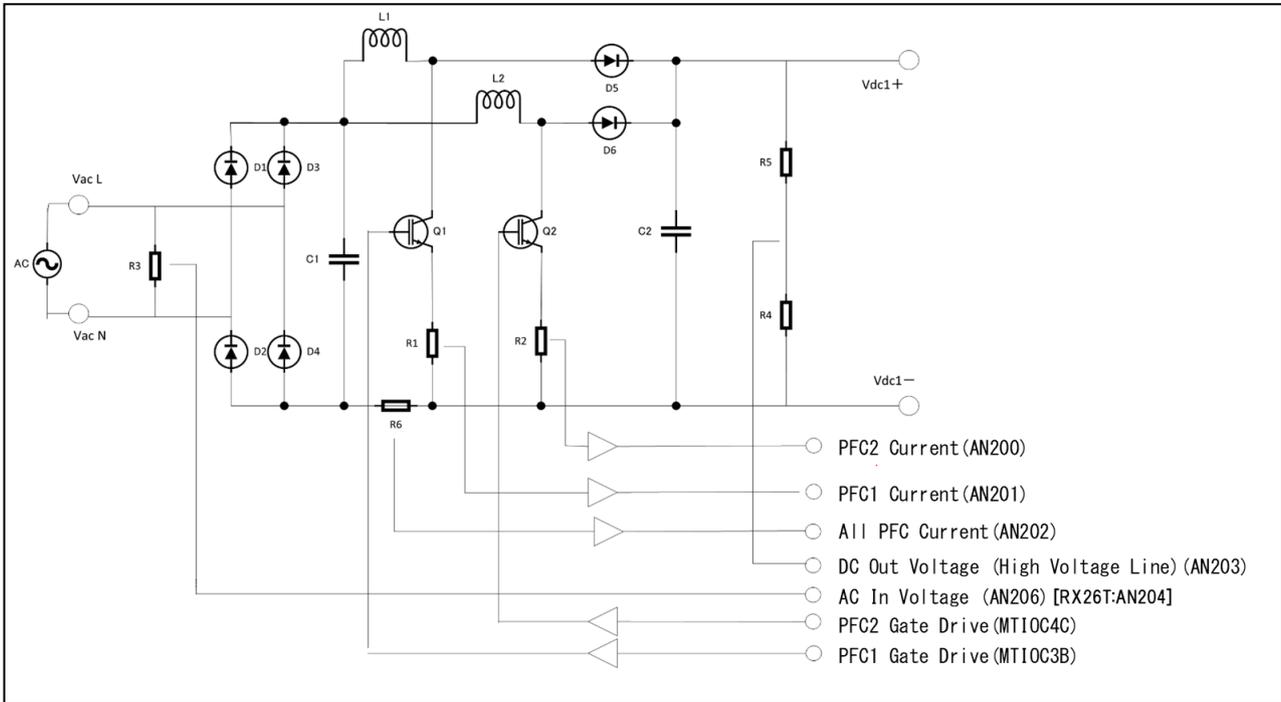
Figure 30 Circuit configuration and control signal connection diagram of AC-DC converter/PFC control block

V*   : Voltage command value
Vdc   : Actual output voltage (DC)
Vac   : AC input voltage
K   : Current command value calculation coefficient
I*   : Current command value
Iac   : PFC-current Ipfc
Duty*   : Modulation factor output from the current PI
DutyF   : Modulating factor calculated by Feed Forward
DutyOut   : Actual duty output
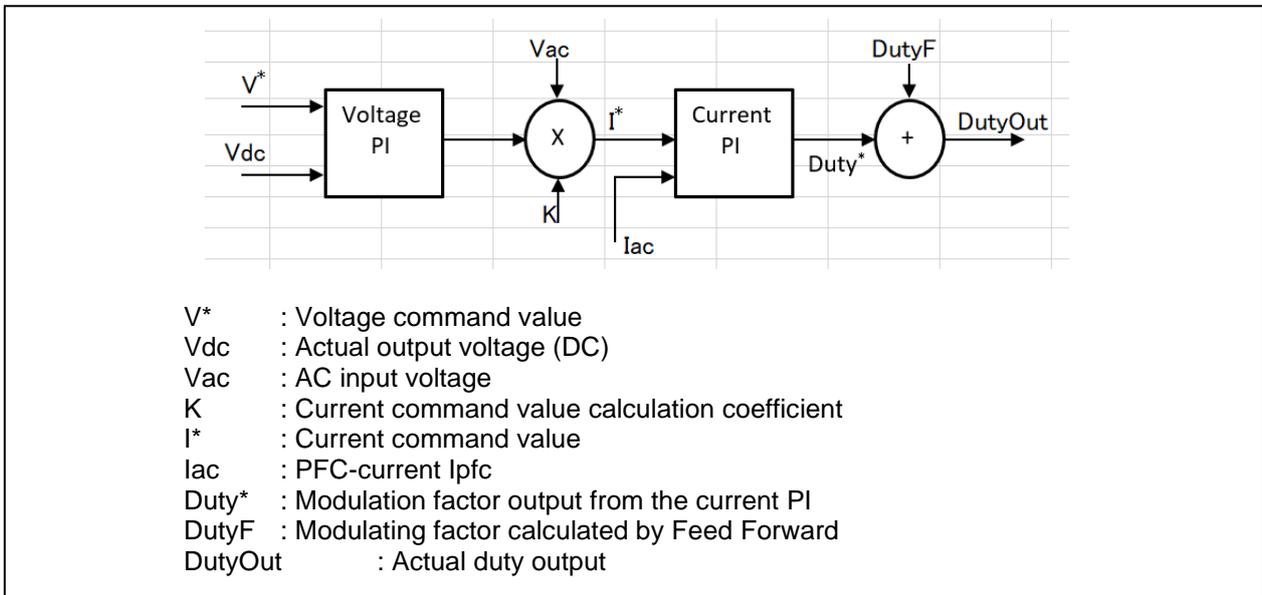
Figure 31 AC-DC control logic diagram

4.2.2 DC-DC converter control

DC-DC converter unit performs bi-directional voltage conversion, which also serves as a step-up operation (battery discharge supplying power from the battery) and a step-down operation (battery charge). In voltage-conversion control, MTU6/7 of RX66T/RX26T MTU3d is set to complementary PWM-mode as U/V/W phase output, and the positive and negative phases of the U-phase are used to drive the half-bridge of the chopper circuit. By utilizing complementary PWM, it is possible to drive by the synchronous rectification method. However, if AC-DC output is higher than the boost voltage of DC-DC, switching operation by the positive and negative phases of the U-phase will be effective in step-down. Therefore, the positive phase of the U-phase is not driven during step-up. Note that voltage sampling on the high voltage side is shared with the output voltage detection (VDC voltage detection (AN203)) of AC-DC.
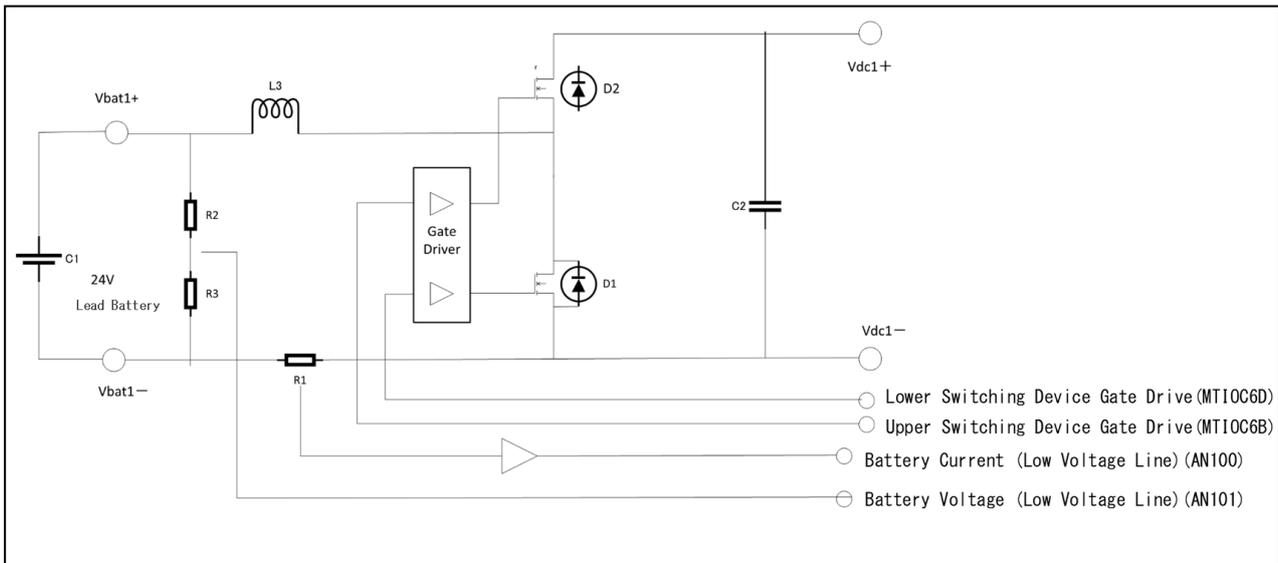
Figure 32 Circuit configuration and control signal connection diagram of DC-DC converter control block

V*   : Voltage command value
Vout   : Actual output voltage (voltage on the high voltage side when boost and voltage on the battery when buck)
I*   : Current command value
Idc   : DC current (discharging current of the battery when boost and charging current of the battery when buck)
Duty*   : Modulation factor output from the current PI
DutyF   : Modulating factor calculated by Feed Forward
DutyOut   : Actual duty output

Figure 33 DC-DC control logic diagram

4.2.3　DC-AC inverter control

GPT0/1/2 of RX66T/RX26T GPTW is set to complementary PWM mode, and U/V/W phase is outputted. By simultaneously controlling the positive phase of the U phase and the negative phase of the V phase, the negative phase of the U phase and the positive phase of the V phase, and the positive phase of the V phase, control is achieved by shifting the phase by 180 degrees. DC-AC has open-loop control of voltages. Offset part corrects the offset of the output due to dead time, non-linearity, etc. Here, K is the peak value of 140 for outputting a fixed 100Vrms. Voltage feed forward control can absorb the effect of input voltage ripple.
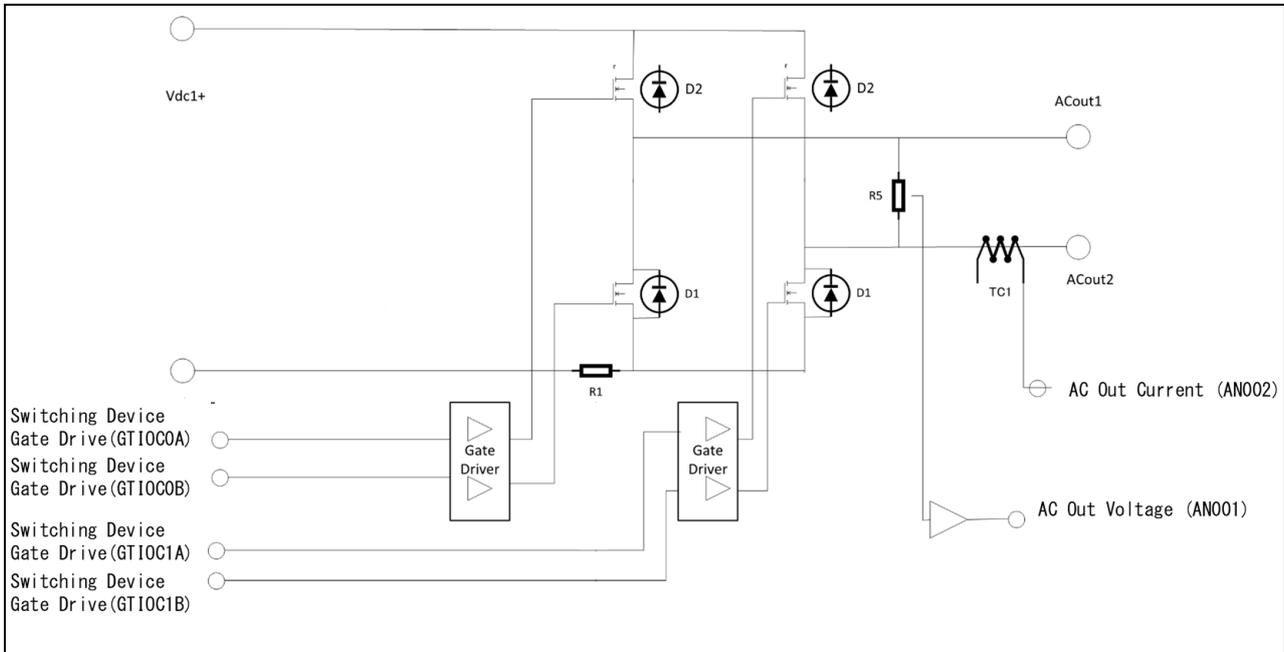
Figure 34 Circuit configuration and control signal connection diagram of DC-AC inverter control block

Pe*　　: Command value
Offset　: Offset of output due to dead time, non-linearity, etc.
K　　　: Voltage command calculation coefficient (140)
DutyOut　　　: Actual duty output
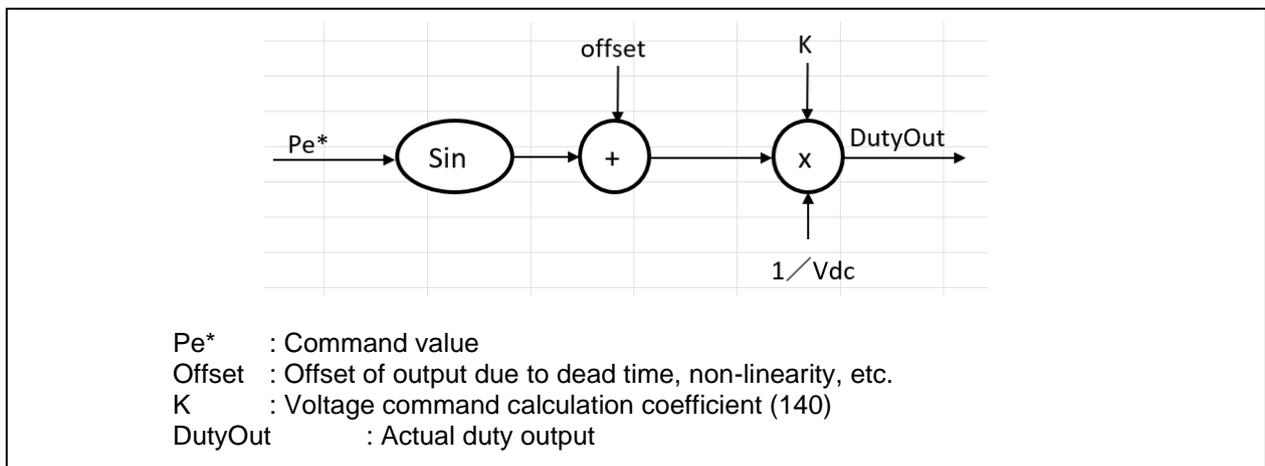
Figure 35 DC-AC control logic diagram

4.3　Functions list

The function list of this control program is shown below. Some functions are provided for extension (functions not used in this software) so that they can be easily incorporated by the user. Please refer to Notes in the table below for non-use functions.

Table 20 Functions list

| File | | Function | | | | Notes |
Path	Name	Name	Arguments	Return Type	Overview	es
src	main.c	main	void	void	Main function	
	r_pwr_control.c	r_pwr_User_CustomIO_init	void	void	IO port initialization	
		r_pwr_User_Ctrl_Init	void	void	Initialization of error setting value, etc.	
		r_pwr_Seg_Control	uint16_t data	void	7Seg indication	
	r_pwr_interrupt.c	interrupt_CMT0	void	void	1kHz interrupt	
		interrupt_MTU34_carrier	void	void	AC-DC (PFC) Control 60kHz interrupt (1 skipped)	
		r_pwr_error_stop	void	void	System shutdown in the event of an error	
		r_pwr_check_error_curloop	void	void	Error check at 30 kHz cycle	
	r_pwr_pfc_ctrl.c	r_pwr_User_Pfc_Init	void	void	PFC initialization	
		r_pwr_User_DCDC_Low_Init	void	void	Buck operation initialization	
		r_pwr_User_DCDC_High_Init	void	void	Boost operation initialization	
		r_pwr_DCAC_Init	void	void	DC-AC initialization	
		r_pwr_DCDC_HighToLow	void	void	Buck operation control (battery charge)	
		r_pwr_DCDC_LowToHigh	void	void	Boost operation control (battery discharging)	
		r_pwr_pfc_control	void	void	PFC operation control function	
		r_pwr_DCAC_Control	void	void	DC-AC control	
	r_pwr_Sequence.c	r_pwr_SEQ_Exec_Event	uint8_t ucEvent	void	Event Matrix Processing Functions	
		r_pwr_Seq_Init	void	void	Sequence initialization	
		r_pwr_SEQ_Act_Run	uint8_t ucState	uint8_t	RUN Event Handling Functions	
		r_pwr_SEQ_Act_Stop	uint8_t ucState	uint8_t	STOP Event-Handling Functions	
		r_pwr_SEQ_Act_Reset	uint8_t ucState	uint8_t	RESET Event-Handling Functions	
		r_pwr_SEQ_Act_Error	uint8_t ucState	uint8_t	ERROR Event-Handling Functions	
		r_pwr_SEQ_Act_None	uint8_t ucState	uint8_t	NONE Event-Handling Functions	
		r_pwr_SEQ_Init_Start	void	void	START Event-Handling Functions	
	r_pwr_IOLIB_AD.c	r_pwr_ad_S12AD0_init	uint16_t u2_mode	void	S 12 AD initialization	

RENESAS

src\PWR_IOLIB		r_pwr_ad_S12AD1_init	uint16_t u2_mode	void	S 12 AD 1 initialization	
		r_pwr_ad_S12AD2_init	uint16_t u2_mode	void	S 12 AD 2 initialization	
		r_pwr_ad_S12AD0_set_channel	uint32_t u4_ch_list	void	S12AD Channel Settings	
		r_pwr_ad_S12AD0_set_range	int16_t s2_ch, int16_t s2_offset, float f_range	void	S12AD offset/range setting	
		r_pwr_ad_S12AD1_set_channel	uint32_t u4_ch_list	void	S12AD1 Channel Settings	
		r_pwr_ad_S12AD1_set_range	int16_t s2_ch, int16_t s2_offset, float f_range	void	S12AD1 offset/range setting	
		r_pwr_ad_S12AD2_set_channel	uint32_t u4_ch_list	void	S12AD2 Channel Settings	
		r_pwr_ad_S12AD2_set_range	int16_t ch, int16_t s2_offset, float f_range	void	S12AD2 offset/range setting	
	r_pwr_IOLIB_CLOCK.c	r_pwr_CLOCK_init	void	void	Operation clock setting	
	r_pwr_IOLIB_CMT.c	r_pwr_interval_CMT0_init	uint16_t u2_freq	void	CMT0 initialization	
		r_pwr_interval_CMT1_init	uint16_t u2_freq	void	CMT1 initialization	Not use
		r_pwr_interval_CMT2_init	uint16_t u2_freq	void	CMT2 initialization	Not use
		r_pwr_interval_CMT3_init	uint16_t u2_freq	void	CMT3 initialization	Not use
	r_pwr_IOLIB_INV_MTU_AD.c	r_pwr_pwmcontrol_MTU34_init	uint32_t u4_FreqCarrier, uint32_t u4_Deadtime, uint32_t u4_Decimation	void	AC-DC (PFC) MTU3/4 initialization for control PWMs	
		r_pwr_pwmcontrol_MTU34_set_uvw_3shunt	float f_refu, float f_refv, float f_refw	void	AC-DC (PFC) MTU3/4 compare setting for control PWMs	
		r_pwr_pwmcontrol_MTU67_init	uint32_t u4_FreqCarrier, uint32_t u4_Deadtime, uint32_t	void	DC-DC (PFC) MTU6/7 initialization for control PWMs	

RENESAS

			u4_Decimation			
		r_pwr_pwmcontrol_MTU67_set_uvw_3shunt	float f_refu, float f_refv, float f_refw	void	MTU6/7 compare setting for DC-DC control PWMs	
		r_pwr_pwmcontrol_GPT012_init	uint32_t u4_FreqCarrier, uint32_t u4_Deadtime, uint32_t u4_Decimation	void	GPT0/1/2 initialization for DC-AC control PWMs	
		r_pwr_pwmcontrol_GPT012_set_uvw_3shunt	float f_refu, float f_refv, float f_refw	void	GPT0/1/2 compare setting for DC-AC control PWMs	
		r_pwr_pwmcontrol_CMPC2_DA_init	void	void	Initialization of CMPC2,DA0 for ipfc detection (for POE for output-shutdown)	
		r_pwr_pwmcontrol_poe3_init	void	void	POE3 initialization	
	r_pwr_IOLIB_IO.c	r_pwr_User_CustomIO_init	void	void	Board I/O initialization [RX66T version is included in r_pwr_control.c]	
	r_pwr_IOLIB_IWDT.c	r_pwr_IWDT_init	void	void	IWDT initialization	Not use
	r_pwr_MATHLIB.c	r_pwr_limit_PN	float data, float limitp, float limitn	float	Data range limit processing	
		r_pwr_limit	float data, float limit	float	Negative data range limit processing	
		r_pwr_Inv_Calc_Lpf	float * input_lpf, float input, float k_filter	void	LPF calculation processing	
src\REL_src	resetprg.c	PowerON_Reset_PC	void	void	Power-on reset processing	
	sbrk.c	sbrk	size_t size	_SBYTE *	Memory area allocation processing	

4.4 Variables list

The following table lists the global variables used in this control program. Some variables include those for internal operation. Variables for internal operation are not prefixed with "g".

Table 21 Variables list

File Name	Variable Name	Overview
r_pwr_interrupt.c	g_f_ACDC_offset_IpfcAll	PFC current offset
	g_f_DCDC_offset_Idc	Battery current offset
	g_f_LpfFactor_CurrentOff	Filter coefficient at offset calculation
	g_f_ErrLevel_OV_pfc	PFC output voltage protection level
	g_f_ErrLevel_Vbat_OV	Battery overvoltage protection level
	g_f_ErrLevel_Vbat_UV	Battery undervoltage protection level
	g_f_ErrLevel_Ibat_Plus_OC	Battery charge current protection level
	g_f_ErrLevel_Ibat_Minus_OC	Battery discharge current protection level
	g_f_ErrLevel_OC_pfc	PFC overcurrent protection level

	g_f_ACDC_Mu_Ref	AC-DC module output setting U-phase
	g_f_ACDC_Mv_Ref	AC-DC module output setting V-phase
	g_f_ACDC_Mw_Ref	AC-DC module output setting W-phase (Not used for control)
	g_f_DCDC_Mu_Ref	DC-DC module output setting U-phase
	g_f_DCDC_Mv_Ref	DC-DC module output setting V-phase (Not used for control)
	g_f_DCDC_Mw_Ref	DC-DC module output setting W-phase (Not used for control)
	g_f_DCAC_Mu_Ref	DC-AC module output setting U-phase
	g_f_DCAC_Mv_Ref	DC-AC module output setting V-phase
	g_f_DCAC_Mw_Ref	DC-AC module output setting W-phase (Not used for control)
	g_f_ACDC_IpfcAll	PFC total current value
	g_f_ACDC_IpfcU	PFC2 current value
	g_f_ACDC_IpfcV	PFC1 current value
	g_f_ACDC_offset_IpfcU	PFC2 offset current
	g_f_ACDC_offset_IpfcV	PFC1 offset current
	g_f_DCDC_Idc	Battery charge/discharge current value
	g_f_ACDC_Vdc	high voltage line DC voltage (PFC output voltage value)
	g_f_DCDC_Vbat	low voltage line DC voltage (Battery voltage)
	g_f_DCDC_Vbat_Lpf	Filtered value of battery voltage value
	g_f_ACDC_Vac	Incoming AC-voltage of AC-DC
	g_f_ACDC_Vac_Plus	Absolute value of the AC voltage
	g_f_VacTemp_New	New buffer for AC voltage offset calculation
	g_f_VacTemp_Old	OLD buffer for AC voltage offset calculation
	g_f_ACDC_offset_Vac	AC voltage offset
	g_f_Offset_VacSum	Accumulated AC voltage offset
	g_f_Offset_Lpf_Vac	Filter value for AC voltage offset (Average filter)
	g_f_DCAC_offset_Vout	DC-AC voltage AD offset
	g_f_DCAC_Vout	DC-AC voltage value
	g_f_DCAC_offset_Iac_Hall	DC-AC AC current offset
	g_f_DCAC_Iac_Hall	DC-AC AC current
	_f_VacRMS	AC-DC input voltage rms value
	_f_IacRMS	AC-DC input current rms value
	_f_IacRMSLpf	Filtered value of AC-DC input current rms value
	_f_IacRMSSum	Cumulative value for current rms value calculation
	_f_VacRMSSum	Cumulative value for voltage rms value calculation
	_f_VacTemp	Buffer for calculating the effective voltage value
	_f_IacTemp	Buffer for current rms value calculation
	g_s4_position_trigger	AD sampling trigger timing setting value A
	g_s4_position_triggerB	AD sampling trigger timing setting value B (To trigger at one point, set to the same value as Trigger A.)
	g_u2_ModeSystem	Operating-mode 0: STOP 1: RUN 2: ERROR
	g_u2_ModeSystem_Request	Command acceptance (control operation mode) 0:STOP 1:RUN 2:ERROR 3:RESET
	g_u2_TimeSetting_Offset	Variable for setting calibration time at startup
	g_u2_TimeCnt_Offset	Count value for calibration at startup
	g_u2_ErrorFlag_CurLoop	Error Flag
	g_u2_Cnt_VacOffset	Count for AC voltage offset calculation
	g_u2_Enable_VacOffset	Flag for AC voltage offset calculation

RENESAS

	g_u2_Cnt_Offset_Lpf_Vac	Count value for AC voltage offset filter (average filter expression)
	Ics_cnt	Subtracted count value for ICS
	_u2_CntRmsCal	Count for RMS calculation
	g_u2_poe_flag	Flag on POE Error
	g_u2_deci_cnt	Control period thinning count value
	g_u2_delay	Count value for the delay time before charging the battery
	g_u2_seg_data	7Seg indication data
	g_u2_seg_time	Counted value for 7Seg indication cycle
	g_u2_seg_error_temp	Buffered value of the erroneous part of 7Seg indication data
	g_u2_led1_display	LED1 data
	g_u2_led2_display	LED2 data
	g_u2_led3_display	LED3 data
	g_u2_sw1_status	SW1 input data
	g_u2_sw2_status_old	SW2 input-data OLD
	g_u2_sw2_status	SW2 Input data-NEW
	g_u1_Error_Status	Command input error display flag
r_pwr_IOLIB_INV_MTU_AD.c	_u2_LibVersion	Library version
	_u2_Clock	Operating clock (160MHz)
	_u2_HalfCarrierC1	PWM generated timer MTU3/4 50% duty for AC-DC
	_u2_TopCarrierC1	PWM generated timer MTU3/4 "Carrier cycle/2" for AC-DC (MTU3.TGRA)
	_u2_DeadtimeC1	PWM generated timer MTU3/4 dead-time for AC-DC
	_u2_HalfCarrierC2	PWM generated timer MTU6/7 50% duty for DC-DC
	_u2_TopCarrierC2	PWM generated timer MTU6/7 "Carrier cycle/2" for DC-DC (MTU6.TGRA)
	_u2_DeadtimeC2	PWM generated timer MTU6/7 dead-time for DC-DC
	_u2_HalfCarrierC3	PWM generated timer GPT0/1/2 50% duty for DC-AC
	_u2_TopCarrierC3	PWM generated timer GPT0/1/2 "Carrier cycle/2" for DC-AC (GPTWx.GTCCRA)
	_u2_DeadtimeC3	PWM-generated timer GPT0/1/2 dead-time for DC-AC
r_pwr_pfc_ctrl.c	g_f_Vref_Pfc	PFC output command value
	g_f_Vref_Pfc_Temp	Buffer for PFC output command (for software start)
	g_f_Vref_Pfc_Ripple	Maximum allowable value of the ripple on the positive side of the PFC output
	g_f_KpFactor_Vpfc	PFC voltage control PI gain Kp
	g_f_KiFactor_Vpfc	PFC voltage control PI gain Ki
	g_f_I_Pfc_Limit	PFC current command value limit
	g_f_I_Pfc_Refi	Integral value of PFC voltage PI output
	g_f_I_Pfc_RefOver	Maximum value of PFC voltage PI output
	g_f_I_Pfc_Ref	PFC current command value
	g_f_KpFactor_Ipfc	PFC current control PI gain Kp
	g_f_KiFactor_Ipfc	PFC current control PI gain Ki
	g_f_Duty_Pfc_Limit	PFC duty limit
	g_f_Iref_Pfc	PFC current command value (sine wave)
	g_f_Duty_Pfc_Refi	Integral value of PFC current control output
	g_f_Duty_Pfc_Ref	Output duty calculated with PFC current control
	g_f_Duty_FF_buf	Duty calculated with FF control
	g_f_Duty_FF	Duty (before limit) combined with PI control and FF control

	g_f_K_Duty_FF	Factor of duty of FF control
	g_f_PFC_SoftStart_Cnt	Count value for software start
	g_f_pfc_duty	Duty (after limit) combined with PI control and FF control
	g_f_Vref_DCDC_Low	Buck control voltage command
	g_f_KpFactor_VDC-DC_Low	Buck control voltage control PI gain Kp
	g_f_KiFactor_VDC-DC_Low	Buck control voltage control PI gain Ki
	g_f_I_DCDC_Low_Refi	Integral of buck control voltage control
	g_f_I_DCDC_Low_Ref	Output current command for buck control voltage control
	g_f_I_DCDC_Low_RefOver	Max. of buck control voltage control
	g_f_I_DCDC_Low_Limit	Buck control current command limiter
	g_f_KpFactor_IDC-DC_Low	Buck control current control PI gain Kp
	g_f_KiFactor_IDC-DC_Low	Buck control current control PI gain Ki
	g_f_Duty_DCDC_Low_Refi	Buck control current control integral
	g_f_Duty_DCDC_Low_Ref	Buck control output duty
	g_f_Duty_DCDC_Low_Limit	Buck control output limiter
	g_f_K_Duty_DCDC_Low_FF	Calculated buck control FF control duty
	g_f_Vref_DCDC_High	Boost control voltage command
	g_f_KpFactor_VDC-DC_High	Boost control voltage control PI gain Kp
	g_f_KiFactor_VDC-DC_High	Boost control voltage control PI gain Ki
	g_f_I_DCDC_High_Refi	Integral of boost control voltage control
	g_f_I_DCDC_High_Ref	Output current command for boost control voltage control
	g_f_I_DCDC_High_RefOver	Max. of Boost control voltage control
	g_f_I_DCDC_High_Limit	Boost control current command limiter
	g_f_KpFactor_IDC-DC_High	Boost control current control PI gain Kp
	g_f_KiFactor_IDC-DC_High	Boost control current control PI gain Ki
	g_f_Duty_DCDC_High_Refi	Boost control current control integral
	g_f_Duty_DCDC_High_Ref	Boost control output duty
	g_f_Duty_DCDC_High_Limit	Boost control output limiter
	g_f_K_Duty_DCDC_High_FF	Calculated boost control FF control duty
	g_f_DCAC_theta	Calculated DC-AC power
	g_f_DCAC_dtheta	Δ-angle for calculating DC-AC outputting period
	g_f_DCAC_Vamp	DC-AC output voltage peak
	g_f_DCAC_Vout_Ref	Calculate DC-AC sinusoidal voltage command
	g_f_DCAC_Mref	DC-AC power duty computation
	g_f_DCAC_SinOff	Adjusted DC-AC output offset
	g_u2_ACDC_Status	AC-DC operation status flag
	g_u2_DCDC_Status	DC-DC operation status flag
	g_u2_DCAC_Status	DC-AC operation status flag

4.5   Macro definitions list

The following table lists the macro definitions used in this control program.

Table 22 Macro definitions list

File	Definition	Definition Value	Overview
DTL_pfc_ctrl.h	SEQ_ACDC_VAC_REF	80 (Vrms)	AC-DC's threshold Threshold value for PFC operation
	SEQ_DCDC_BOOST_VDC_REF	153 (V)	DC-DC high voltage Threshold for Boost operation judgment.
	SEQ_DCDC_BOOST_VBAT_REF	23 (V)	Battery value Threshold for boost operation judgment.
	SEQ_DCDC_BUCK_VBAT_REF	27.5 (V)	DC-DC low voltage

RENESAS

			Threshold for buck operation judgment.
	CTRL_ACDC_VDC_REF	170 (V)	Set the output voltage of the PFC.
	CTRL_DCDC_VDC_REF	150 (V)	Sets the high voltage reference of DC-DC. Voltage command value when battery discharge.
	CTRL_DCDC_VBAT_REF	27 (V)	Sets the low voltage reference of DC-DC. Voltage command value when battery charging.
	CTRL_DCAC_VAC_REF	140 (V)	Sets DC-AC power. 100Vrms peaks at 140V.
	DELAY_ON	65000	Sets the delay time prior to Buck operation. Actual time = set value/30k
	SEG_TIME_ALL	5000	Sets the total duration for displaying 7SEG. Do not set it for 3 seconds or less. Time = set value/1000

4.6 Control flow

4.6.1 Main processing
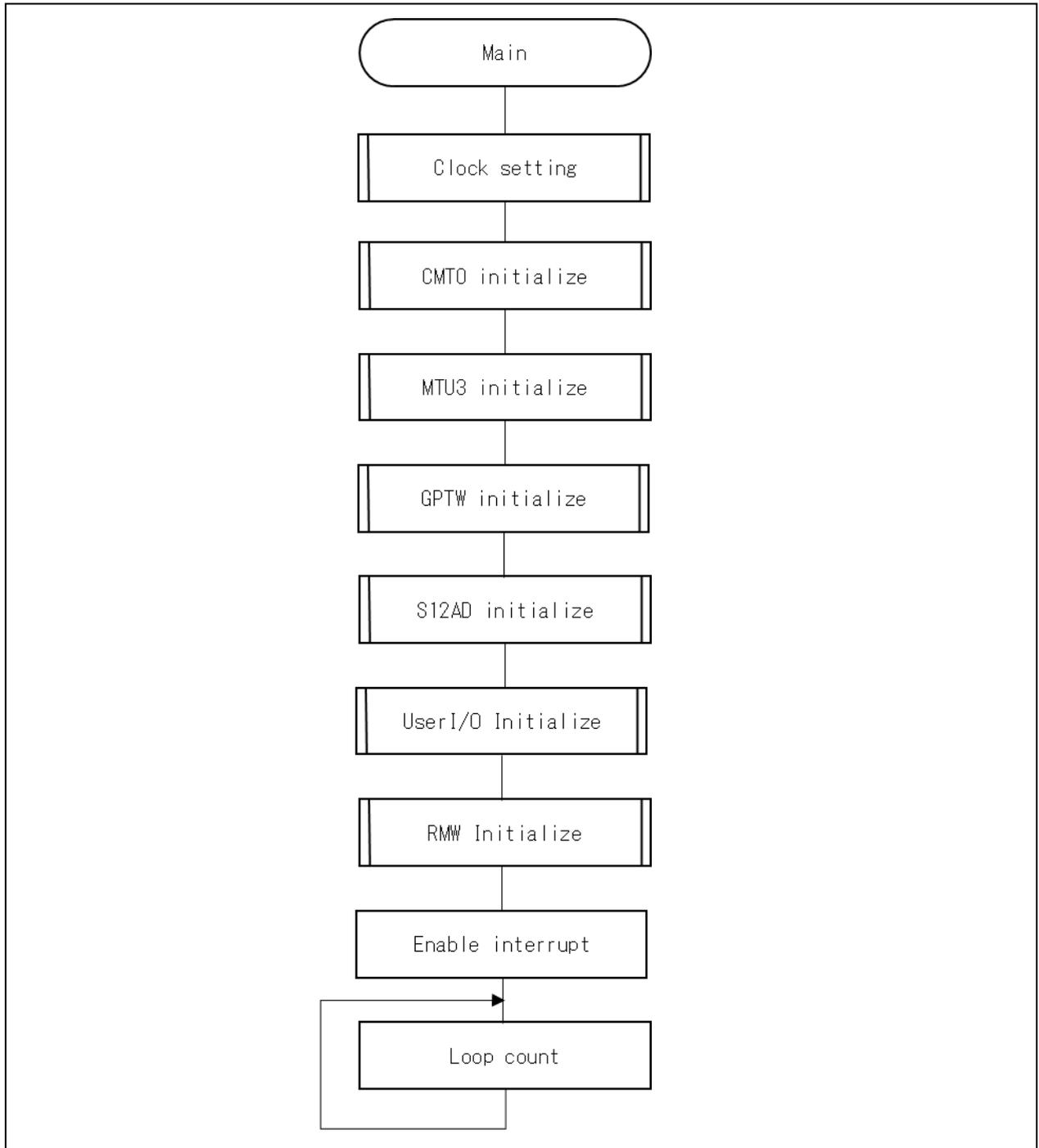
Figure 36 Main processing

4.6.2　1 kHz cycle sequence processing
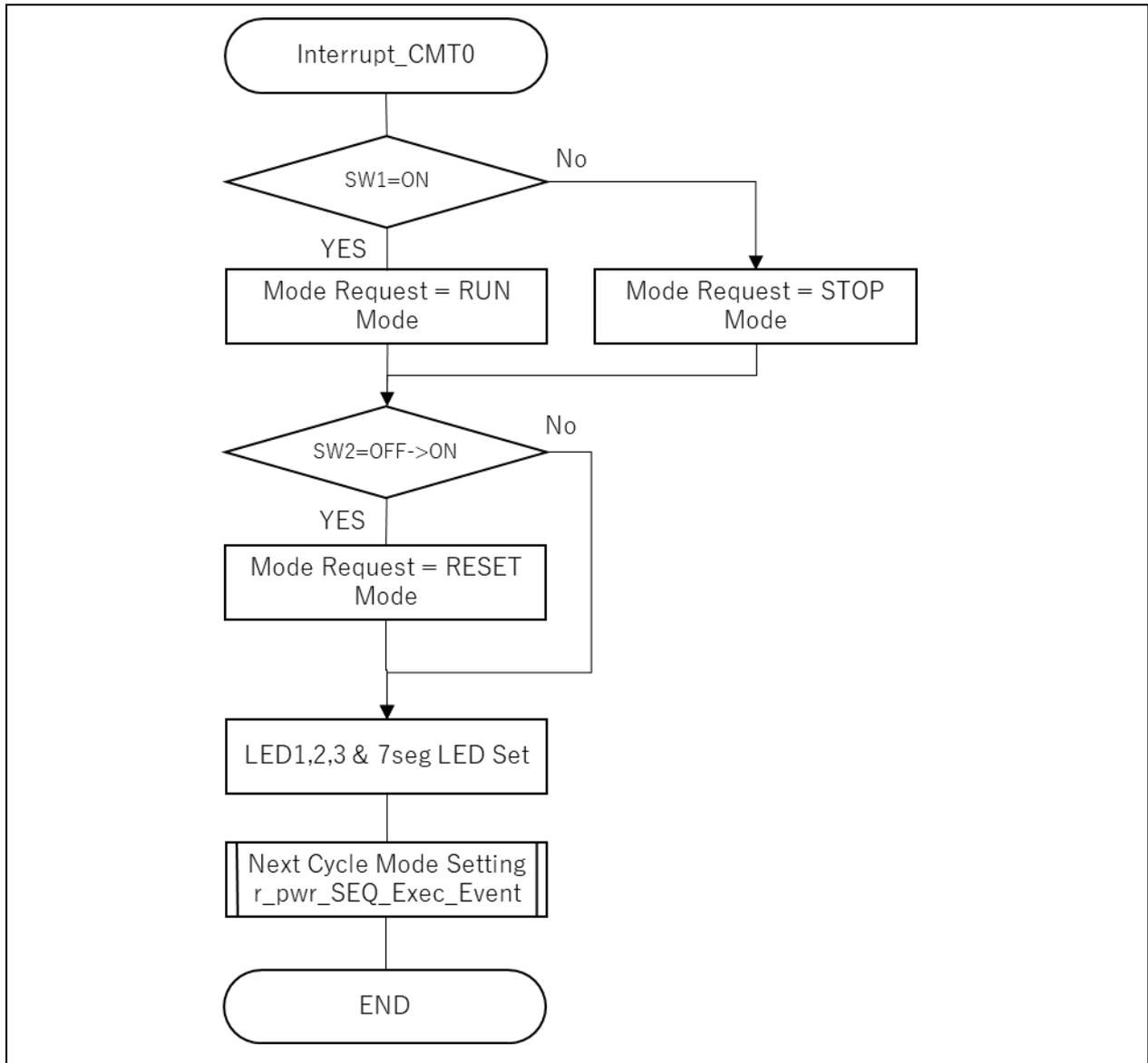
Figure 37 1kHz period sequence processing (CMT0 interrupt processing)
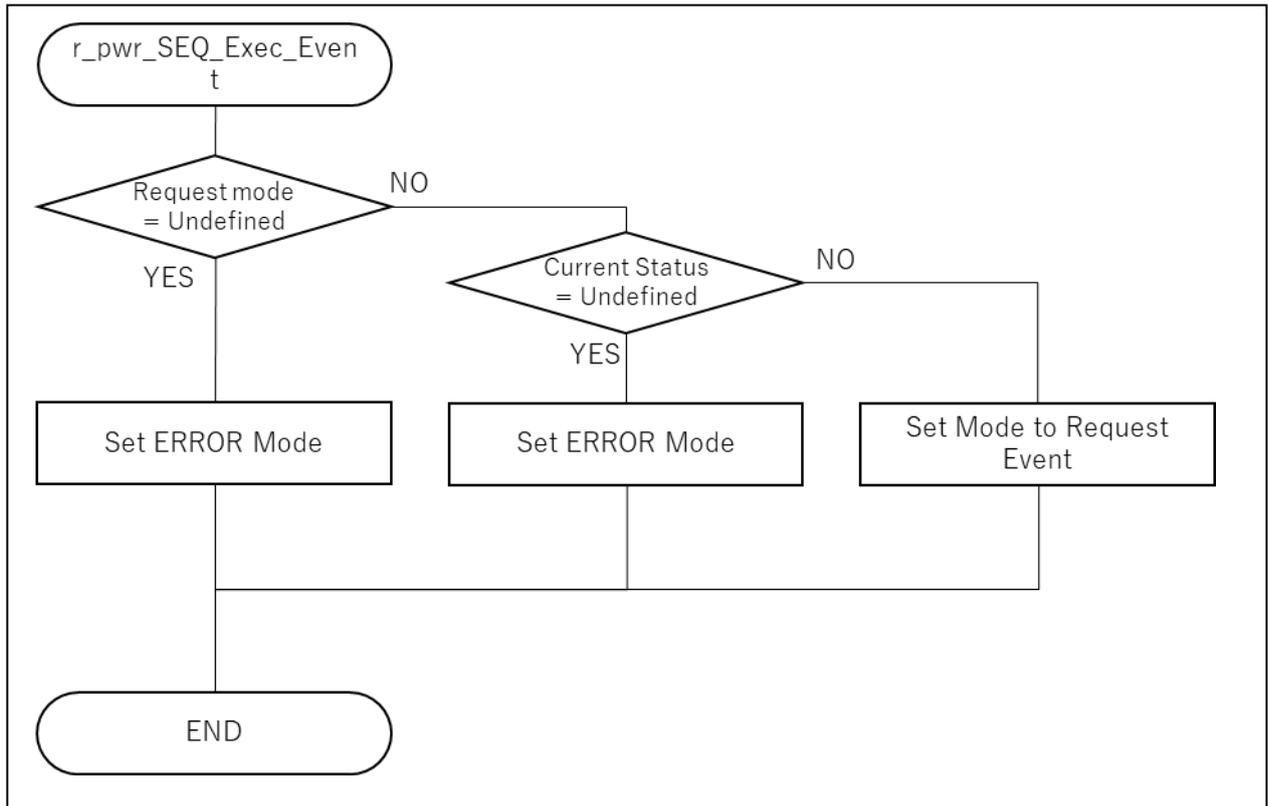
Figure 38 Next cycle mode setting processing

4.6.3   30kHz cycle system control processing
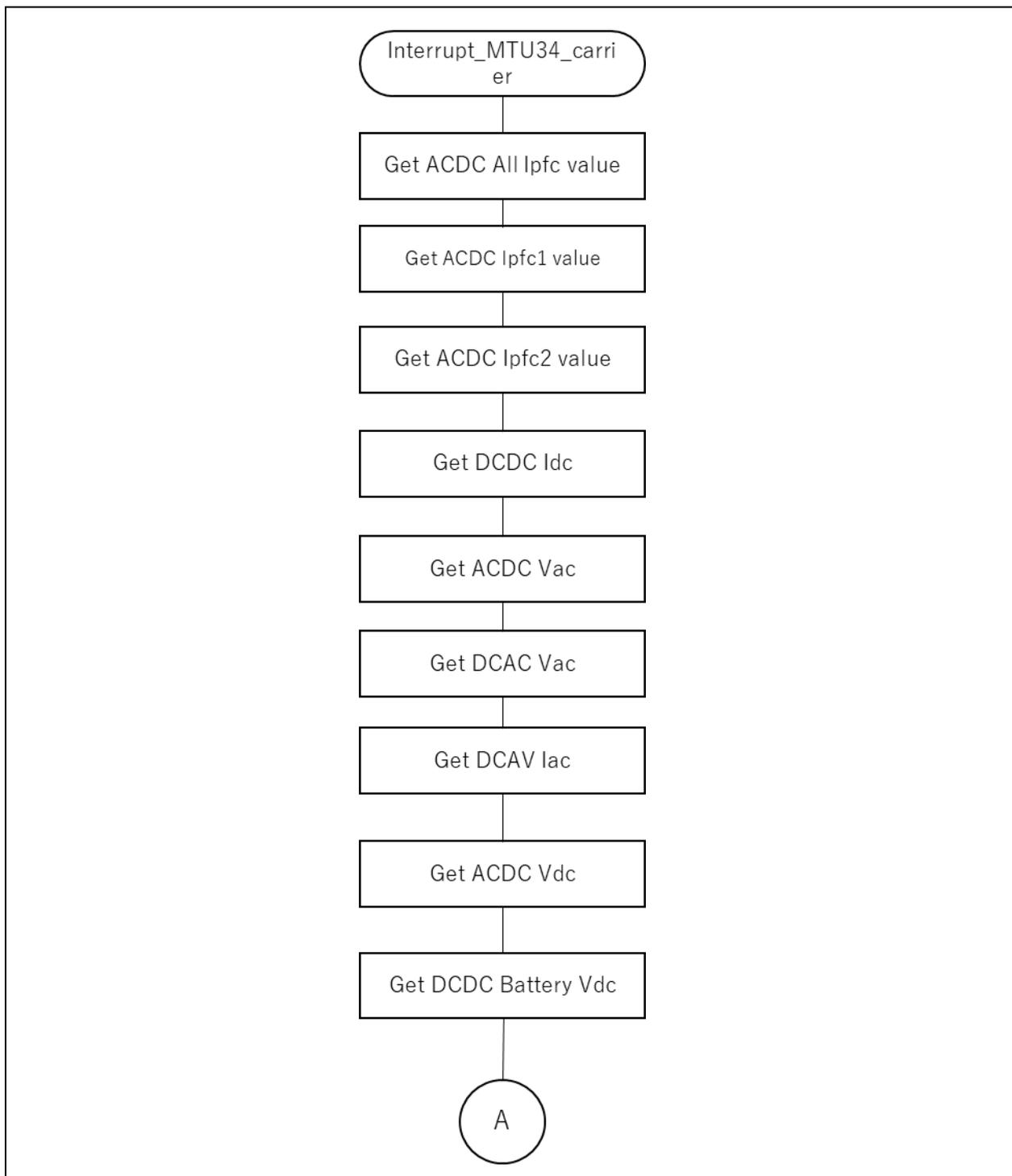
Figure 39 System control process (MTU3/4 interrupt process), Part 1
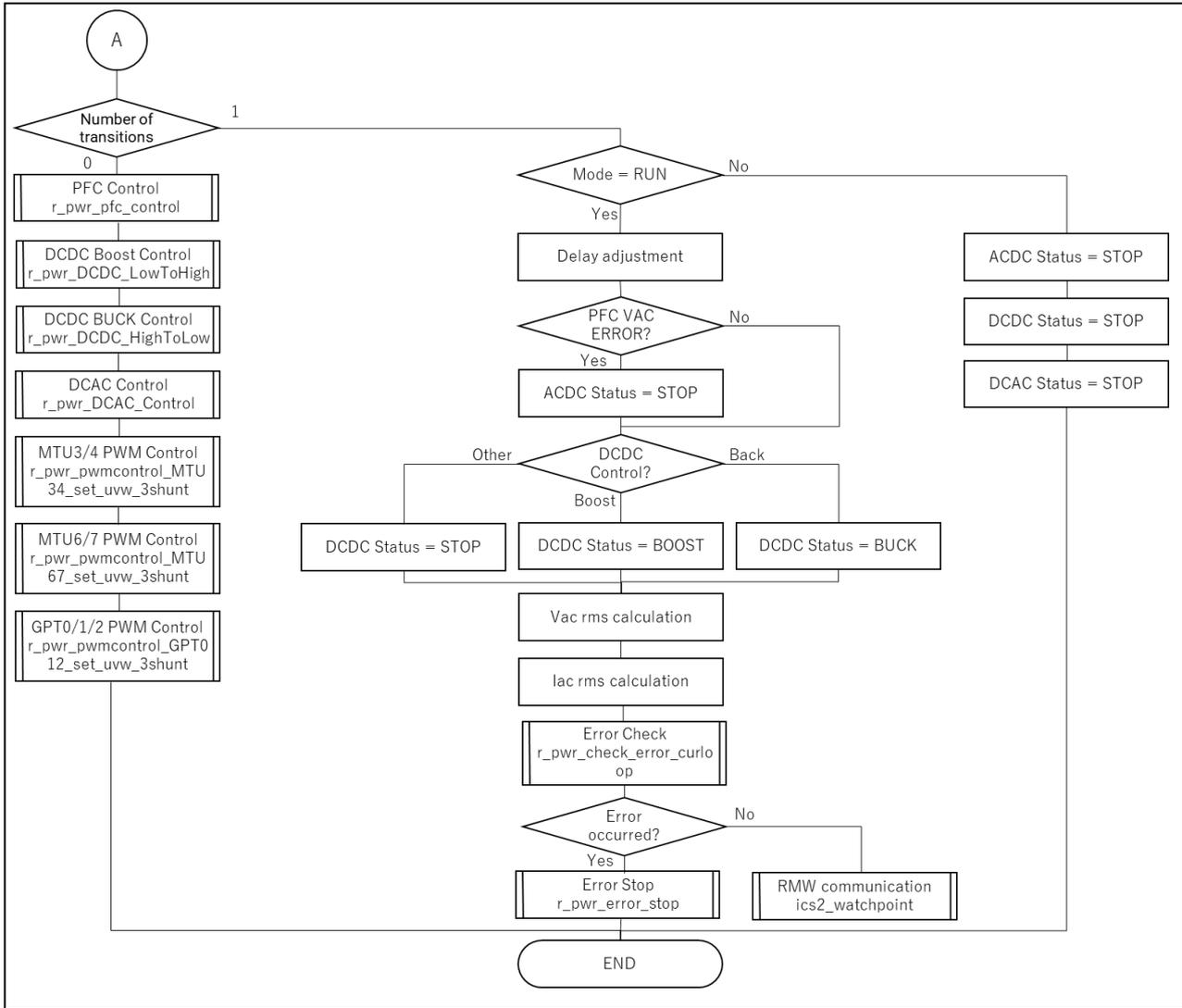
Figure 40 System control process (MTU3/4 interrupt process) Part 2
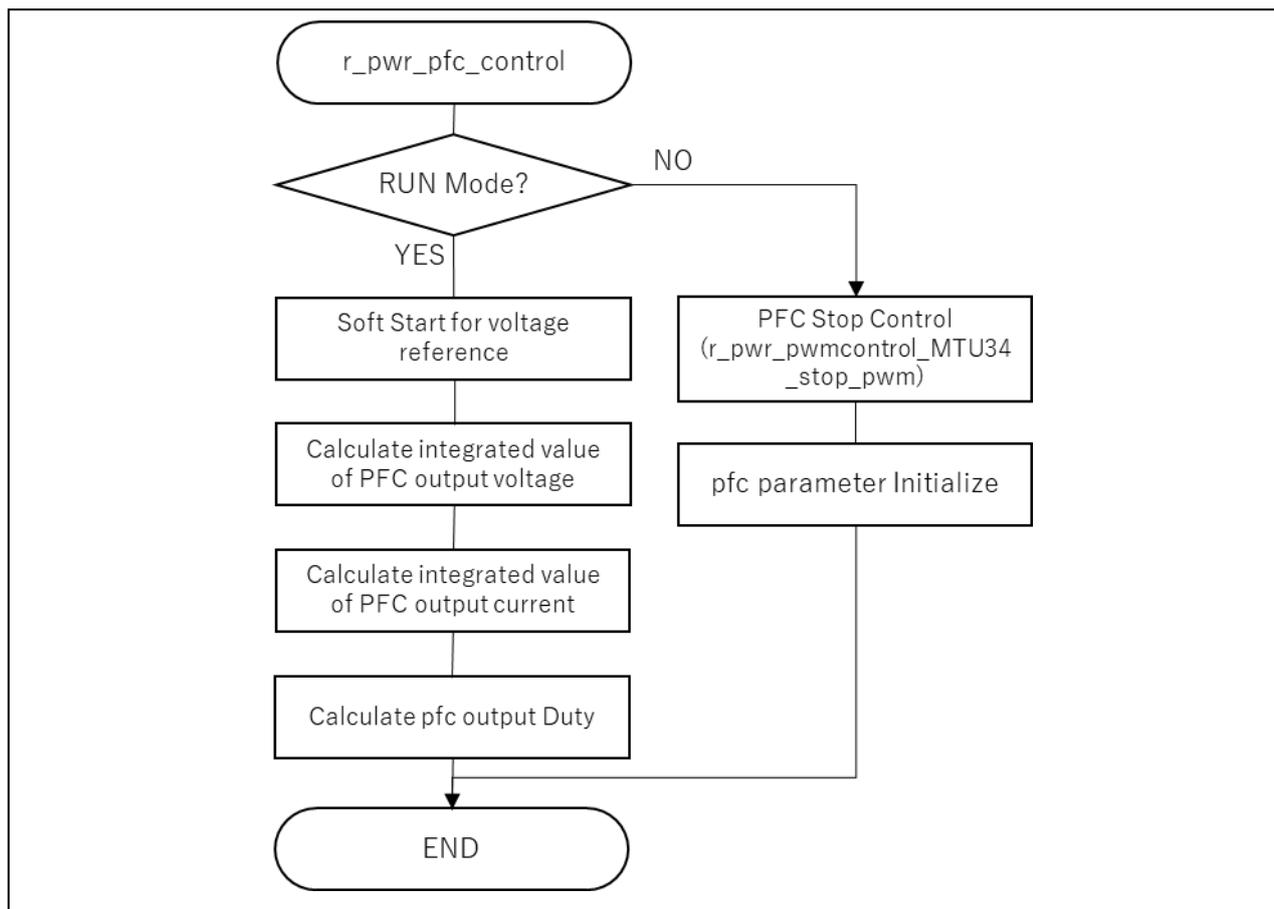
Figure 41 AC-DC converters (PFC control) process
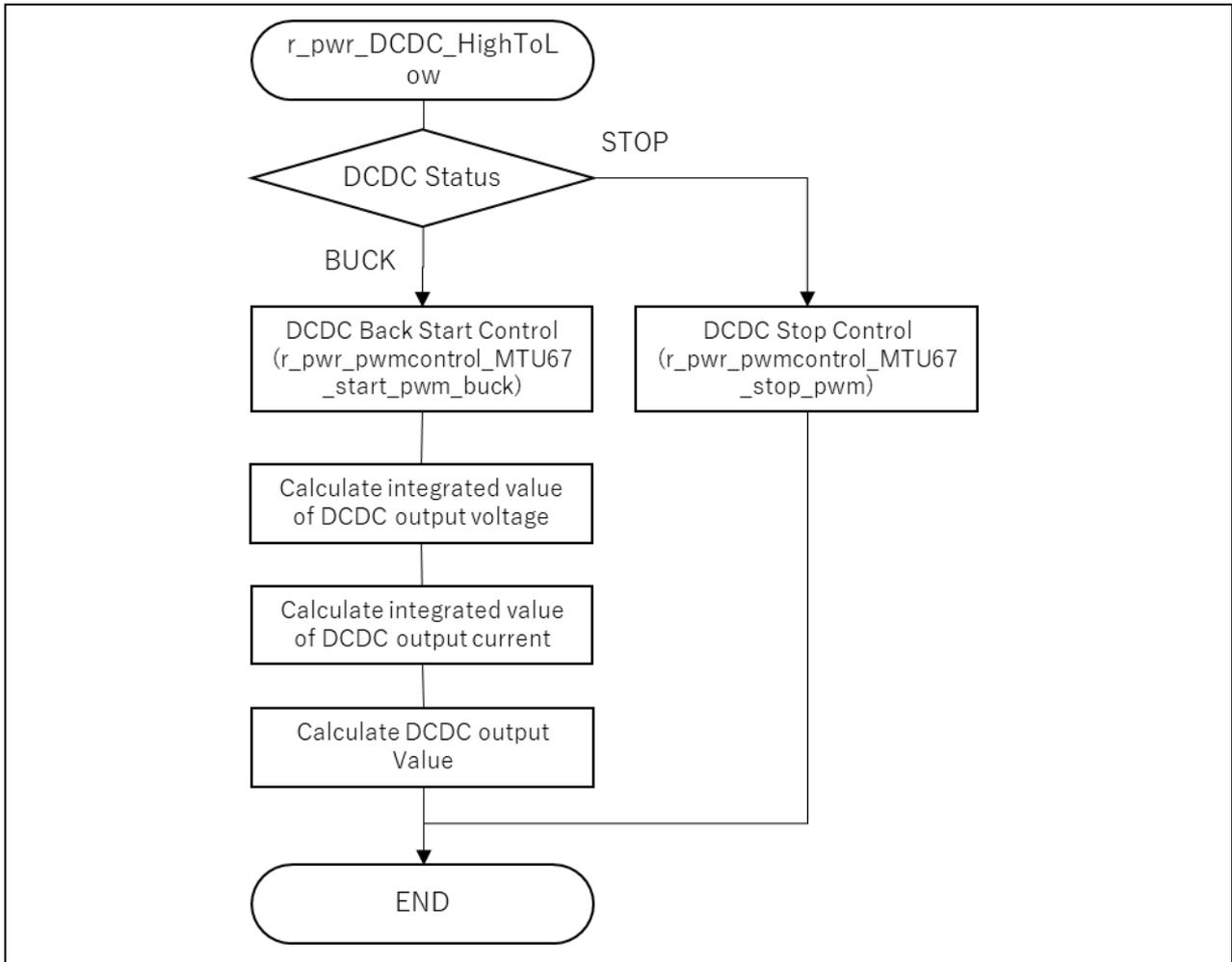
Figure 42 DC-DC converter (Buck converter) process
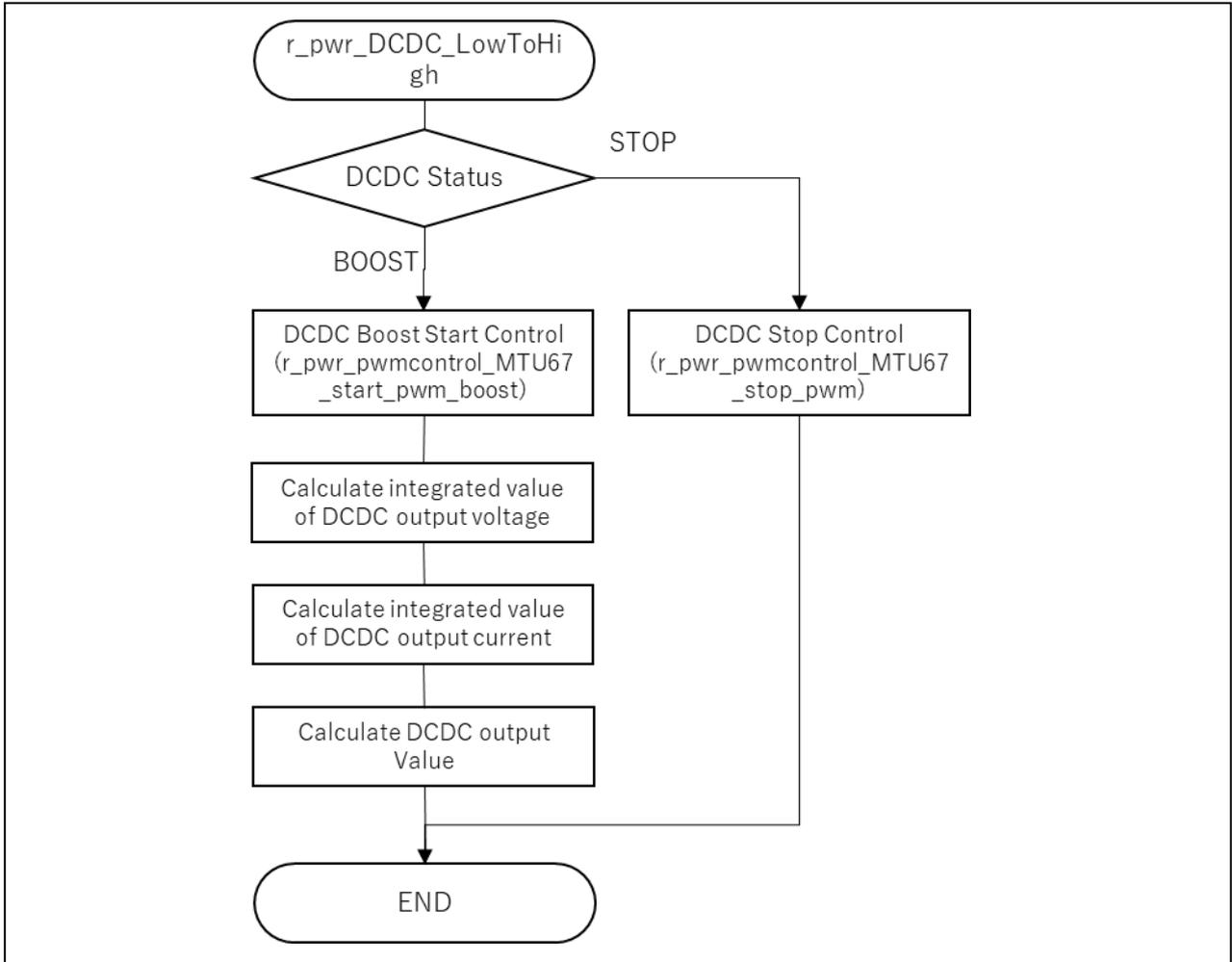
Figure 43 DC-DC converter (Boost converter) process
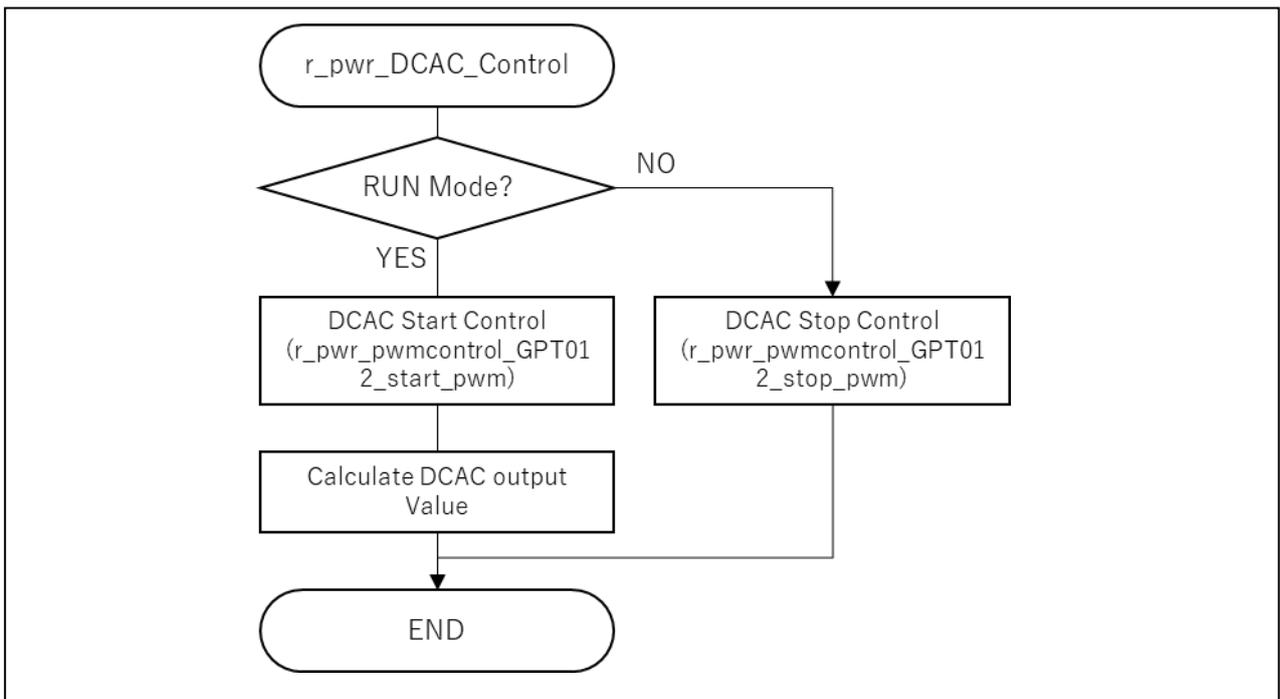
Figure 44 DC-AC inverter process
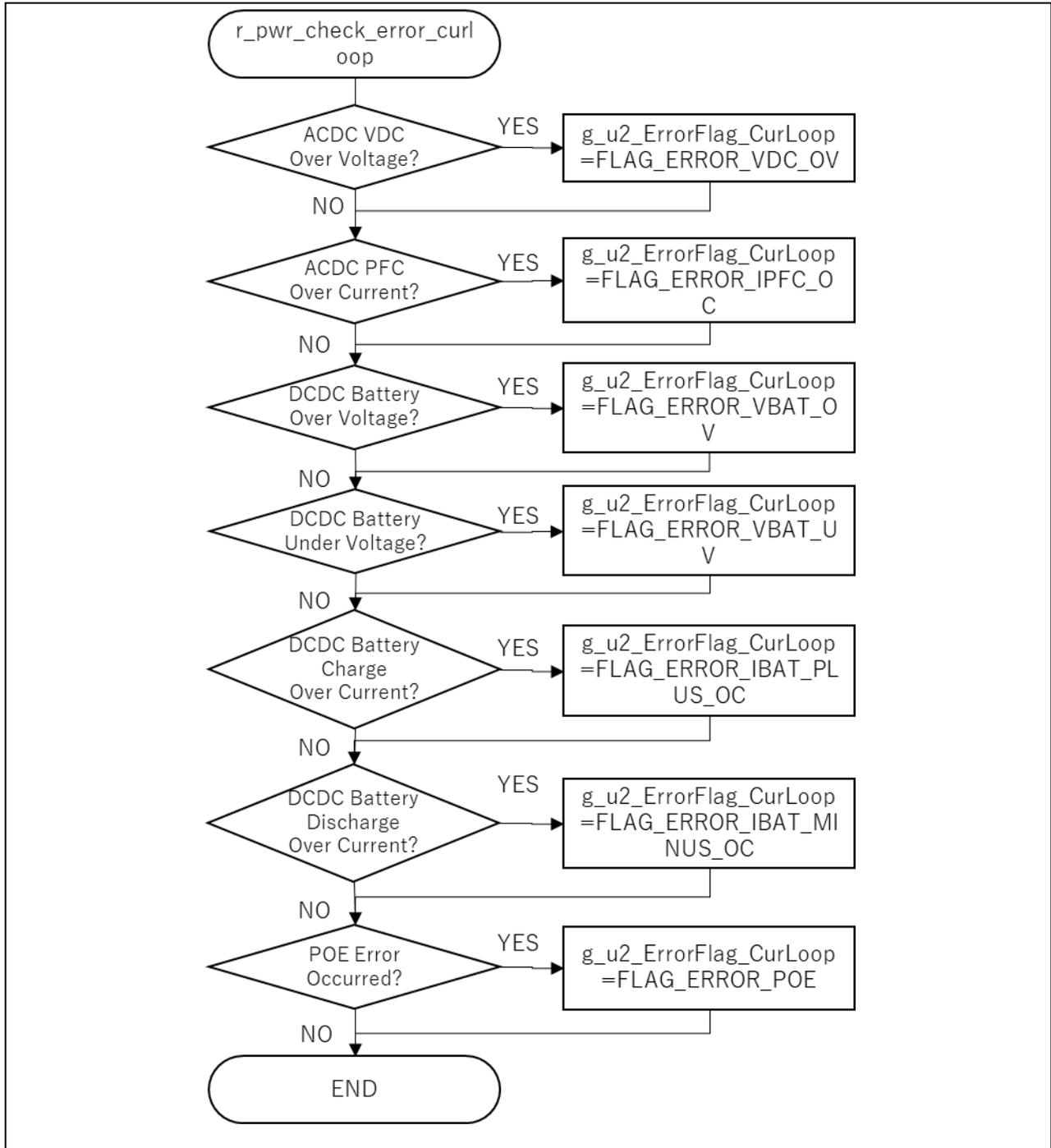
Figure 45 Current cycle error check process
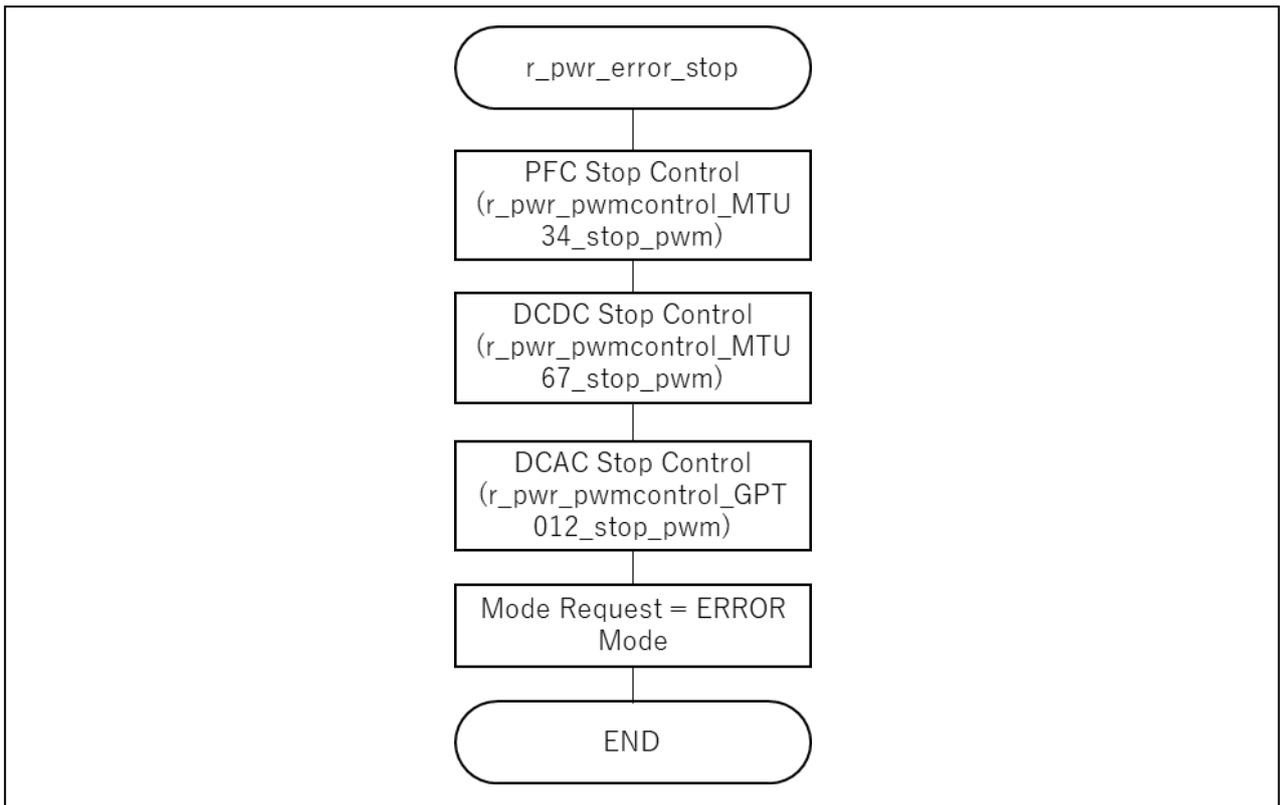
Figure 46 Error stop process

5. Renesas Motor Workbench, Motor Control Development Support Tool

5.1 Overview

In the target software of this application note, the motor control development support tool "Renesas Motor Workbench" is used as a status monitor. For the variables that can be monitored, refer to 4.4 Variables list. Figure 47 shows the operating environment of "Renesas Motor Workbench", and Figure 48 shows an external view of the window of "Renesas Motor Workbench". For more information on how to use this function, refer to the "Renesas Motor Workbench User's Manual (R21UZ0004)". Also, obtain the motor control support tool "Renesas Motor Workbench" from our website.
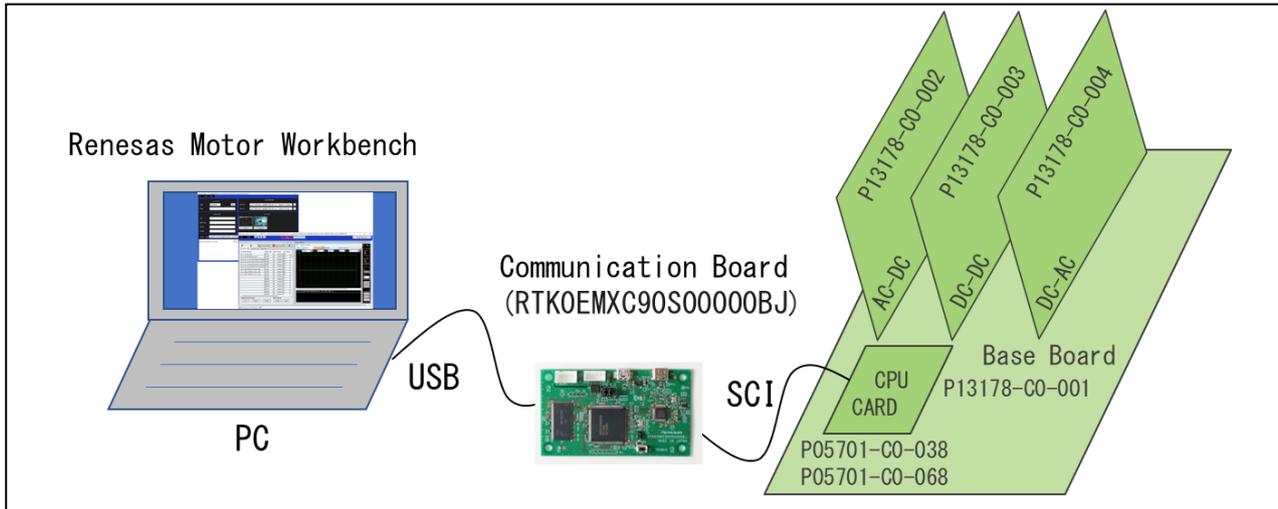
Figure 47 Renesas Motor Workbench Operating conditions
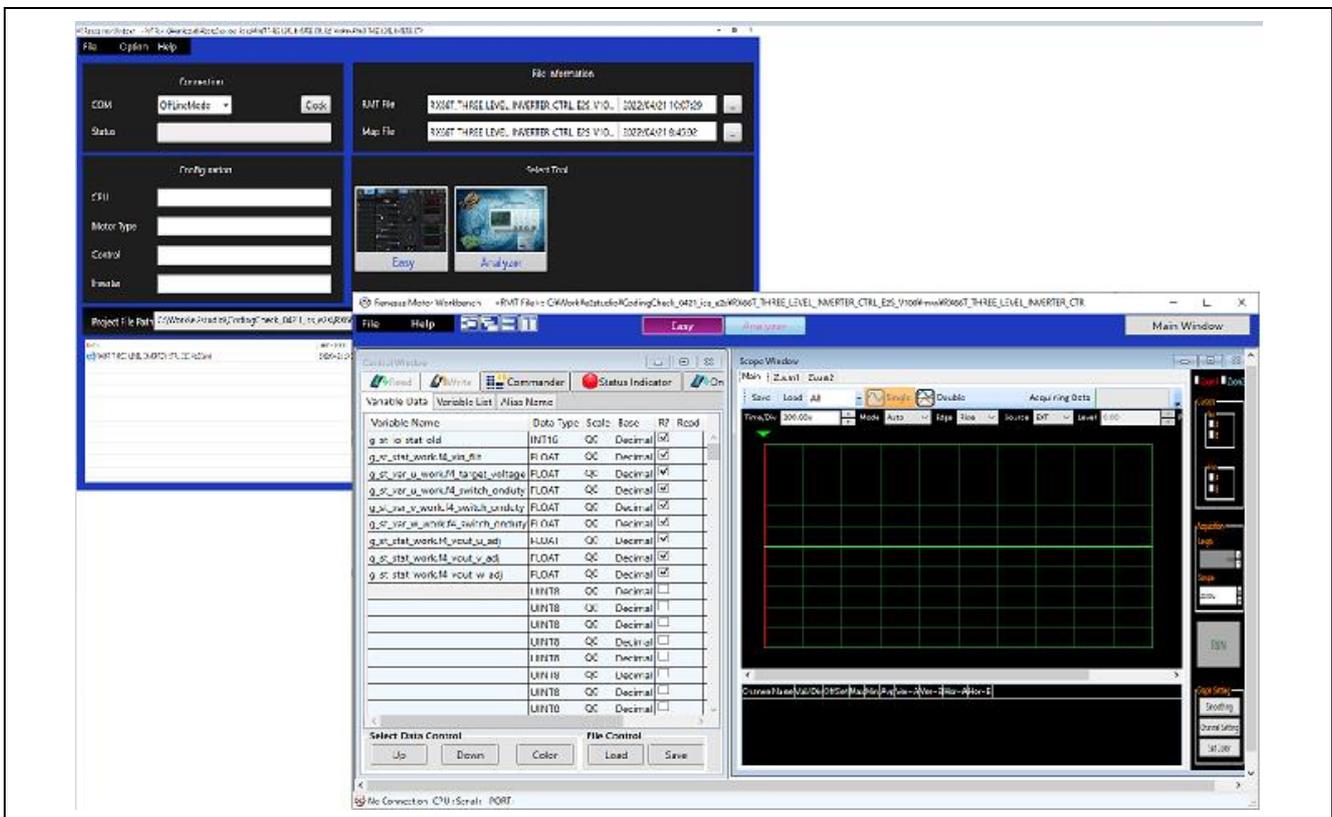
Figure 48 External view of Renesas Motor Workbench

How to use Renesas Motor Workbench3.0 motor control support tool

① Click the tool icon to launch the tool.

② From MENU of Main Panel, select [RMTFile] → [Open RMT File (O)].
Load the RMT file in the "ics" folder of the project folder.

③ Select the COM of the "Connection" COM-connected kit.

④ Click "Analyzer" in the upper-right corner of Select Tool to open Analyzer function window.

5.2 Analyzer list

Variables for displaying waveforms when Analyzer user interface is used are global variables.
For the applicable variables, Refer to Table 21 Variables list.

6. Measurement data

The power factor measurement results of the continuous inverter system UPS system in this application note are shown in 6.1, and the instantaneous power failure test results are shown in 6.2.

6.1 Power factor measurement results

Figure 49 shows the measurement environment and Figure 50 shows the measurement results.
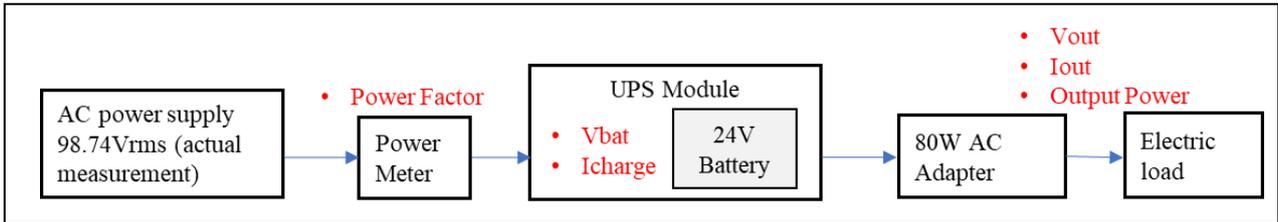
Figure 49 Measurement environment

Operation	Power Factor	Output Power (W)	Vout (V)	Iout (A)	Vbat (V)	Icharge (A)
AC-DC (PFC)	0.46	0.1978	19.78	0.01		
	0.7722	9.83	19.66	0.5		
	0.9091	19.49	19.49	1		
	0.9671	29.04	19.36	1.5		
	0.9736	38.46	19.23	2		
	0.9791	47.8	19.12	2.5		
	0.9815	57.12	19.04	3		
	0.9839	66.5145	18.95	3.51		
	0.987	75.6286	18.86	4.01		
AC-DC (PFC)+ DC-DC (Buck)	0.9846	85.2708	18.86	4.01	26.06	0.37
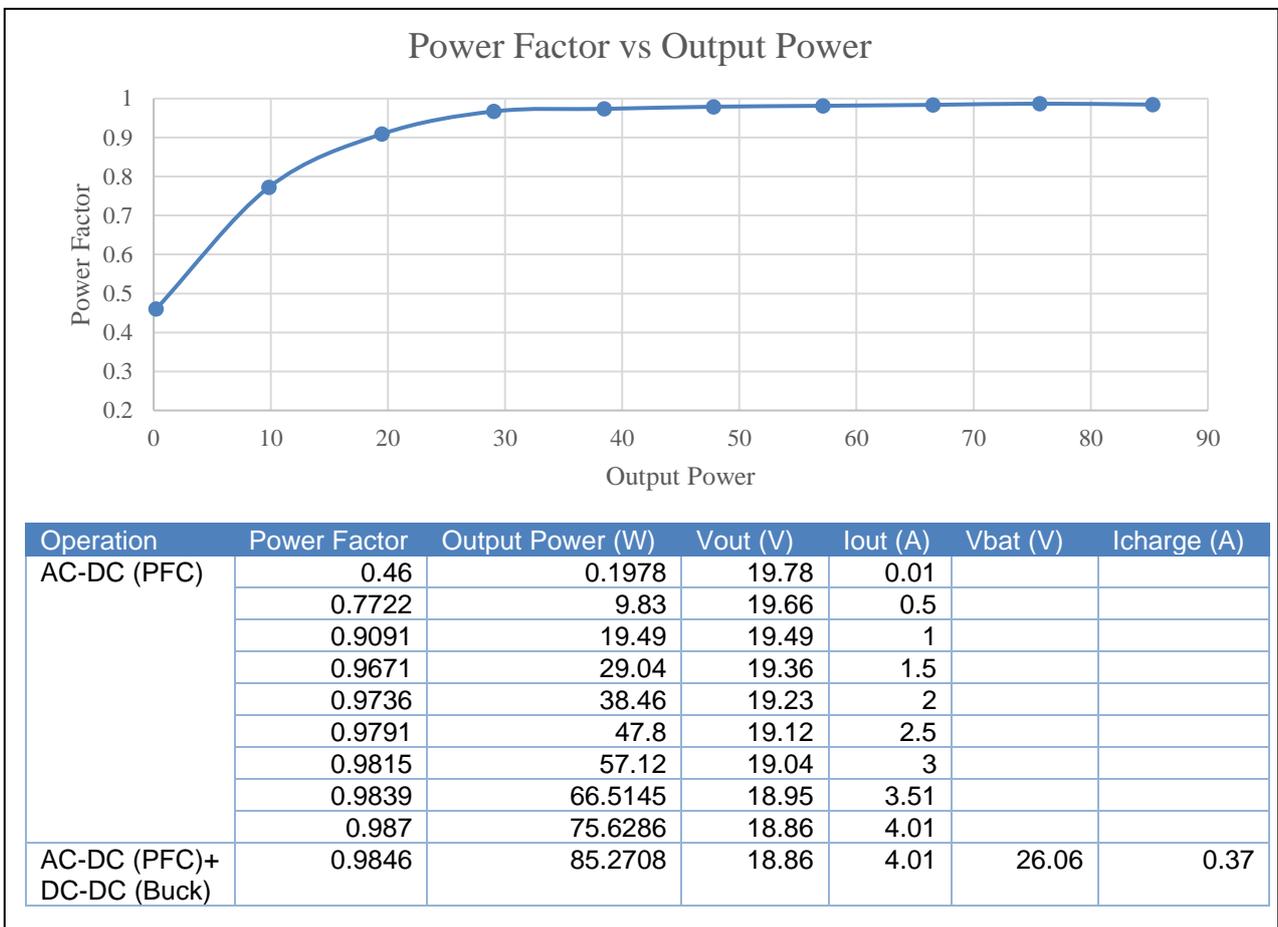
Figure 50 Power factor measurement results

6.2   Results of instantaneous power failure test

The following shows the results of an instantaneous power failure test with a total load of 100W or more by connecting an AC adapter (set to 60W) to the load and an actual notebook computer. Figure 51 shows the test environment, Figure 52 shows the AC output waveform in the event of a momentary power failure, and Figure 53 shows the AC output waveform in the event of recovery from an instantaneous power failure.
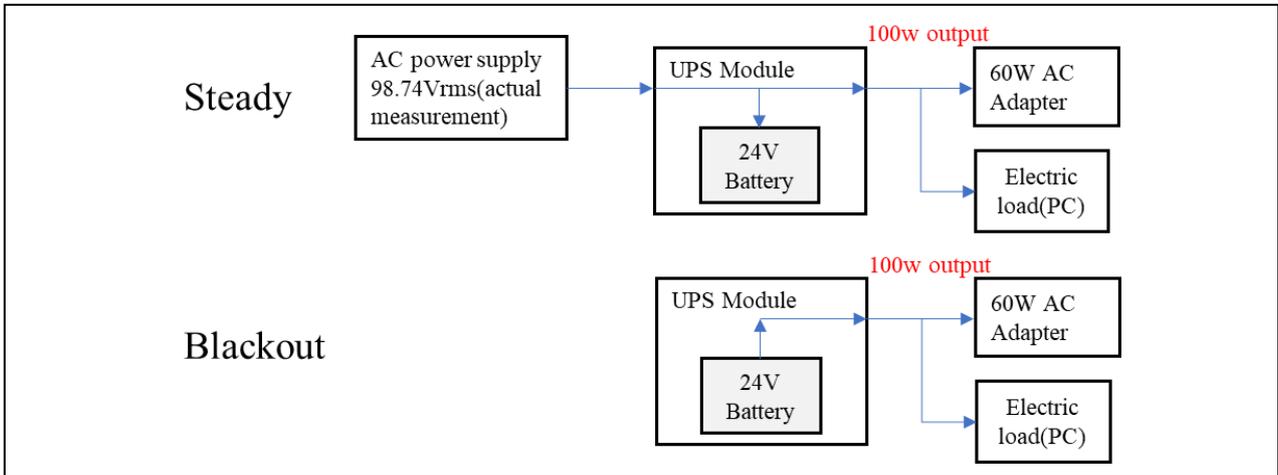
Figure 51 Momentary power loss test environment

When an instantaneous power failure occurs, the power supply from AC-DC (interleaved PFC) is interrupted as shown in ①, but as shown in ②, the power supply is started from the (instantaneous power failure is detected and DC-DC (Boost Converter) to maintain the voltage of DC-DC's high voltage line (same line as AC-DC's output voltage). Thus, as shown in ③, the power output operation of DC-AC inverter is not disturbed and the output is continued.

Figure 52 AC output waveform during momentary power failure

RENESAS

As shown in ①, when the AC power supply is restarted (when the power failure is restored), the power supply from AC-DC (interleaved PFC) is restarted as shown in ② and the power supply from DC-DC (Boost Converter is also stopped. Operation is performed without dropping the voltage of the high voltage line (the line that is the same as the output voltage of AC-DC), which is the input voltage of DC-AC. Thus, as shown in ③, the power output operation of DC-AC inverter is not disturbed and the output is continued.

Figure 53 AC output waveform at recovery from momentary power loss

Revision History

Rev.	Date	Description Page	Summary
1.00	Jun.14.22	-	First edition
1.10	Jun.1.23	1	Added RX26T, RX660 to applied products
1.20	Feb.23.24	All	Added RX26T explanation by the addition of the RX26T version project.

General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Precaution against Electrostatic Discharge (ESD)

    A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.

2. Processing at power-on

    The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.

3. Input of signal during power-off state

    Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.

4. Handling of unused pins

    Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.

5. Clock signals

    After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.

6. Voltage application waveform at input pin

    Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).

7. Prohibition of access to reserved addresses

    Access to reserved addresses is prohibited. The reserved addresses are provided for possible future expansion of functions. Do not access these addresses as the correct operation of the LSI is not guaranteed.

8. Differences between products

    Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

Notice

1. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation or any other use of the circuits, software, and information in the design of your product or system. Renesas Electronics disclaims any and all liability for any losses and damages incurred by you or third parties arising from the use of these circuits, software, or information.

2. Renesas Electronics hereby expressly disclaims any warranties against and liability for infringement or any other claims involving patents, copyrights, or other intellectual property rights of third parties, by or arising from the use of Renesas Electronics products or technical information described in this document, including but not limited to, the product data, drawings, charts, programs, algorithms, and application examples.

3. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.

4. You shall be responsible for determining what licenses are required from any third parties, and obtaining such licenses for the lawful import, export, manufacture, sales, utilization, distribution or other disposal of any products incorporating Renesas Electronics products, if required.

5. You shall not alter, modify, copy, or reverse engineer any Renesas Electronics product, whether in whole or in part. Renesas Electronics disclaims any and all liability for any losses or damages incurred by you or third parties arising from such alteration, modification, copying or reverse engineering.

6. Renesas Electronics products are classified according to the following two quality grades: "Standard" and "High Quality". The intended applications for each Renesas Electronics product depends on the product's quality grade, as indicated below.

    "Standard": Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; industrial robots; etc.

    "High Quality": Transportation equipment (automobiles, trains, ships, etc.); traffic control (traffic lights); large-scale communication equipment; key financial terminal systems; safety control equipment; etc.

    Unless expressly designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not intended or authorized for use in products or systems that may pose a direct threat to human life or bodily injury (artificial life support devices or systems; surgical implantations; etc.), or may cause serious property damage (space system; undersea repeaters; nuclear power control systems; aircraft control systems; key plant systems; military equipment; etc.). Renesas Electronics disclaims any and all liability for any damages or losses incurred by you or any third parties arising from the use of any Renesas Electronics product that is inconsistent with any Renesas Electronics data sheet, user's manual or other Renesas Electronics document.

7. No semiconductor product is absolutely secure. Notwithstanding any security measures or features that may be implemented in Renesas Electronics hardware or software products, Renesas Electronics shall have absolutely no liability arising out of any vulnerability or security breach, including but not limited to any unauthorized access to or use of a Renesas Electronics product or a system that uses a Renesas Electronics product. RENESAS ELECTRONICS DOES NOT WARRANT OR GUARANTEE THAT RENESAS ELECTRONICS PRODUCTS, OR ANY SYSTEMS CREATED USING RENESAS ELECTRONICS PRODUCTS WILL BE INVULNERABLE OR FREE FROM CORRUPTION, ATTACK, VIRUSES, INTERFERENCE, HACKING, DATA LOSS OR THEFT, OR OTHER SECURITY INTRUSION ("Vulnerability Issues"). RENESAS ELECTRONICS DISCLAIMS ANY AND ALL RESPONSIBILITY OR LIABILITY ARISING FROM OR RELATED TO ANY VULNERABILITY ISSUES. FURTHERMORE, TO THE EXTENT PERMITTED BY APPLICABLE LAW, RENESAS ELECTRONICS DISCLAIMS ANY AND ALL WARRANTIES, EXPRESS OR IMPLIED, WITH RESPECT TO THIS DOCUMENT AND ANY RELATED OR ACCOMPANYING SOFTWARE OR HARDWARE, INCLUDING BUT NOT LIMITED TO THE IMPLIED WARRANTIES OF MERCHANTABILITY, OR FITNESS FOR A PARTICULAR PURPOSE.

8. When using Renesas Electronics products, refer to the latest product information (data sheets, user's manuals, application notes, "General Notes for Handling and Using Semiconductor Devices" in the reliability handbook, etc.), and ensure that usage conditions are within the ranges specified by Renesas Electronics with respect to maximum ratings, operating power supply voltage range, heat dissipation characteristics, installation, etc. Renesas Electronics disclaims any and all liability for any malfunctions, failure or accident arising out of the use of Renesas Electronics products outside of such specified ranges.

9. Although Renesas Electronics endeavors to improve the quality and reliability of Renesas Electronics products, semiconductor products have specific characteristics, such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Unless designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not subject to radiation resistance design. You are responsible for implementing safety measures to guard against the possibility of bodily injury, injury or damage caused by fire, and/or danger to the public in the event of a failure or malfunction of Renesas Electronics products, such as safety design for hardware and software, including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult and impractical, you are responsible for evaluating the safety of the final products or systems manufactured by you.

10. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. You are responsible for carefully and sufficiently investigating applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive, and using Renesas Electronics products in compliance with all these applicable laws and regulations. Renesas Electronics disclaims any and all liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.

11. Renesas Electronics products and technologies shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations. You shall comply with any applicable export control laws and regulations promulgated and administered by the governments of any countries asserting jurisdiction over the parties or transactions.

12. It is the responsibility of the buyer or distributor of Renesas Electronics products, or any other party who distributes, disposes of, or otherwise sells or transfers the product to a third party, to notify such third party in advance of the contents and conditions set forth in this document.

13. This document shall not be reprinted, reproduced or duplicated in any form, in whole or in part, without prior written consent of Renesas Electronics.

14. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products.

(Note1)   "Renesas Electronics" as used in this document means Renesas Electronics Corporation and also includes its directly or indirectly controlled subsidiaries.

(Note2)   "Renesas Electronics product(s)" means any product developed or manufactured by or for Renesas Electronics.

(Rev.5.0-1 October 2020)

Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,
Koto-ku, Tokyo 135-0061, Japan
www.renesas.com

Trademarks

Renesas and the Renesas logo are trademarks of Renesas Electronics Corporation. All trademarks and registered trademarks are the property of their respective owners.

Contact information

For further information on a product, technology, the most up-to-date version of a document, or your nearest sales office, please visit: www.renesas.com/contact/.