RX Family

Digital Power Conversion (Totem Pole Interleaved PFC (AC-DC Converter))

Summary

This application note is intended to describe how to drive and control a totem pole interleaved PFC, which is a AC-DC converter using RX66T group or RX26T group, and how to use motor control development support tool [RMW][*1]. The totem pole interleaved PFC board described in this application note is a board that runs on 50Hz 100V 100W power board kit [*2]'s Base Board(P13178-C0-001). For further information on Base Board(P13178-C0-001) and digital power control, please refer to the Digital Power Conversion (UPS (CCM Interleaved PFC, Chopper DC-DC Converter)) (R01AN6465) of separate application notes.

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.

2: 50Hz 100V 100W power supply board kit is made by Desk Top Laboratories Inc.

Operation check device

The operation of the sample program is checked with the following devices.

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 sample program for this application note is shown below.

- RX66T_P13178_TPPFC_CSP_RV100 (IDE: CS+)
- RX66T_P13178_TPPFC_E2S_RV100 (IDE: e^{2}studio)
- RX26T_P13178_TPPFC_CSP_RV100 (IDE: CS+)
- RX26T_P13178_TPPFC_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 (UPS (CCM Interleaved PFC, Chopper DC-DC Converter)) (R01AN6465)
- Digital Power Conversion (LLC Resonant Converter (DC-DC Converter)) (R01AN7118)

Contents

1. Overview

This application note describes how to control and implement the totem pole interleaved PFC of AC-DC converters in a digital-power-control *1 using RX66T/RX26T group. This section also explains how to use motor control development support tool [RMW].

Note 1: Digital power control means AC-DC converters, DC-DC converters, and DC-AC inverters. Please refer to Digital Power Conversion (UPS (CCM Interleaved PFC, Chopper DC-DC Converter)) (R01AN6465) in the separate application notes for more information.

1.1 Development environment

Table 1 and Table 2 show the development environment of 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
	Totem pole interleaved PFC Board (AC-DC Board)	P13178-C0-005 (Applicable board in this application notes)

Table 2 Software development environment

Device	IDE Version	RX Smart Configurator *3	Toolchain version *2
RX66T	CS+: V8.09.00	Version 2.16.0	CC-RX: V3.05.00
	e²studio:2023-01	e²studio plug-in version	
RX26T	CS+:V8.10.00	Version 2.19.0	CC-RX: V3.05.00
	e²studio:2023-10	e²studio 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. Totem Pole PFC overview

The totem pole PFC is a bridgeless PFC for AC-DC converters. AC-DC converters are divided into a rectifier circuit and a smoothing circuit. The totem pole PFC eliminates the diode-bridge circuit in the rectifier circuit and uses a switching device instead to integrate the rectifier circuit and the smoothing circuit. The bridgeless circuit is divided into a half-bridgeless circuit in which the low-side diode of the rectifier circuit part is replaced with a switching device, and a full-bridgeless circuit in which all the diode bridges are replaced with a switching device. The totem pole PFC is an PFC of a full-bridgeless circuit. Figure 1 shows an image of the efficient VS cost of AC-DC circuitry. Though totem pole PFC are more efficient because they generally replace diode bridges, which account for about 40% of the losses, with switching devices, the costs of the components used tend to be relatively high.

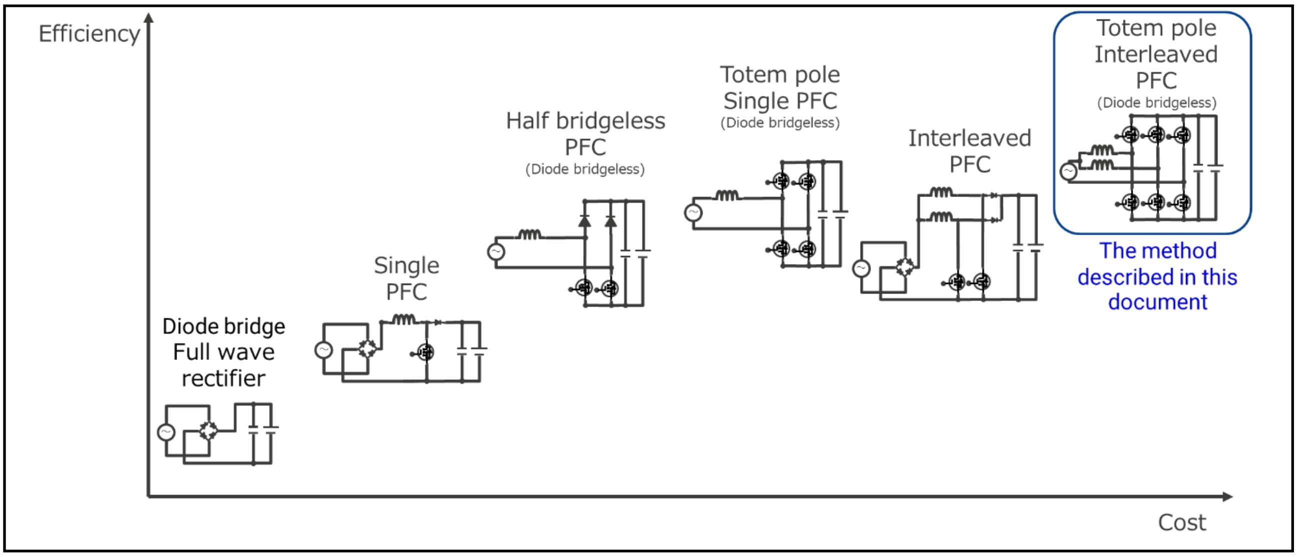


Figure 1 Image of cost-efficiency of AC-DC circuit

2.1 Schematic of a Totem Pole PFC

Figure 2 shows schematic diagram of totem pole PFC (interleaved). Low inductance switching devices are generally used because the left side requires high-speed switching with an interleaved PFC. On the right side, low-speed switching is performed according to the commercial frequency. Therefore, a switching device with a low ON resistor is generally used. The output-voltage and current are determined by the reactance, switching frequency, and Duty. The output-voltage and current can be changed by changing the inductor, MOSFET, and other power semiconductors, and capacitors that are used without changing the circuit configuration. In general, the inductor size can be reduced by increasing the switching frequency. However, since the number of switching times of the power semiconductor increases, the loss increases. Therefore, it is desirable to select a power semiconductor that matches the switching frequency.

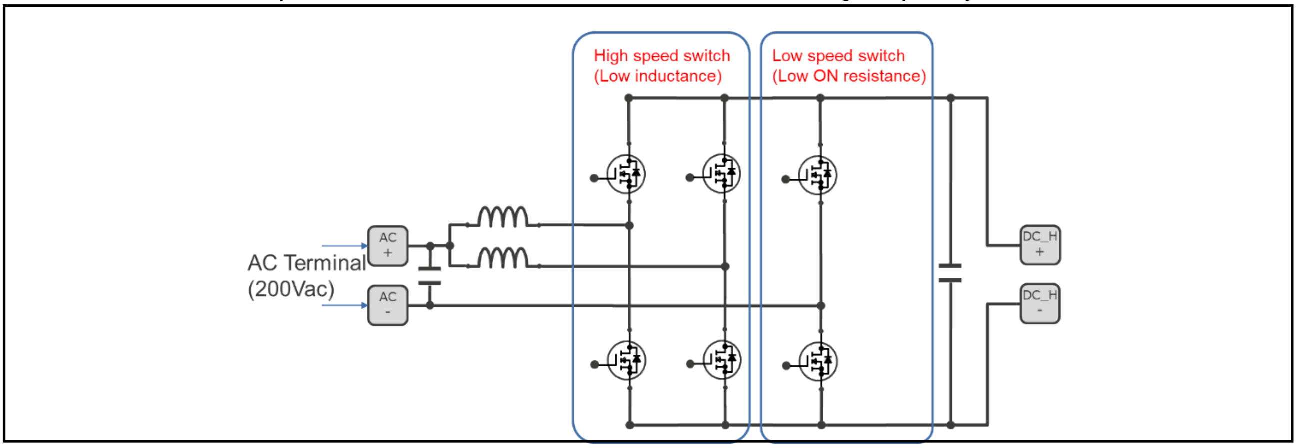


Figure 2 Schematic diagram of totem pole PFC (interleaved)

2.2 Outline of totem pole PFC operation

As shown in Figure 3 the totem pole PFC has two operation modes: one mode to charge the coil when the voltage is positive and the other mode to discharge the energy from the coil. The totem pole PFC has four operation modes in total. Figure 4 shows the switching waveforms in each mode in an interleaved configuration, and Figure 5 shows an image of the switching waveforms and currents in an interleaved configuration.

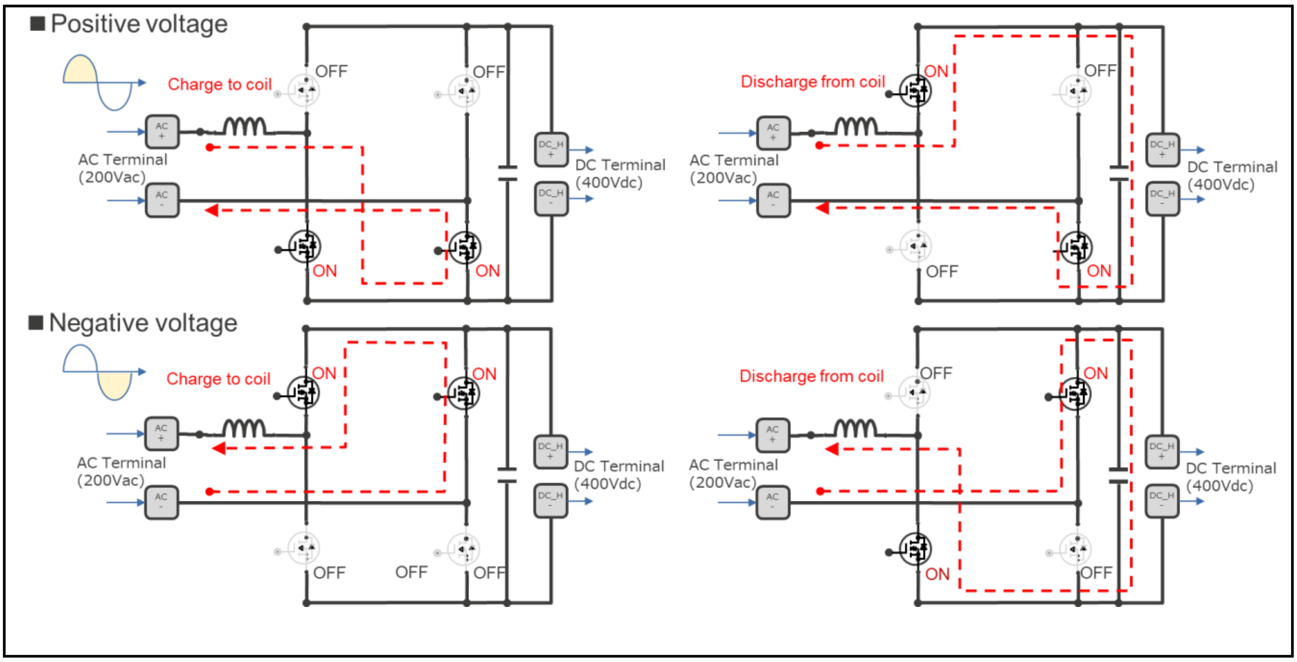


Figure 3 Outline of totem pole PFC operation

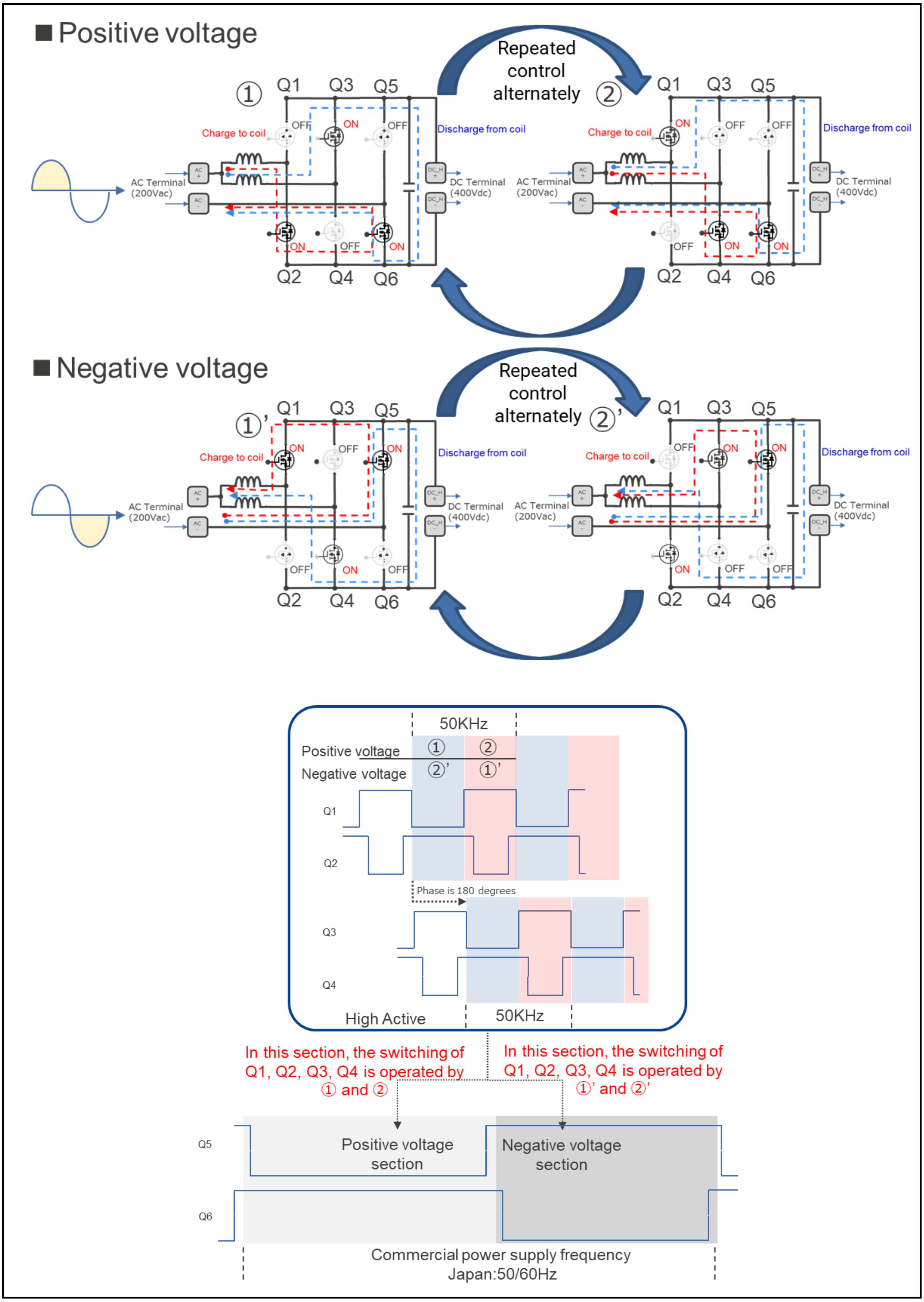


Figure 4 Totem pole PFC (interleaved) operation and switching waveforms

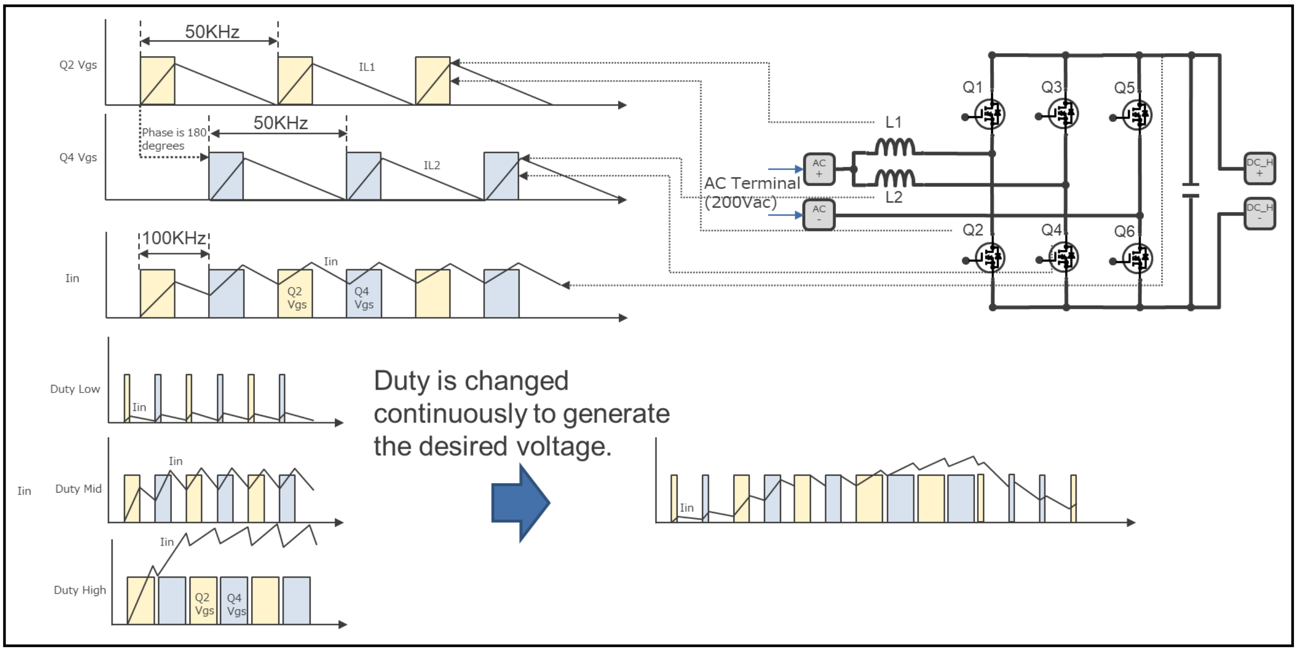


Figure 5 Image of totem pole PFC (interleaved) switching wave form and current

3. Hardware Description

The totem pole interleaved PFC board is a board that runs on Base Board of 50Hz 100V 100W power supply board kit. It consists of three boards as shown in Table 3. Base Board is a baseboard into which various converters (AC-DC, DC-DC) and inverter boards (DC-AC) are inserted. Each board is controlled by a RX66T CPU Card or RX26T CPU Card. In this application note, only AC-DC converter board (totem pole interleaved PFC board) is mounted and controlled. The totem pole interleaved PFC board hardware-specifications are listed in Table 4.

Table 3 List of used boards

No.	Board name	Model name	Notes
1	CPU Card (Select from the right)	P05701-C0-038	CPU Evaluation Board with R5F566TEADFH
		P05701-C0-068	CPU Evaluation Board with R5F526TFDGFP
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-C0-005	AC-DC converter board (totem pole interleaved PFC board)

Table 4 Totem Pole Interleaved PFC Board Hardware Specifications

Item	Specifications	Notes
Line voltage	230Vrms	Grid voltage
Output voltage	400V	DC, PFC power
PFC method	Totem pole PFC	Interleaved
PFC switching frequency	50kHz	Interleaved (1 PFC=50kHz)
Dead time	2us	
Power factor	Max 99% or more	300W or more
Effectiveness	Max 95% or more	300W or more (without inrush proof resistor)
Protection	PFC Output Overvoltage Protection	430V
	PFC Over Current Protection (Software)	10A
	PFC Over Current Protection (Hardware)	15A (POE3B protected)
Status display	7Seg method + LED indication	Error information and operation status display (shown in Base Board)

3.1 Hardware configuration

Figure 6 shows the configuration diagram of Base Board of 50Hz 100V 100W power board kit, totem pole interleaved PFC board, and RX66T/RX26T CPU CARD used in this application note. Figure 7 to Figure 9 show the external views of each board, and Table 5 shows the base board connector list.

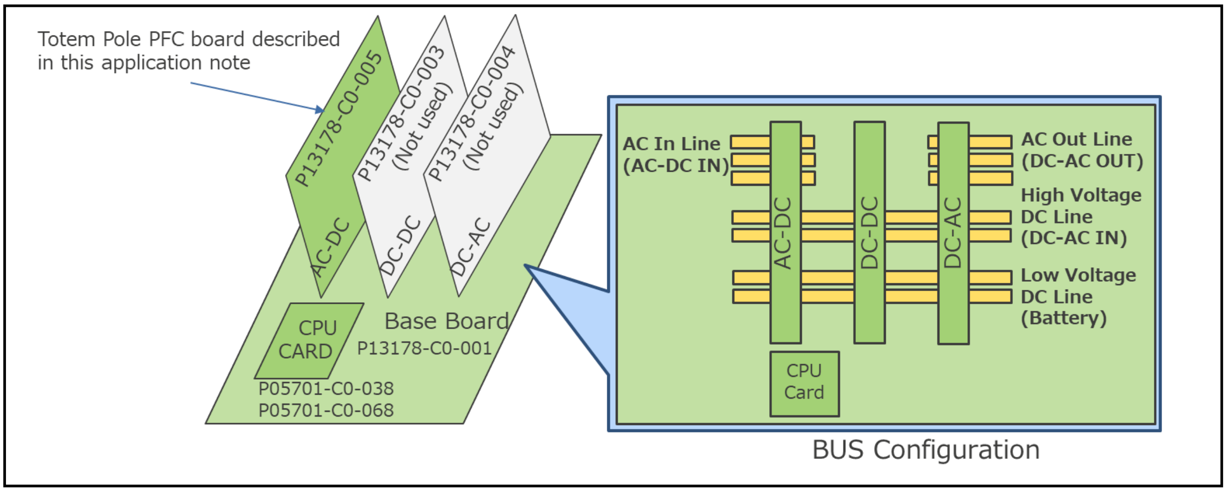


Figure 6 Board configuration diagram

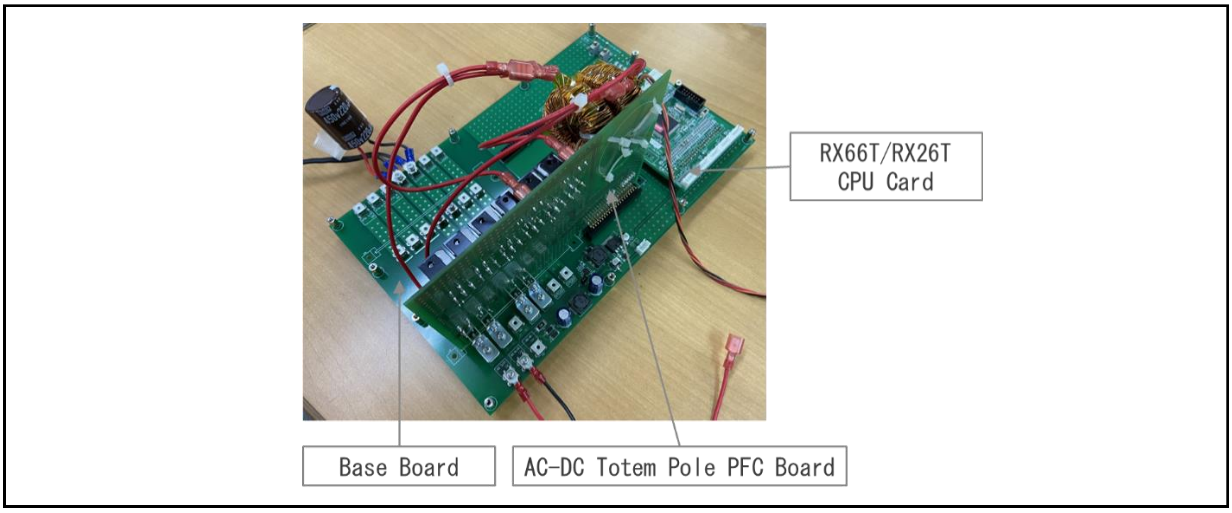


Figure 7 Overall Configuration External View

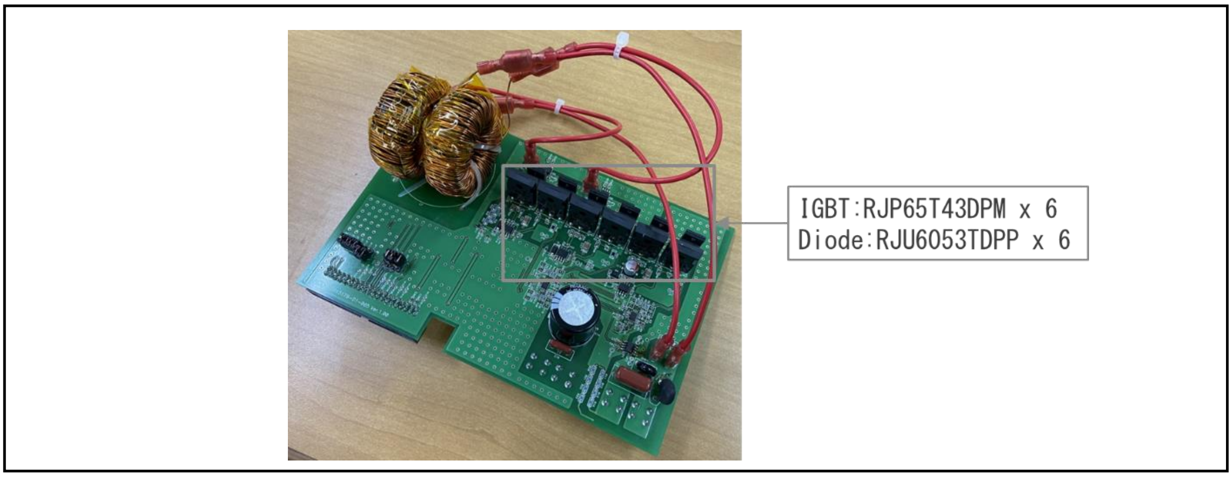


Figure 8 External View of Totem Pole Interleaved PFC Board

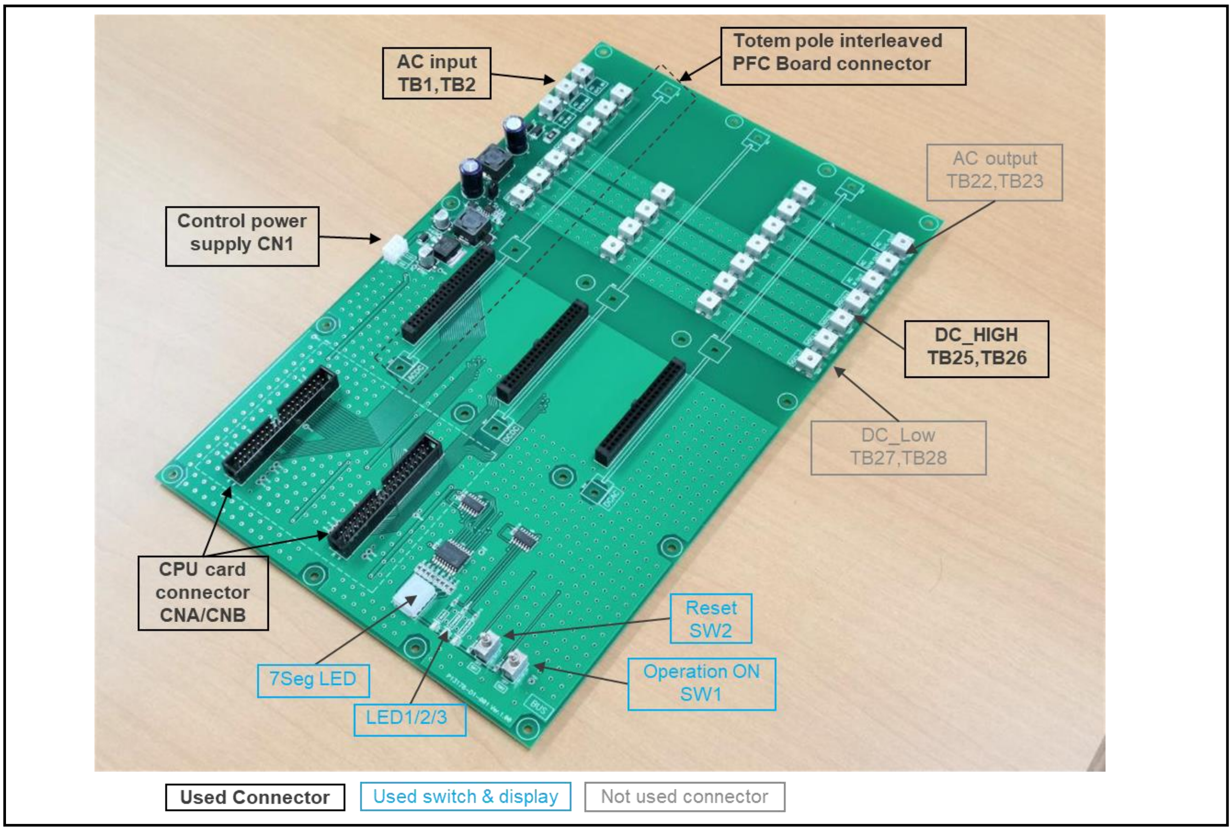


Figure 9 Baseboard External View

Table 5 Baseboard Connectors

Terminal name	Definitions	Notes
TB1	AC_U/ACL	ACL In
TB2	AC_V/ACN	ACN In
TB25	VDCH+	PFC Out
TB26	VDCH-	PFC Out
CNA/CNB	CPU Card connector	RX66T (P05701-C0-038) OR RX26T (P05701-C0-068)

3.2 Configuration of MCU Function

The configuration of MCU function is shown in Figure 10.

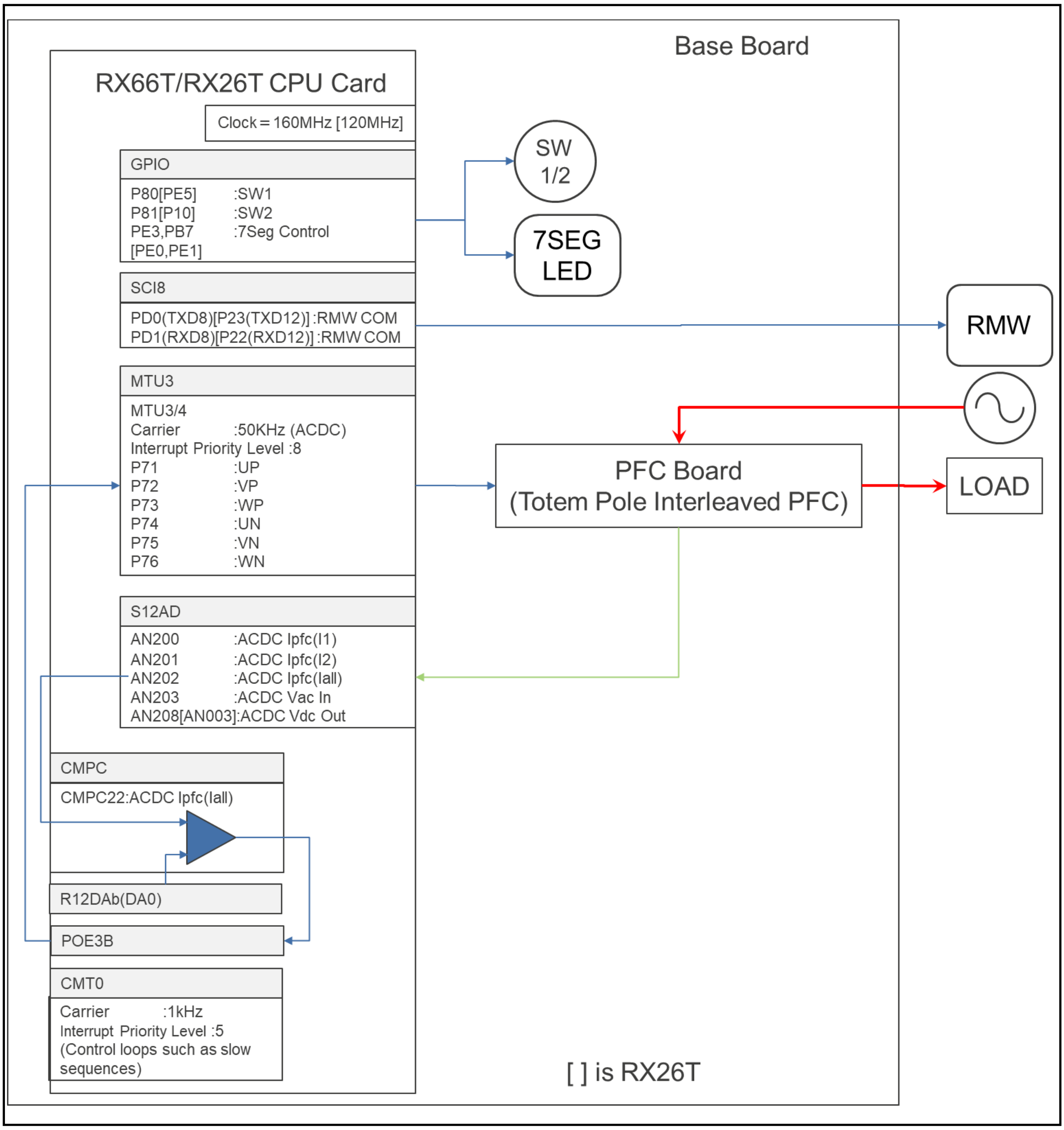


Figure 10 MCU Function Connection Configuration Diagram

3.3 MCU peripheral function

Table 6 shows the peripheral functions of RX66T/RX26T used in this system.

Table 6 List of Peripheral Functions Used

MCU modular	Function
12-bit AD(S12ADH)	PFC1/2 current detection (S12AD2-AN200, AN201, AN202) AC input-voltage detection (S12AD2-AN203) PFC output-DC voltage detection (S12AD2-AD208 [RX26T:S12AD-AN003])
Interval timer (CMT)	1ms interval timer (CMT0)
PWM Out Timer (MTU3d)	50kHz Complementary PWM Output-(PFC Control MTU3/4)
Comparators (CMPC)	Of S12AD2-AN202 and reference Compared with R12DAb (DA0), if the reference is exceeded, Outputting event-signal to POE3B (CMPC22)
12-bit DA(R12DAb)	CMPC Reference Generation (DA0)
Port output enable (POE3B)	PFC drive (MTU3/4 of MTU3d) is stopped by CMPC event-signal (when PFC limit current is exceeded).

3.4 Pin interface

Table 7 shows pin interfaces of RX66T/RX26T used in this system.

Table 7 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	Including 7Seg Control (LED)
SCI	SCI8 [SCI12]	PD0(TXD8)	P23 (TXD12)	RMW communication (send)
		PD1(RXD8)	P22 (RXD12)	RMW communication (receive)
MTU3d	MTU3/4	P71(MTIOC3B)		PFC UP (Fast LEG1)
		P72(MTIOC4A)		PFC VP (Fast LEG2)
		P73(MTIOC4B)		PFC WP (Slow LEG)
		P74(MTIOC3D)		PFC UN (Fast LEG1)
		P75(MTIOC4C)		PFC VN (Fast LEG2)
		P76(MTIOC4D)		PFC WN (Slow LEG)
S12ADH	S12AD2	P52 (AN200)		Ipfc (I1)
		P53 (AN201)		Ipfc (I2)
		P54 (AN202)		Ipfc (All)
		P55 (AN203)		Vac
		P62 (AN208)	P43 (AN003)	Vdc

3.5 User interface

Table 8 shows the user interfaces of this system, and Table 9 shows the details of errors.

Table 8 List of user interfaces

Item	Interface component	Function
Run switch	Toggle switch (SW1)	Start/stop command ON : start OFF: Stopped
Reset switch	Toggle switch (SW2)	Reset input OFF⇒ON : Reset input
Operation display	Red LED1	Displaying start/stop or error Lit: Activated Off: Stopped or fault
Error status display	7Seg LED	Error flag (1 to 255) is displayed in 5 digits per second. Refer to Table 9 for error flags. (Example) For error 016 (0x0010) 0 display/sec -> 1 display/sec -> 6 display/sec -> blank display/sec -> blank display/sec

Table 9 List of Error Flags

Error flag display	Error description	Set value	Error flag (hex)
0 0 1 □ □	PFC Overvoltage Protection	430V	0x0001
0 0 2 □ □	PFC Over Current Protection (Software)	10A	0x0002
0 1 6 □ □	PFC Over Current Protection (Hardware)	15A (POE3B protected)	0x0010

□:Blank display

4. Software Description

Software-processing of this application note is divided into AC-DC converter-control block (totem pole interleaved PFC) and user interface-control block. The user interface controls set the parameters required to control the totem pole interleaved PFC and communicate with Renesas Motor Workbench. The totem pole interleaved PFC unit performs complementary PWM switching to switch switching devices according to the loading conditions. The software module configuration is shown in Figure 11.

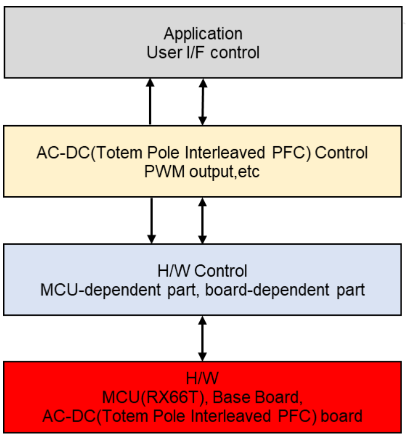


Figure 11 Module Configuration

4.1 Software configuration

Table 10 shows the folder and file structure.

Table 10 Folder and file structure

Folder name	File name	Description
src	main.c	Main functions, user interface control
	intprg.c	Interrupt handler
	r_pwr_control.c	Initializing process
	r_pwr_interrupt.c	Interrupt processing
	r_pwr_Sequence.c	Sequential control
	r_pwr_pfc_ctrl.c	PFC control software
	r_pwr_control.h	Error parameter related definitions
	r_pwr_interrupt.h	Control parameter definition
	r_pwr_Sequence.h	Sequence Parameter Related Definitions
	r_pwr_pfc_ctrl.h	PFC parameter definitions
src\REL_src	resetprg.c	Processing at power-on
	dbsct.c	B, R section-setting
	sbrk.c	Memory allocation processing
	vecttbl.c	Vector table initialization processing
	iodefine.h	RX66T IO Register Definitions
	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 related procedures
	r_pwr_IOLIB_CLOCK.c	operation clock setting process
	r_pwr_IOLIB_CMT.c	CMT related procedures
	r_pwr_IOLIB_INV_MTU_AD.c	MTU3d related procedures
	r_pwr_IOLIB_IO.c	I/O relation process [Only RX26T version]
	r_pwr_IOLIB_IWDT.c	IWDT related procedures
	r_pwr_IOLIB_POE.c	POE3B related procedures
	r_pwr_MATHLIB.c	Arithmetic Operation Related Definitions
	r_pwr_IOLIB.h	MCU dependent part defined
	r_pwr_MATHLIB.h	Arithmetic Operation Related Definitions
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

4.2 State transition

Figure 12 shows the state transition diagram in the application note target software. The software subject to this application note manages the system status 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, it goes through "Power ON Reset" and transitions to "STOP Mode" and enters standby status.

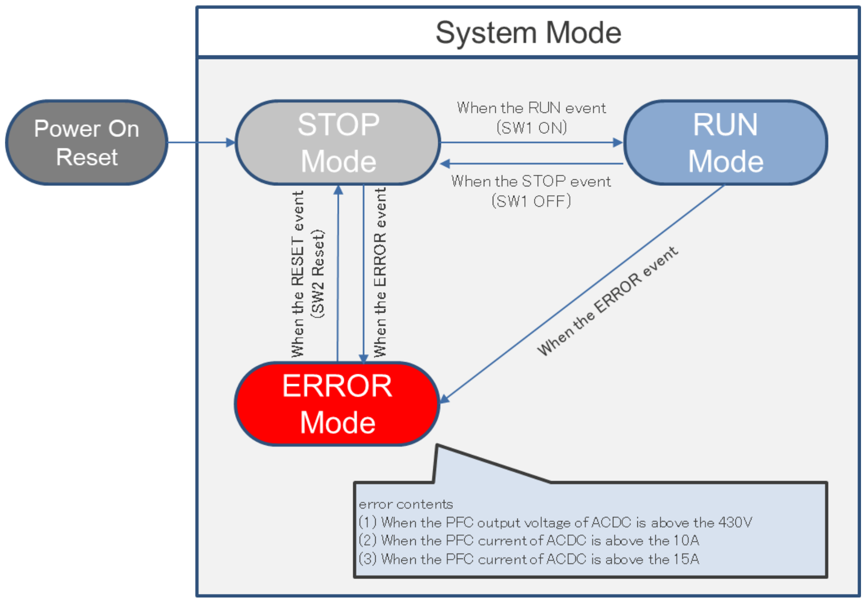
(2) Transitions to "RUN Mode" in SW1 ON and executes AC-DC converter control (totem pole interleaved PFC circuitry).

(3) All processes are terminated by SW1 OFF, the status changes to "STOP Mode", and the system enters the standby status.

■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 9 Error Flags for the details of the error.

(2) By resetting SW2 (OFF→ON→OFF), it changes to "STOP Mode" and enters the standby status.



		Current Mode		
		STOP (0)	RUN (1)	ERROR (2)
EVENT	STOP (0)	STOP	STOP	ERROR
	RUN (1)	RUN	RUN	ERROR
	ERROR (2)	ERROR	ERROR	ERROR
	RESET (3)	STOP	ERROR	STOP

Figure 12 State Transition Diagram

4.3 Control method

For software-processing of this application note, MTU3/4 of RX66T/RX26T MTU3d is set to complementary PWM mode, and U/V/W phase is outputted. The U-phase is used as PFC1 of high-speed LEG. The V-phase is used as PFC2 of high-speed LEG, and the V-phase is used as complementary PWM wave form shifted by 180 degrees. The W-phase is used to drive a low-speed LEG, which is driven by the frequency of the commercial power supply (50/60Hz in Japan). PFC is driven digitally, and the duty is calculated by combining feed-forward control and PI control.

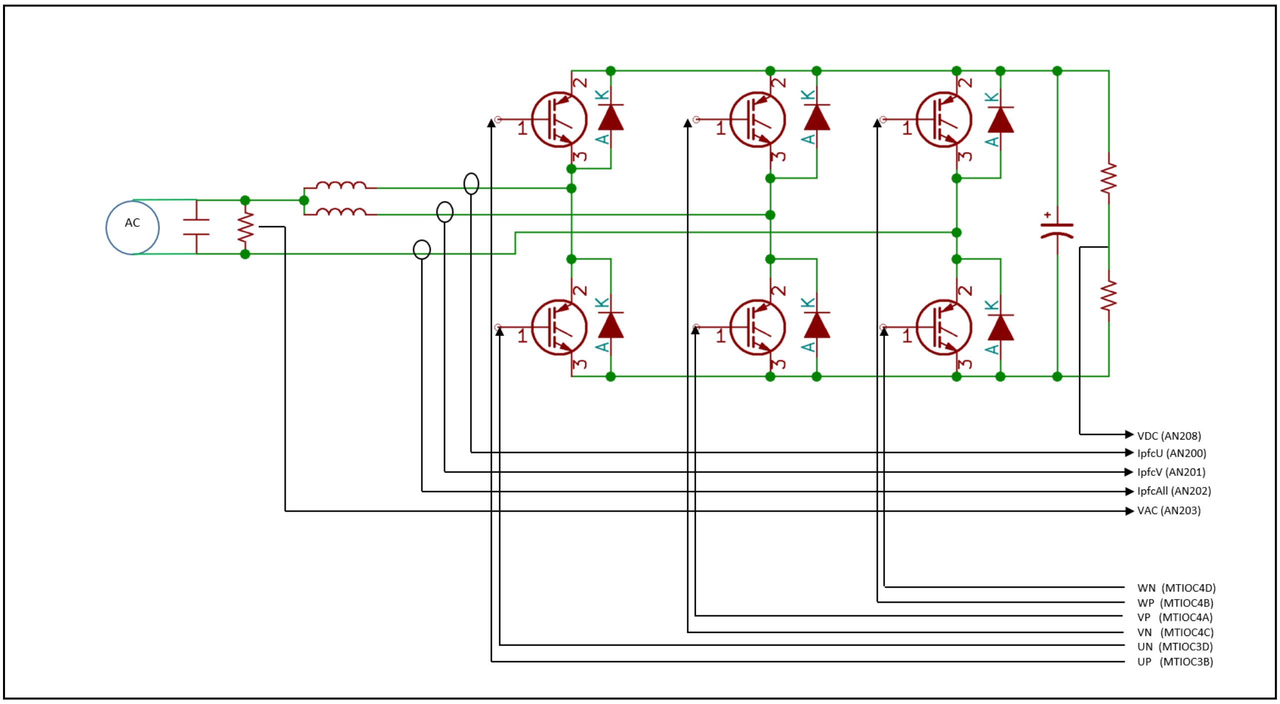
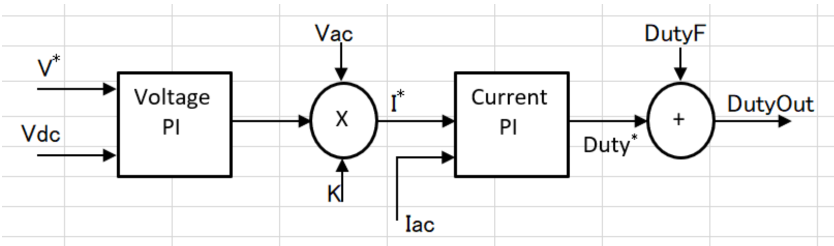


Figure 13 Circuit configuration and control signal wiring diagram of AC-DC converter (totem pole interleaved PFC) control unit



V*	**: Voltage command value**
Vdc	**: Actual output voltage (DC)**
Vac	**: AC line voltage**
K	**: Current command value calculation coefficient**
I*	**: Current command value**
Iac	**: PFC current Ipfc**
Duty*	**: Modulation factor from current PI**
DutyF	**: Modulation factor calculated by Feed Forward**
DutyOut	**: Actual duty output**

Figure 14 AC-DC Control Logic Diagram

4.4 Functions list

The function list of this control program is shown Table 11. Some functions are provided as extensions (functions not used in this software) so that they can be easily incorporated by the user. Refer to Notes in the list below for the unused functions.

Table 11 Functions list

File		Function				Note
Path	Name	Name	Arguments	Return Type	Overview	
src	main.c	main	void	void	Main functional	
	r_pwr_control.c	r_pwr_User_Ctrl_Init	void	void	Parameter Default	
		r_pwr_User_CustomIO_init	void	void	Initializing IO	
		r_pwr_Seg_Control	uint16_t data	void	Functions for displaying 7seg	
	r_pwr_interrupt.c	Interrupt_CMT0	void	void	1kHz Interrupt, Input/Error Indication, Sequencing	
		Interrupt_MTU34_carrier	void	void	50kHz interrupt process, AD check, PWM outputsetting, error check	
		r_pwr_check_error_curloop	void	void	Error checking	
		r_pwr_error_stop	void	void	Error Handling	
	r_pwr_Sequence.c	r_pwr_SEQ_Exec_Event	uint8_t ucEvent	void	Event handling function	
		r_pwr_SEQ_Act_Run	uint8_t ucState	uint8_t	RUN event-handling	
		r_pwr_SEQ_Act_Stop	uint8_t ucState	uint8_t	STOP event-handling	
		r_pwr_SEQ_Act_None	uint8_t ucState	uint8_t	NONE event-handling	
		r_pwr_SEQ_Act_Reset	uint8_t ucState	uint8_t	RESET event-handling	
		r_pwr_SEQ_Act_Error	uint8_t ucState	uint8_t	ERROR event-handling	
		r_pwr_SEQ_Init_Start	void	void	Event startup processing	
		r_pwr_Seq_Init	void	void	Sequence initialization	
	r_pwr_pfc_ctrl.c	r_pwr_Pfc_Control	void	void	PFC control	
		r_pwr_User_Pfc_Init	void	void	PFC initialization process	
		r_pwr_abs	float	float	Abs functional	

src\PWR_IOLIB	r_pwr_IOLIB_AD.c	r_pwr_ad_S12AD0_init	uint16_t mode	void	S12AD initialization	
		r_pwr_ad_S12AD1_init	uint16_t mode	void	S12AD1 initialization	
		r_pwr_ad_S12AD2_init	uint16_t mode	void	S12AD2 initialization	
		r_pwr_ad_S12AD0_set_channel	uint32_t ch_list	void	S12AD channels setting	
		r_pwr_ad_S12AD1_set_channel	uint32_t ch_list	void	S12AD1 channels setting	
		r_pwr_ad_S12AD2_set_channel	uint32_t ch_list	void	S12AD2 channels setting	
		r_pwr_ad_S12AD0_set_range	int16_t ch, int16_t offset, float range	void	S12AD offsetting and range setting	
		r_pwr_ad_S12AD1_set_range	int16_t ch, int16_t offset, float range	void	S12AD1 offsetting and range setting	
		r_pwr_ad_S12AD2_set_range	int16_t ch, int16_t offset, float range	void	S12AD2 offsetting and 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 freq	void	CMT0 initialization	
		r_pwr_interval_CMT1_init	uint16_t freq	void	CMT1 initialization	Not use
		r_pwr_interval_CMT2_init	uint16_t freq	void	CMT2 initialization	Not use
		r_pwr_interval_CMT3_init	uint16_t freq	void	CMT3 initialization	Not use
	r_pwr_IOLIB_INV_MTU_AD.c	r_pwr_tppfc_MTU34_init	uint32_t usFreqCarrier, uint32_t usDeadtime, uint32_t usDecimation	void	AC-DC(PFC) MTU3/4 initialization for control PWM	
		r_pwr_tppfc_MTU34_set_uvw_3shunt	float refu, float refv, float refw	void	AC-DC(PFC) MTU3/4 compare setting for control PWM	
		r_pwr_tppfc_CMPC2_DA_init	void	void	Initialization of CMPC2, DA0 for ipfc detection (for output-shutdown POE3B)	
		r_pwr_tppfc_poe3_init	void	void	POE3B 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 computation	
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	

4.5 Variables list

Table 12 shows the global variables used in this control program.

Table 12 Variable List

File Name	Variable Name	Overview
r_pwr_interrupt.c	g_u1_Error_Status	Command input error display flag
	g_u2_ModeSystem	Operating-mode display 0: STOP 1: RUN 2: ERROR
	g_u2_ModeSystem_Request	Command acceptance (controls operation mode) 0:STOP 1:RUN 2:ERROR 3:RESET
	g_u2_TimeSetting_Offset	Variable for setting calibration time at start
	g_u2_TimeCnt_Offset	Calibration count value at startup
	g_f_ErrLevel_OV_pfc	Pfc voltage-protection-level
	g_f_ErrLevel_OC_pfc	PFC Over Current Protection
	g_f_ACDC_Mu_Ref g_f_ACDC_Mv_Ref g_f_ACDC_Mw_Ref	AC-DC module output setting
	g_u2_ErrorFlag_CurLoop	Error Flag

	g_f_ACDC_IpfcAll	PFC current
	g_f_ACDC_IpfcU g_f_ACDC_IpfcV	Current in each phase of the interleave
	g_f_ACDC_Vdc	PFC output-voltage
	g_f_ACDC_offset_IpfcU g_f_ACDC_offset_IpfcV	Phase current offset of interleaving
	g_f_ACDC_offset_IpfcAll	PFC current offset
	g_f_LpfFactor_CurrentOff	Filter coefficient in offset calculation
	g_f_ACDC_Vac	AC-DC's incoming AC
	g_f_ACDC_Vac_Plus	Absolute AC power
	g_f_VacTemp_New g_f_VacTemp_Old	AC Voltage-Offset Calculation Buffer
	g_u2_Cnt_VacOffset	AC Voltage-Offset Calculation Count
	g_f_ACDC_offset_Vac	AC voltage offset
	g_f_Offset_VacSum	Accumulated AC voltage-offset
	g_u2_Enable_VacOffset	AC Voltage-Offset Calculation Flag
	g_f_Offset_Lpf_Vac	Filter Value for AC Voltage-Offset (Average Filter Expression)
	g_u2_Cnt_Offset_Lpf_Vac	Count for AC Voltage-Offset Filter (Average Filter Expression)
	g_ics_cnt	Thinning count for RMW indication
	g_position_trigger	AD sampling trigger timing setting
	g_u2_poe_flag	Flag for POE3B failure
	g_u2_seg_data	7Seg indication data
	g_u2_seg_time	Count-value for 7Seg indication cycle
	g_u2_seg_error_temp	Buffer value of the error part of 7Seg indication data
	g_u2_led1_display g_u2_led2_display g_u2_led3_display	LED1/2/3 data for viewing
	g_u2_sw1_status g_u2_sw2_status_old g_u2_sw2_status	SW1/2 input data
r_pwr_pfc_ctrl.c	g_f_Vref_Pfc	PFC command
	g_f_Vref_Pfc_Temp	Buffer of PFC command (for soft start)
	g_f_Vref_Pfc_Ripple	Max. allowable PFC output-plus ripple
	g_f_KpFactor_Vpfc g_f_KiFactor_Vpfc	PFC voltage-controlled PI gain
	g_f_I_Pfc_Limit	PFC current command limit
	g_f_I_Pfc_Refi	Integral term and excessive term of PFC voltage output PI

	g_f_I_Pfc_RefOver	
	g_f_I_Pfc_Ref	PFC current command
	g_f_KpFactor_Ipfc g_f_KiFactor_Ipfc	PFC current control PI gain
	g_f_Duty_Pfc_Limit	PFC duty limit
	g_f_Iref_Pfc	PFC current command (sinusoidal waveform)
	g_f_Duty_Pfc_Refi	Integration term for PFC current control
	g_f_Duty_Pfc_Ref	Output duty calculated with PFC current control
	g_f_Duty_FF_buf	Duty calculated by FF control
	g_f_Duty_FF	Duty combined with PI control and FF control (pre-limit)
	g_f_K_Duty_FF	Duty factor for FF control
	g_f_PFC_SoftStart_Cnt	Count value for soft start
	g_f_pfc_duty	Duty combined with PI control and FF control (after limit)
	g_f_ACDC_Vac_Old	AC input-voltage buffering
	g_u2_ACDC_Enable	Flag for starting PFC
	g_f_ACDC_Comp_K	Dead time correction factor
	g_f_ACDC_Comp_Off	Dead time compensation offset
	g_f_ACDC_Vac_Pfc	AC input-voltage storage buffers

4.6 Macro definition list

Table 13 shows the macro definitions used in this control program.

Table 13 Macro definition list

File Name	Definition	Definition Value	Overview
r_pwr_pfc_ctrl.h	CTRL_ACDC_VDC_REF	400	PFC output-voltage setting
r_pwr_interrupt.h	SEG_TIME_ALL	5000	Sets the total duration for 7SEG view. Do not set for 3 seconds or less. Time = set value/1000
r_pwr_control.h	FLAG_ERROR_VDC_OV	0x0001	Overvoltage error flag
	FLAG_ERROR_IPFC_OC	0x0002	Soft overcurrent error flag
	FLAG_ERROR_POE	0x0010	Hard Overcurrent Error Flag

4.7 Control flow

4.7.1 Main process

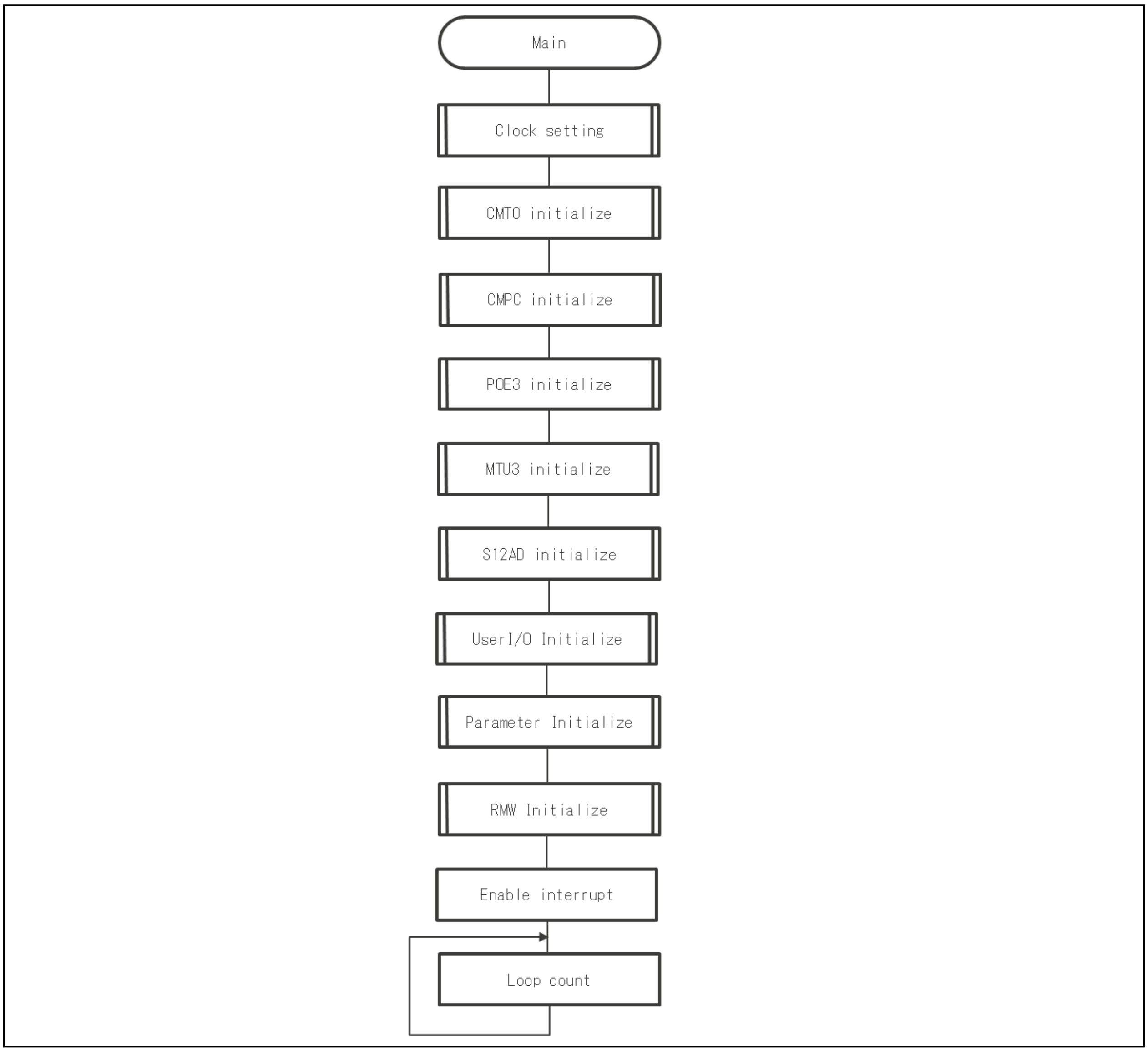


Figure 15 Main Process

4.7.2 1kHz cycle sequence

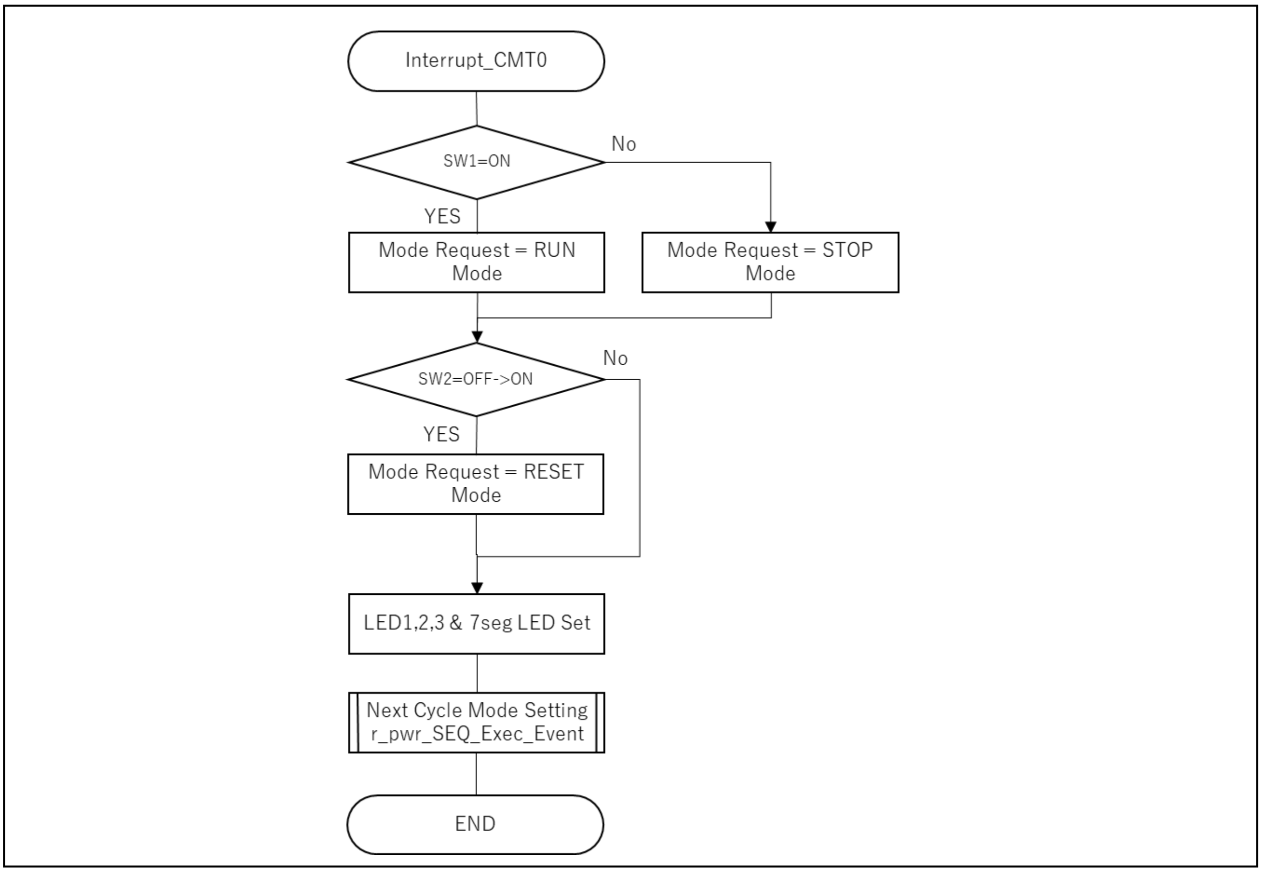


Figure 16 1kHz Cycle Sequence (CMT0 Interrupt Process)

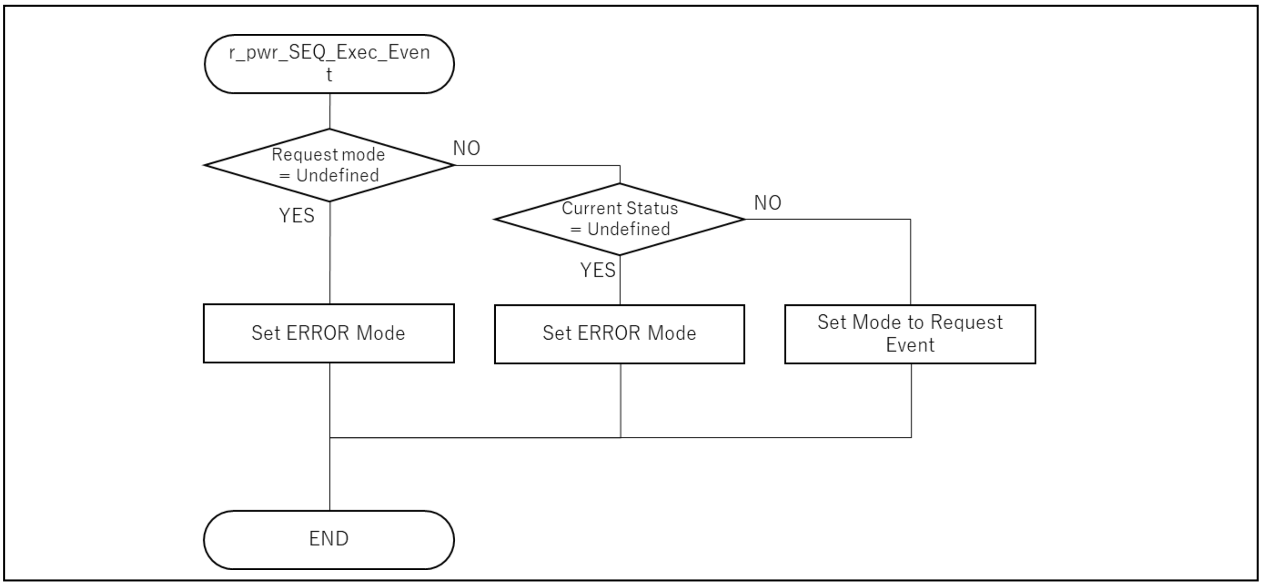


Figure 17 Process for Setting Next Cycle Mode

4.7.3 50kHz cycle control process

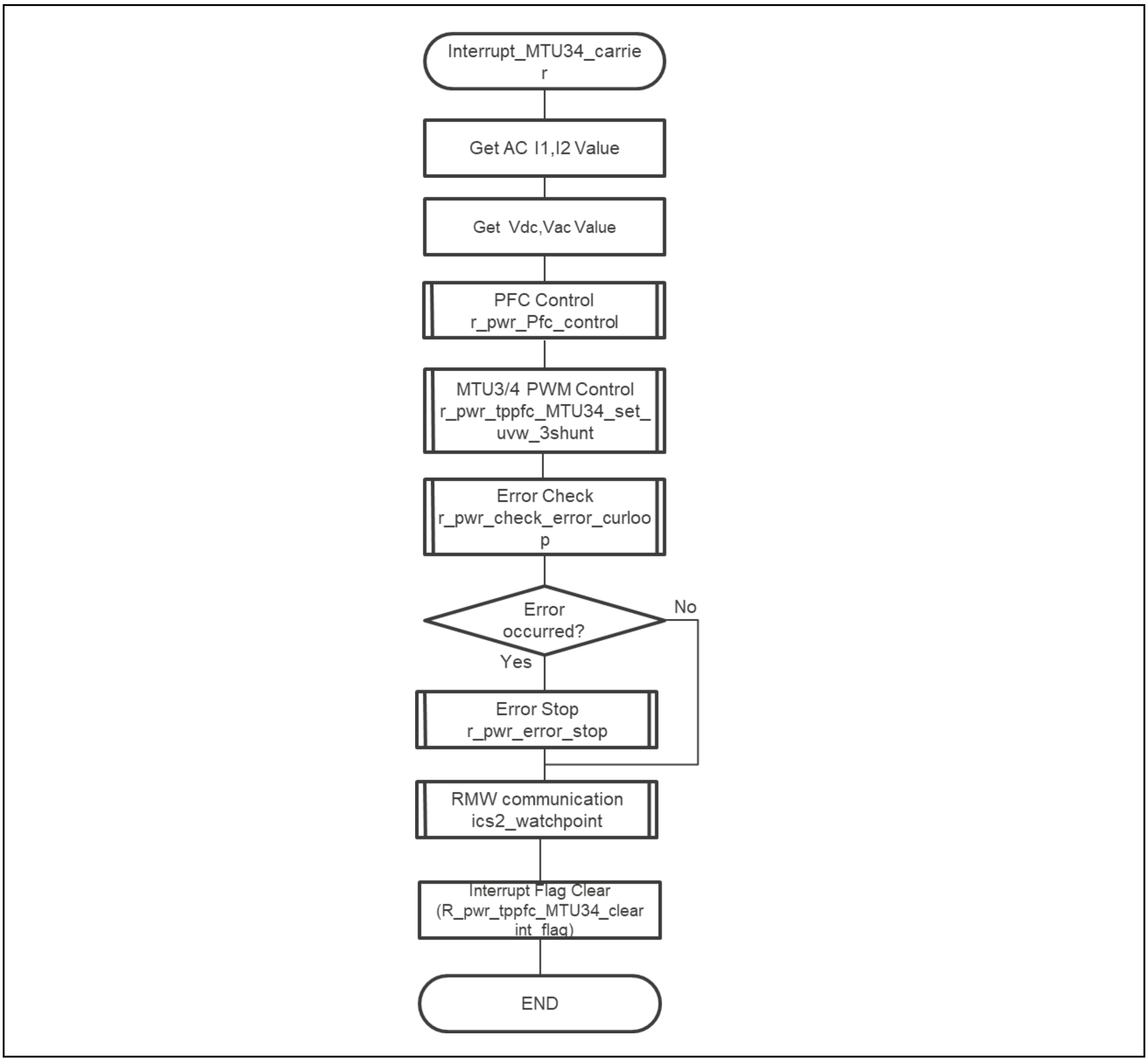


Figure 18 50kHz Cycle System-Controlled Process (MTU3/4 Interrupt Process)

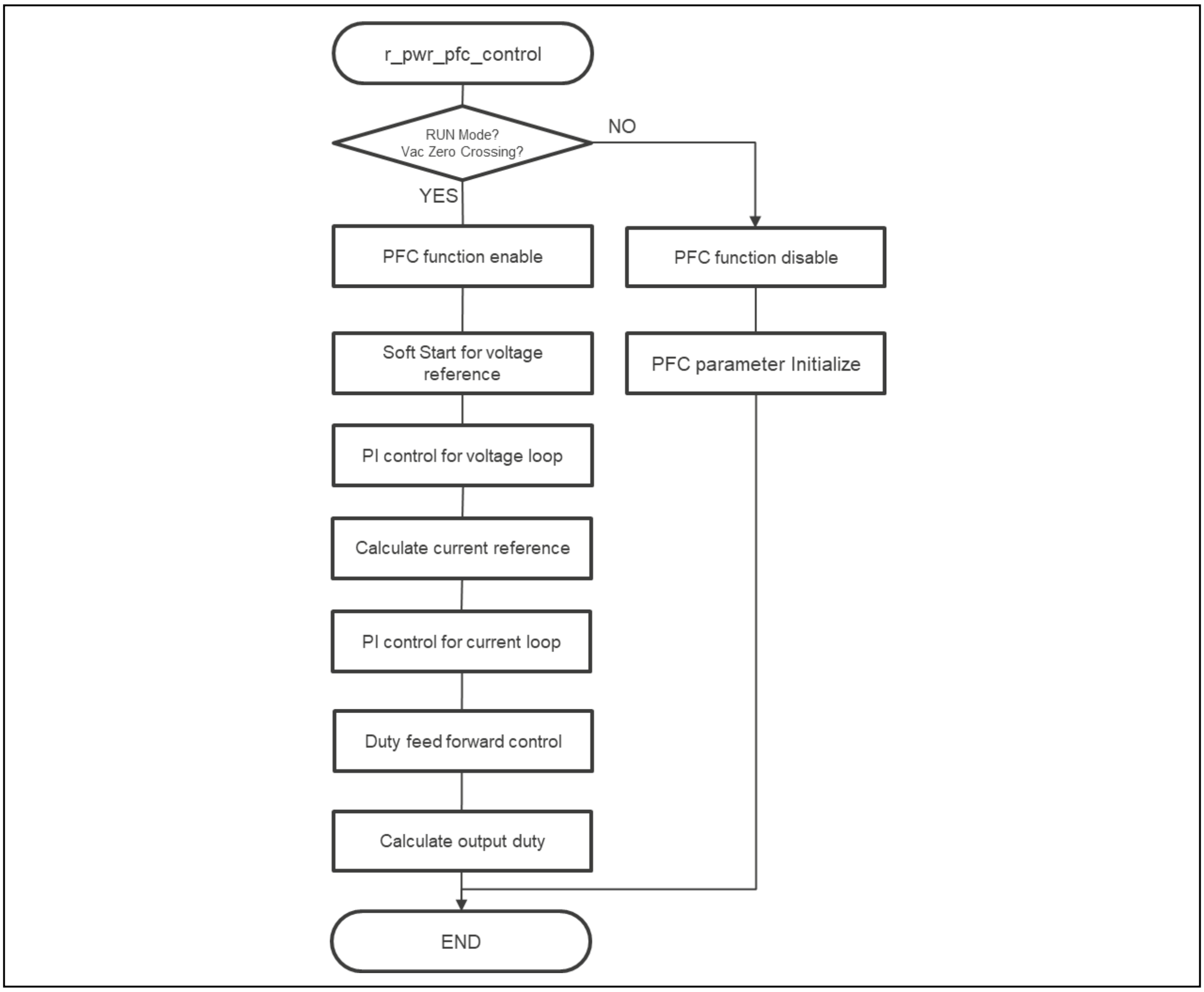


Figure 19 PFC Control Process

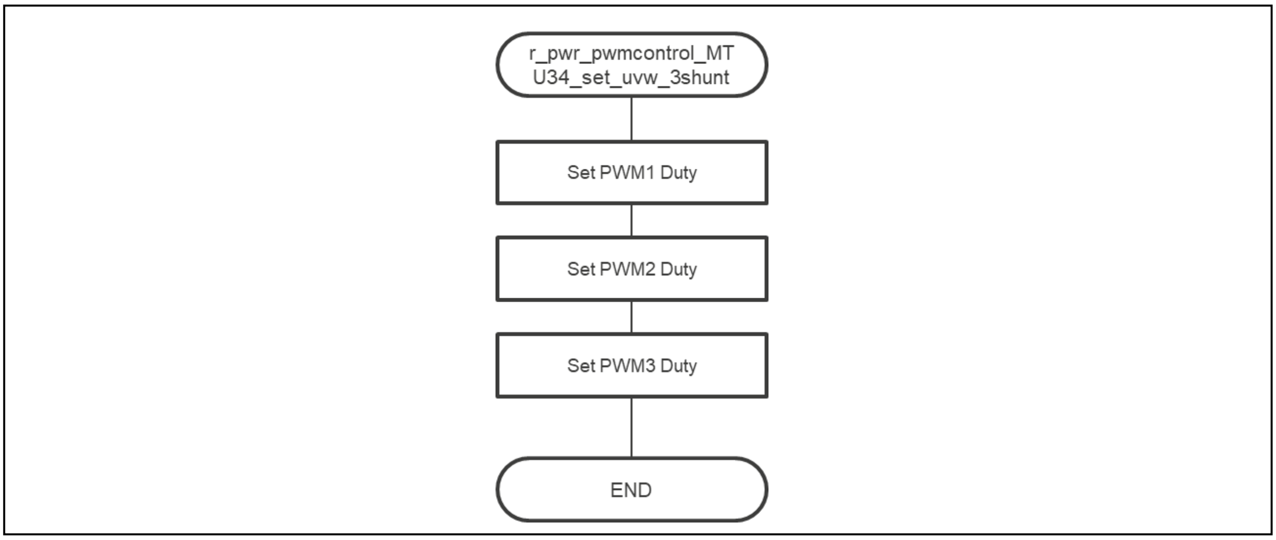


Figure 20 MTU3/4 Duty Setting Process

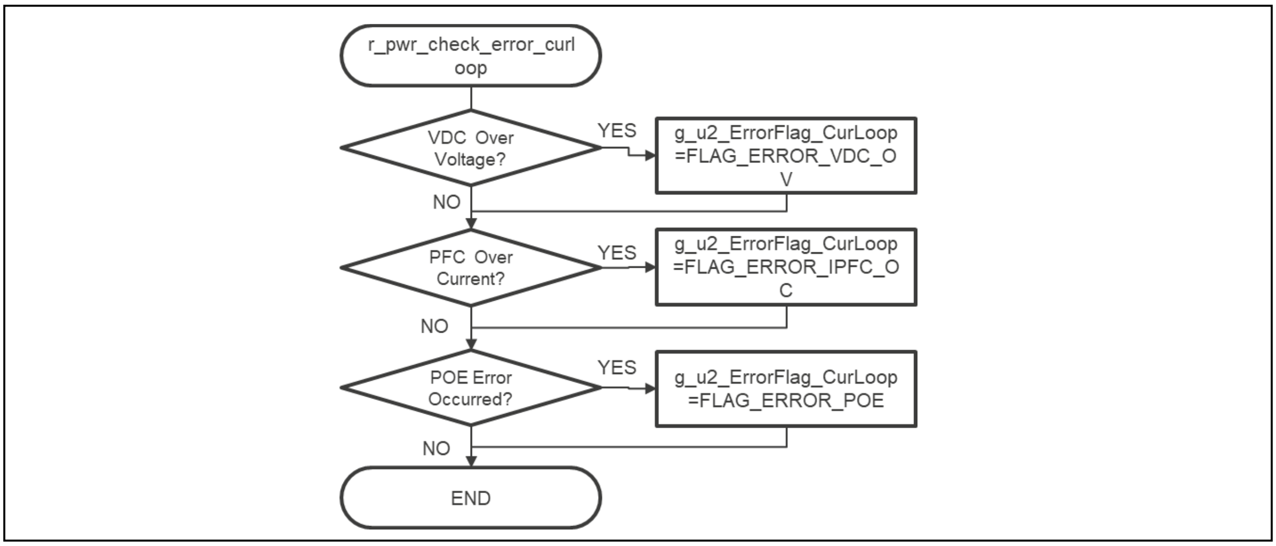


Figure 21 Current Cycle Error Check Process

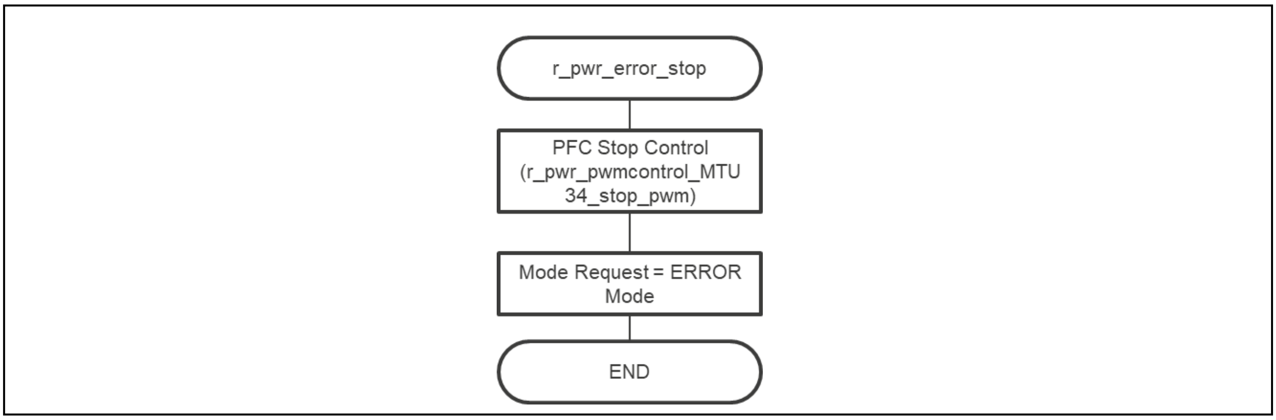


Figure 22 Error Stop Process

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 the status monitor. For the variables that can be monitored, refer to 4.5 Variable List. Figure 23 shows the operating environment of "Renesas Motor Workbench" and Figure 24 shows the outside 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.

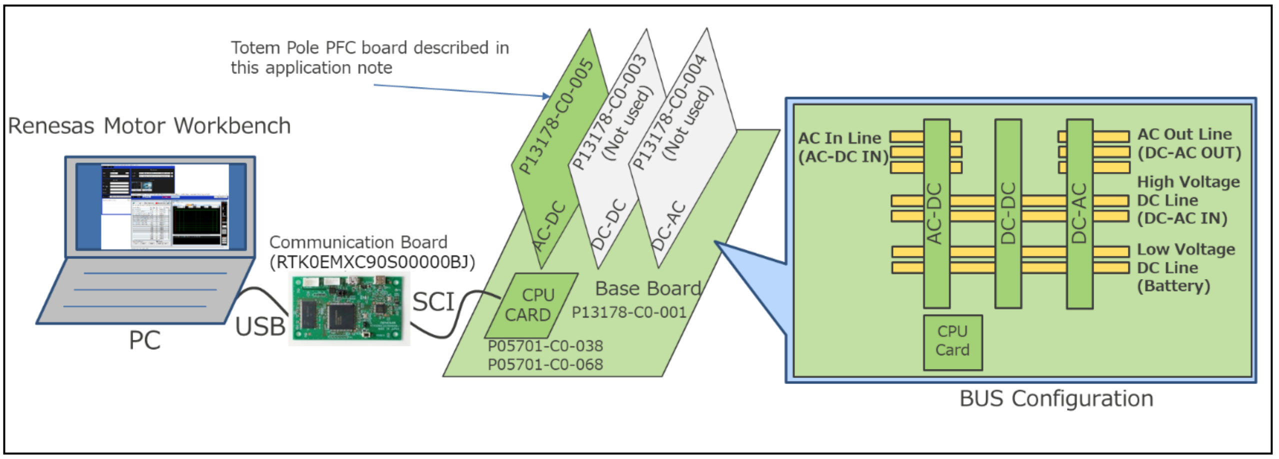


Figure 23 Renesas Motor Workbench Operating Conditions

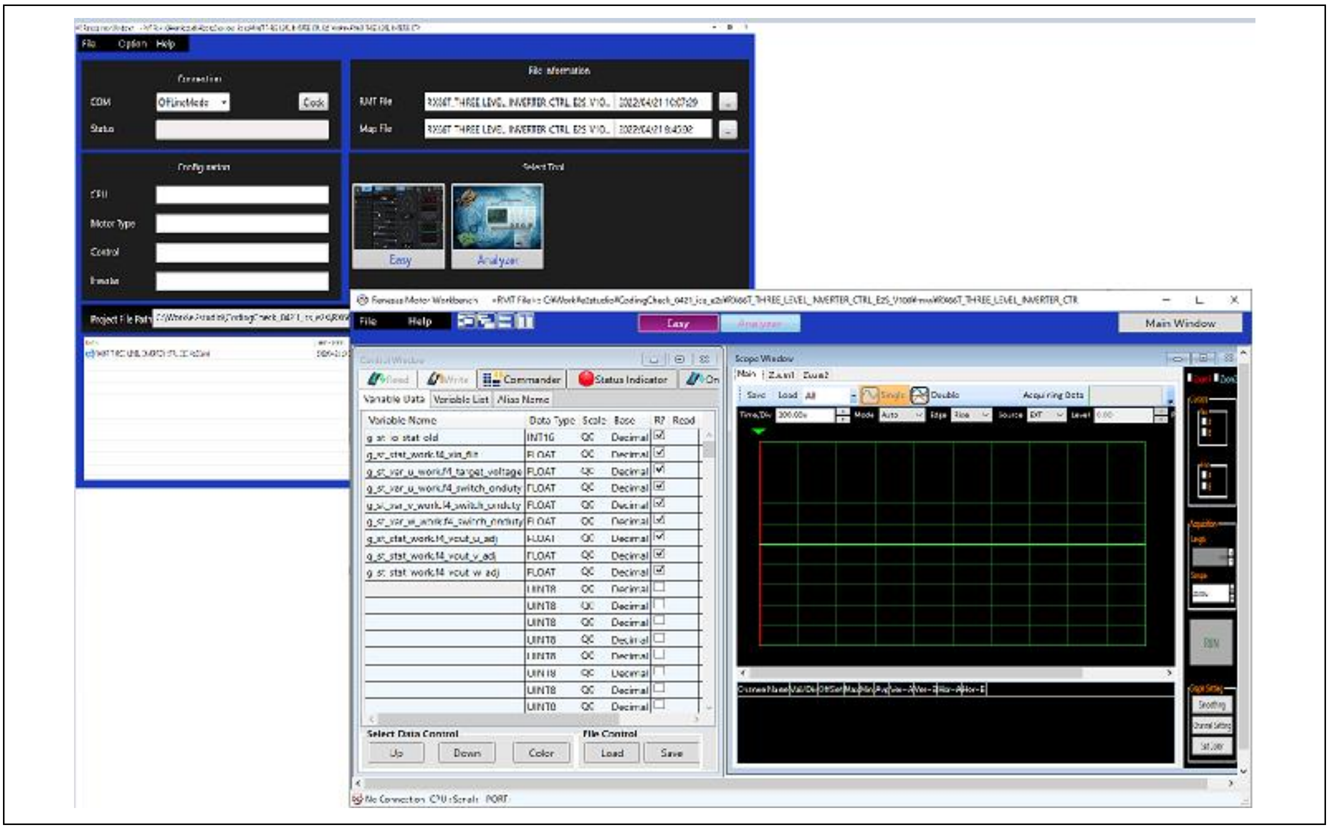
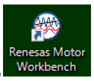


Figure 24 View of Renesas Motor Workbench

How to use Renesas Motor Workbench motor control tool

① Click the tool icon to launch the tool. 

② Select [RMTFile] → [Open RMT File] from MENU on Main Panel.
Import RMT files in the "ics" folder of the project folder.

③ Use the "Connection" COM to select COM of the connected kit.

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

5.2 Analyzer list

The global variables are used for displaying waveforms when Analyzer user interface is used.

Refer to Table 12 Variable List for the target variables.

6. Measurement data

The measured results of the totem pole interleaved PFC and the power factor of this application note are shown in 6.1, and the results of the responsive test are shown in 6.2.

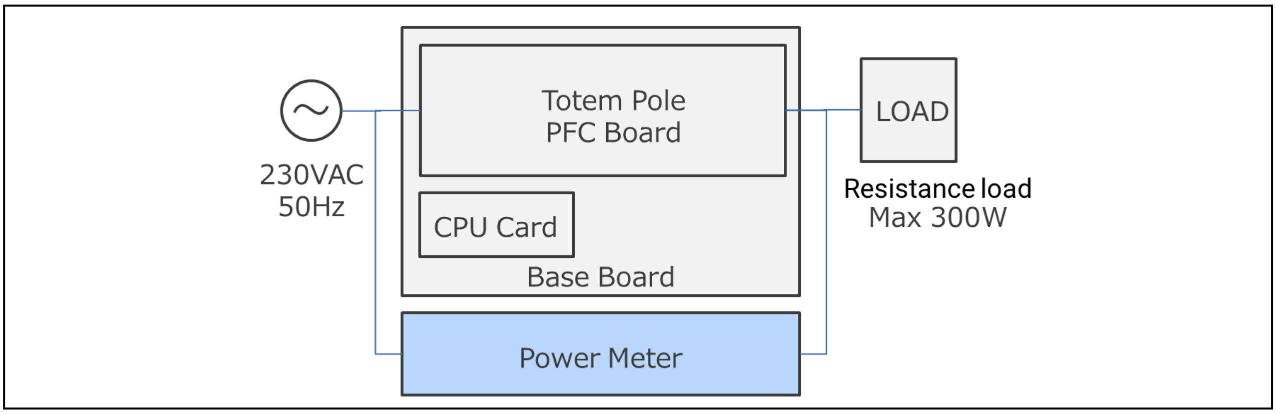


Figure 25 Current wave form when inputting 230V/100V

6.1 Efficiency and power factor measurement results

■Measurement conditions

・The load is a pure resistive load.
・Set the output-voltage to 400V.
・Measured with/without NTC thermistor.

For 220V input, the power factor and efficiency at the time of output power approx. 300W and approx. 155W are measured. For 100V input, the power factor and efficiency at the time of output power approx. 155W are measured. For 230V, the power factor is 99% or more, the efficiency is about 94%, and for 100V, the power factor is 99% or more, and the efficiency is about 90%. Table 14 shows the measurement results when a NTC thermistor is present. Table 15 shows the measurement results when no NTC thermistor is present. The current waveform during measurement is shown in Figure 26.

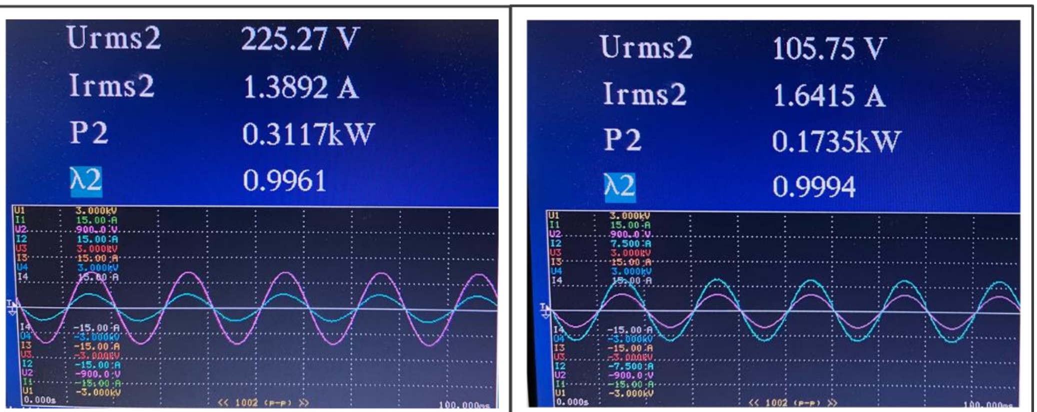
Table 14 Measured power factor and efficiency with NTC thermistor

Input-voltage (Vrms)	Input power (W)	Output power (W)	Power factor (%)	Efficiency (%)
225.27	311.7	294.7	99.61	94.55
225.63	165.8	155.7	99.00	93.9
105.74	173.5	155.7	99.94	89.74

Table 15 Measured power factor and efficiency without NTC thermistor

Input-voltage (Vrms)	Input power (W)	Output power (W)	Power factor (%)	Efficiency (%)
227.2	307.8	294.2	99.61	95.58
105.77	169.1	155.5	99.88	91.96

Urms2: Input voltage effective value
Irms2: Input current effective value
P2: Input power
Λ2: Power factor



Pink : Input voltage(225V/div)
Blue : Input current(3.75A/div)
Current waveform at 230V input

Pink : Input voltage(225V/div)
Blue : Input current(1.875A/div)
Current waveform at 100V input

Figure 26 Current wave form when inputting 230V/100V

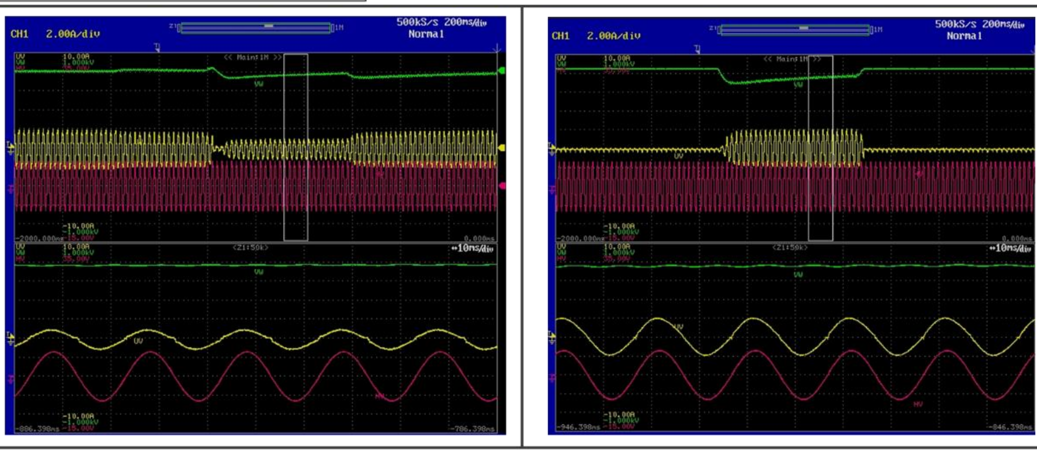
6.2 Response test results

Figure 27 shows the waveform when the load is changed to 0%⇒100% and 50%⇒100% with a DC breaker.

0%:Open ⇒ Approx. 0W.
50%:Resistance 991 Ω ⇒ Approx. 155W.
100%:Resistance 526 Ω ⇒ Approx. 310W.

The output-voltage is constant even if the load fluctuates, and it can be seen that it is functioning as AC-DC convertor without trouble.

Yellow: Input current(2A/div)
Pink: Input voltage(250V/div)
Green: Output voltage(100V/div)



Operation when the load is changed to 100 % ⇒ 50 % ⇒ 100 %

Operation when the load is changed to 0 % ⇒ 100 % ⇒ 0 %

Figure 27 AC Output-Waveform at Load Variation

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Mar.31.23	-	First edition
1.10	Jun.1.23	1	Added RX26T, RX660 to applied products
1.20	Feb.23.24	6	Updated the “Figure4 Totem pole PFC (interleaved) operation and switching waveforms”
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.

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