RX/RA Family

Digital Power Conversion (Vienna PFC Converter (AC-DC Converter))

Summary

This application note is intended to describe how to drive and control Vienna PFC*1, which is a 3 phase AC-DC converter using RX26T group or RA6T2 group, and how to use motor control development support tool [RMW]*2.

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

Note 1: The drive and control of the Vienna PFC utilize the Vienna PFC board from Desk Top Laboratories Inc(DTL).

2: RMW is an abbreviation for Renesas Motor Workbench.

Operation Check Device

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

RX family RX26T Group (R5F526TFCDFP, R5F526TFDGFP) (RXv3 core, maximum operating frequency 120MHz)
RA family RA6T2 Group (R7FA6T2BD3CFP) (Arm® Cortex®-M33 core, maximum operating frequency 240MHz)

It is also applicable to RX family and RA family that has the resources described in this application note or equivalent peripheral functions. (RX72T, RX66T, RX660, RA6T1, etc.)

Target Sample Program

The sample program for this application note is shown below.

- RX26T_P13228_ViePFC_CSP_V100 (IDE：CS+)
- RX26T_P13228_ViePFC_E2S_V100 (IDE：e²studio)
- RA6T2_P13228_ViePFC_FSP590_V100 (IDE：e²studio)

This sample program is compatible with the Renesas CPU Board shown in Table 1. For sample programs compatible with DTL CPU Cards, please contact DTL.

Reference Materials

- RX26T Group User's Manual: Hardware (R01UH0979)
- RA6T2 Group User's Manual: Hardware (R01UH0951)
- 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)
- Digital Power Conversion (Totem Pole Interleaved PFC (AC-DC Converter)) (R01AN6877)

Contents

1. Overview

This application note describes how to control and implement Vienna PFC of 3 Phase AC-DC converter in a digital-power-control *1 using RX26T group or RA6T2 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

Board Type	Board Name	Model	MCU Group Name (pin)	MCU Part No
CPU Board (Renesas)	MCB-RX26T	RTK0EMXE70C00000BJ	RX26T (100pin)	R5F526TFCDFP
	MCB-RA6T2	RTK0EMA270C00000BJ	RA6T2 (100pin)	R7FA6T2BD3CFP
CPU Card (DTL)	RX26T CPU Card*1	P05701-C0-068	RX26T (100pin)	R5F526TFDGFP
	RA6T2 CPU Card*1	P05701-C0-067	RA6T2 (100pin)	R7FA6T2BD3CFP
AC-DC Board (DTL)	Vienna PFC Board*1	P13228-C0-001	-	

Table 2 Software Development Environment

Device	IDE Version	RX Smart Configurator*2	Toolchain version*3	FSP Version
RX26T	CS+:V8.14.00 e²studio:2025-04	Version 2.27.0	CC-RX: V3.07.00	-
RA6T2	e²studio:2025-04	e²studio plug-in version	GCC ARM Embedded: 13.2.1.arm-13-7	FSP5.9.0

Note 1. Vienna PFC Board and CPU Card is made by Desk Top Laboratories Inc.(DTL) If you have any questions about the board and software, please contact DTL.
2. This project does not use code generated by this tool.
3. 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. (https://en-support.renesas.com/knowledgeBase/18398339)

2. Vienna PFC Overview

The Vienna PFC is a bridge-less PFC circuit for AC-DC converters. While AC-DC converters are typically divided into rectifier and smoothing sections, the Vienna PFC eliminates the diode bridge rectifier in the rectifier section. Instead, it uses switching devices to integrate the rectifier and PFC sections into a single circuit.

Figure 1 shows the Vienna PFC circuit. By switching the power semiconductors (Q1 to Q6) connected in series to each phase, the voltage of each phase changes to E/2(v), E(v), and 0(v). The output voltage and current are determined by the reactance, switching frequency, and duty cycle. Output voltage and current can be modified by changing components such as inductors, power semiconductors (e.g., SiC), and capacitors without altering the circuit configuration. Generally, increasing the switching frequency allows for smaller inductors and other components. However, this also increases the switching frequency of the power semiconductors, leading to higher losses. Therefore, it is desirable to select power semiconductors optimized for the switching frequency.

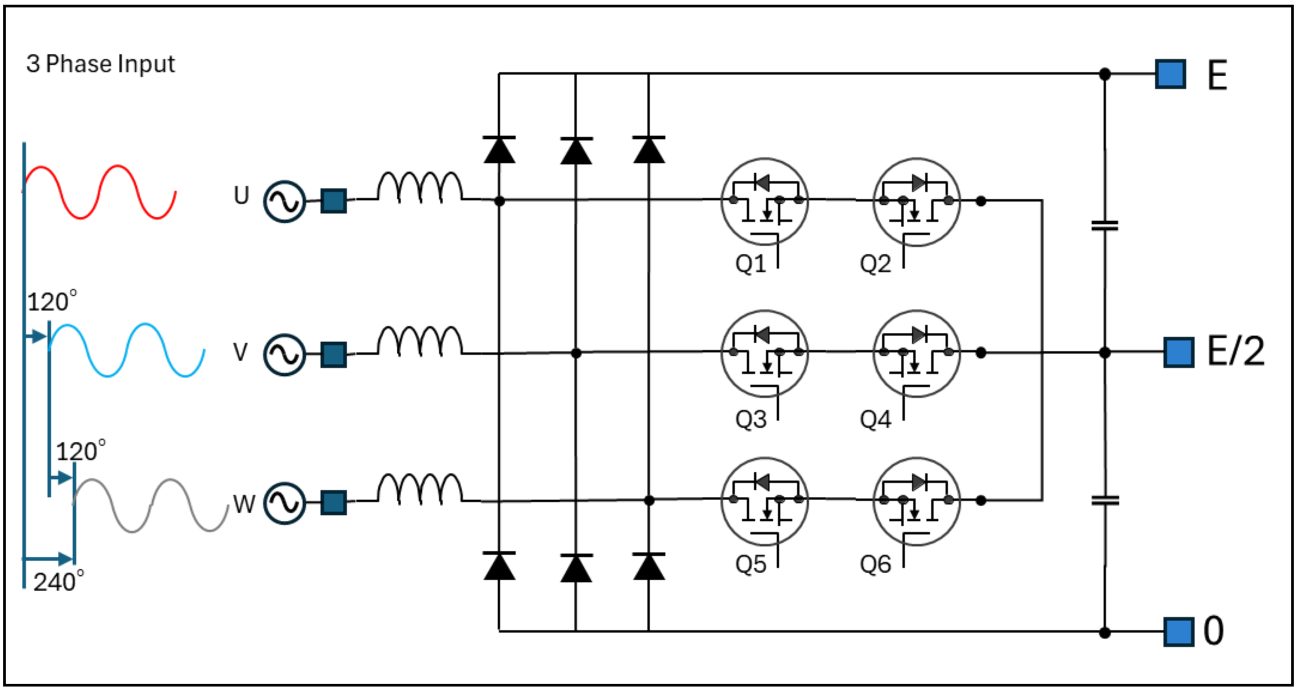


Figure 1 Schematic Diagram of Vienna PFC

2.1 Outline of Vienna PFC Operation

The Vienna PFC controls current flow through two operating modes: positive voltage and negative voltage, as shown in Figure 2. During positive voltage, it consists of mode ② (Q1/Q3/Q5 OFF), where current flows through the diode, and mode ① (Q1/Q3/Q5 ON), where current flows through the SiC. The voltage in mode ② is E, and the voltage in mode ① is E/2. During negative voltage operation, the current direction reverses compared to positive voltage operation. It consists of mode ③ where current flows through the diode (Q2/Q4/Q6 OFF) and mode ① where current flows through the SiC (Q2/Q4/Q6 ON). The voltage in mode ③ is 0V, and the voltage in mode ① is E/2. Figure 3 shows the switching waveforms and current direction.

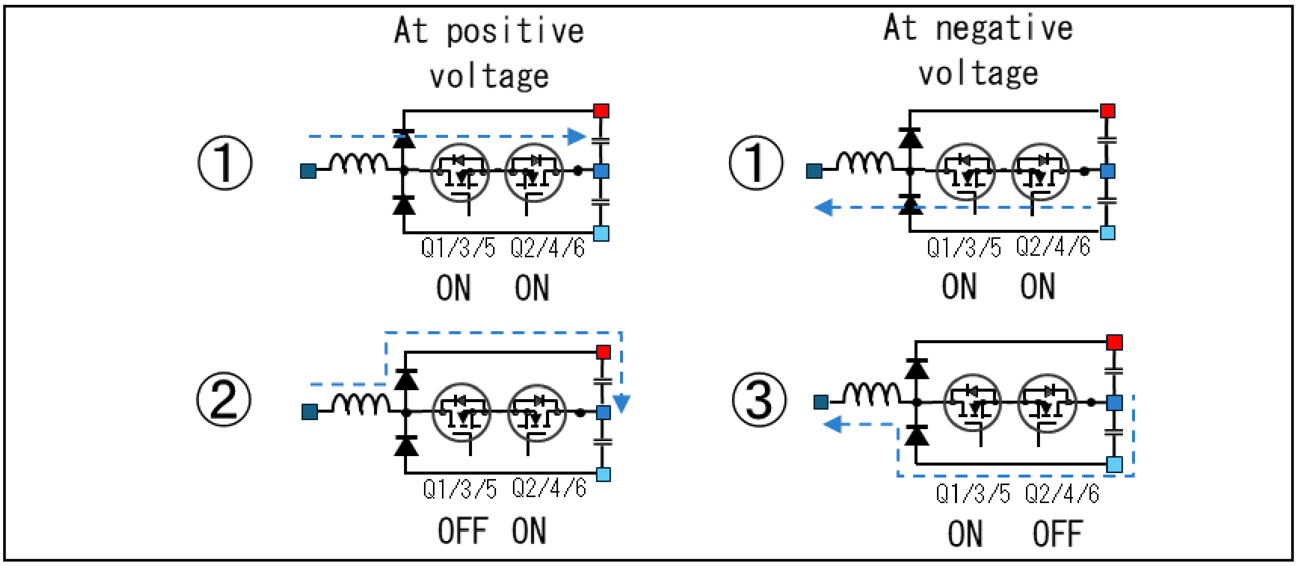


Figure 2 Outline of Vienna PFC Operation

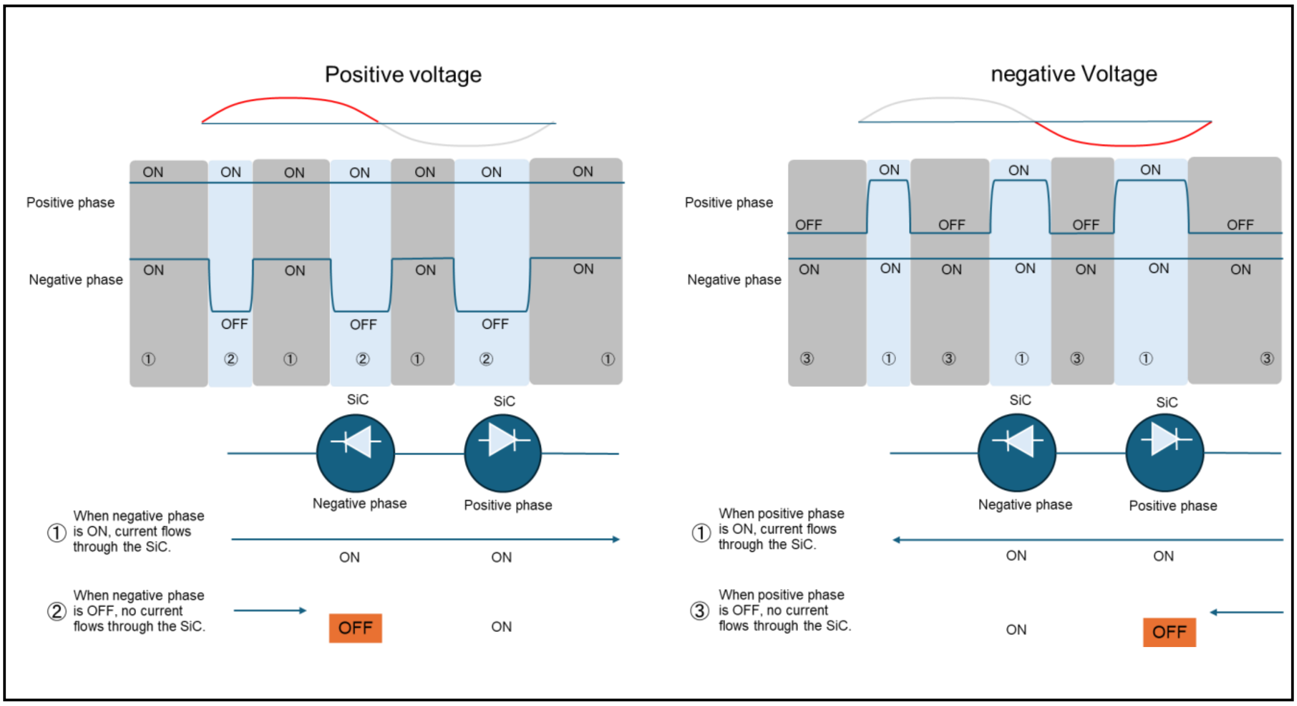


Figure 3 Vienna PFC Switching Operation and Current Direction Image

3. Hardware Description

Vienna PFC Board is a board is a system consisting of two types of boards shown in Table 3. An AC-DC converter board (Vienna PFC board) is connected to either an RX26T CPU Board/Card or an RA6T2 CPU Board/Card to perform PFC control. The hardware specifications of the Vienna PFC board are shown in Table 4.

Table 3 List of Boards Used

No.	Board Type	Board Name	Model name	Remarks
1	AC-DC Converter Board	Vienna PFC Board (DTL)	P13228-C0-001	AC-DC Converter Board (Vienna PFC Board)
2	CPU Board/Card	CPU Board (Renesas)	RTK0EMXE70C00000BJ	R5F526TFCDFP CPU Evaluation Board
			RTK0EMA270C00000BJ	R7FA6T2BD3CFP CPU Evaluation Board
		CPU Card (DTL)	P05701-C0-068	R5F526TFDGFP CPU Evaluation Board
			P05701-C0-067	R7FA6T2BD3CFP CPU Evaluation Board

Table 4 Vienna PFC Board Hardware Specifications

Item	Specifications	Remarks
Input voltage	3 phase AC 200Vrms / 400Vrms	
Output voltage	DC 350V / 700V	
Output power	Max 1.5kW / 3kW	
Circuit method	3Phase 3Level Vienna PFC	
Switching-frequency	50kHz	
Power efficiency	98% or more	Max
Power factor	99% or more	Max
Protection	Output Overvoltage Protection	At 200Vac : 400V At 400Vac : 750V
	Input Overcurrent Protection	10A
	Hardware Current Protection	Using POEG
	A/D Conversion Error	RA6T2 only / Manual reset not possible

3.1 Hardware Configuration

Figure 4 shows the configuration diagram of Vienna PFC Board and RX26T/RA6T2 CPU Board/Card used in this application note, and Figure 5 show the exterior view, Table 5 shows Vienna PFC Board connector list.

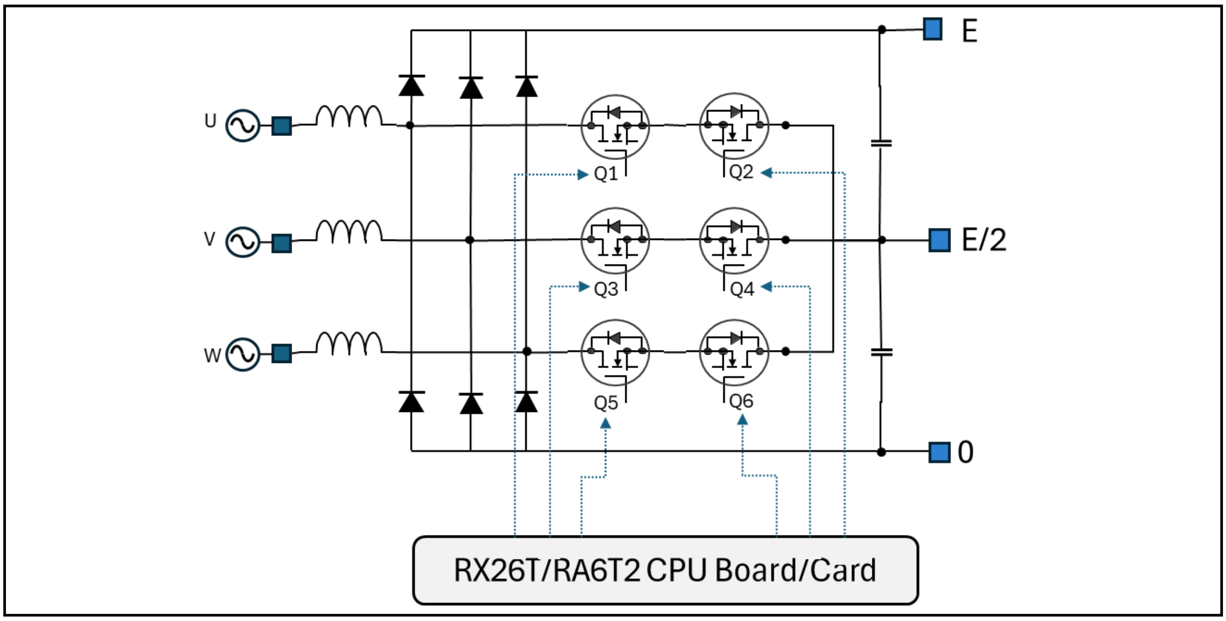


Figure 4 Board Configuration Diagram

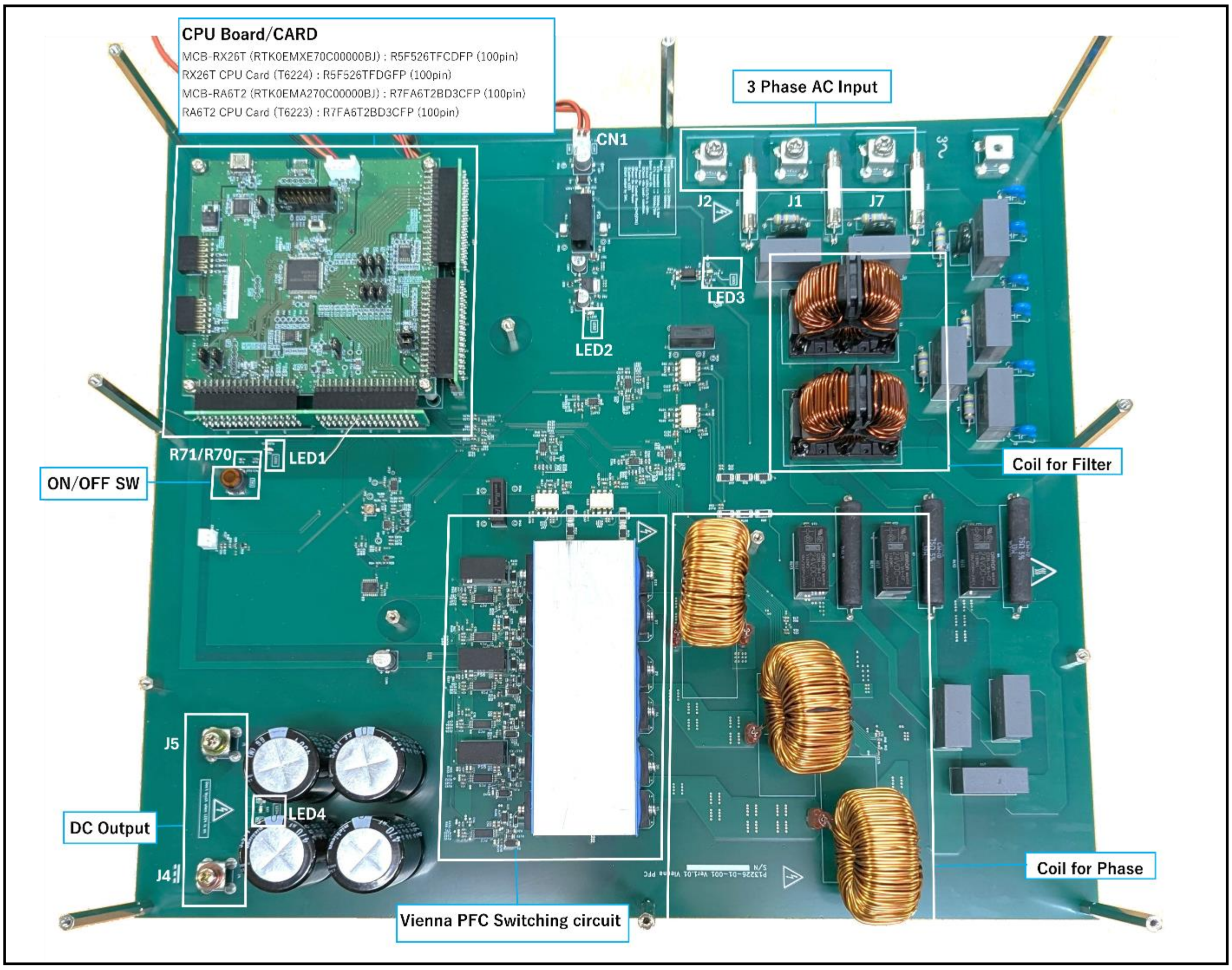


Figure 5 Vienna PFC board Exterior View

Table 5 Vienna PFC Board Connectors

Terminal name	Defined	Remarks
J7/J1/J2	Three-phase AC input	200V/400V M5 J7 : R J1 : S J2 : T
J4/J5	DC output	350V/700V M5 J4 : P J5 : N
CN1	Control power supply	24V/0.5A

3.2 Configuration of MCU Function

The configuration of MCU function is shown in Figure 6.

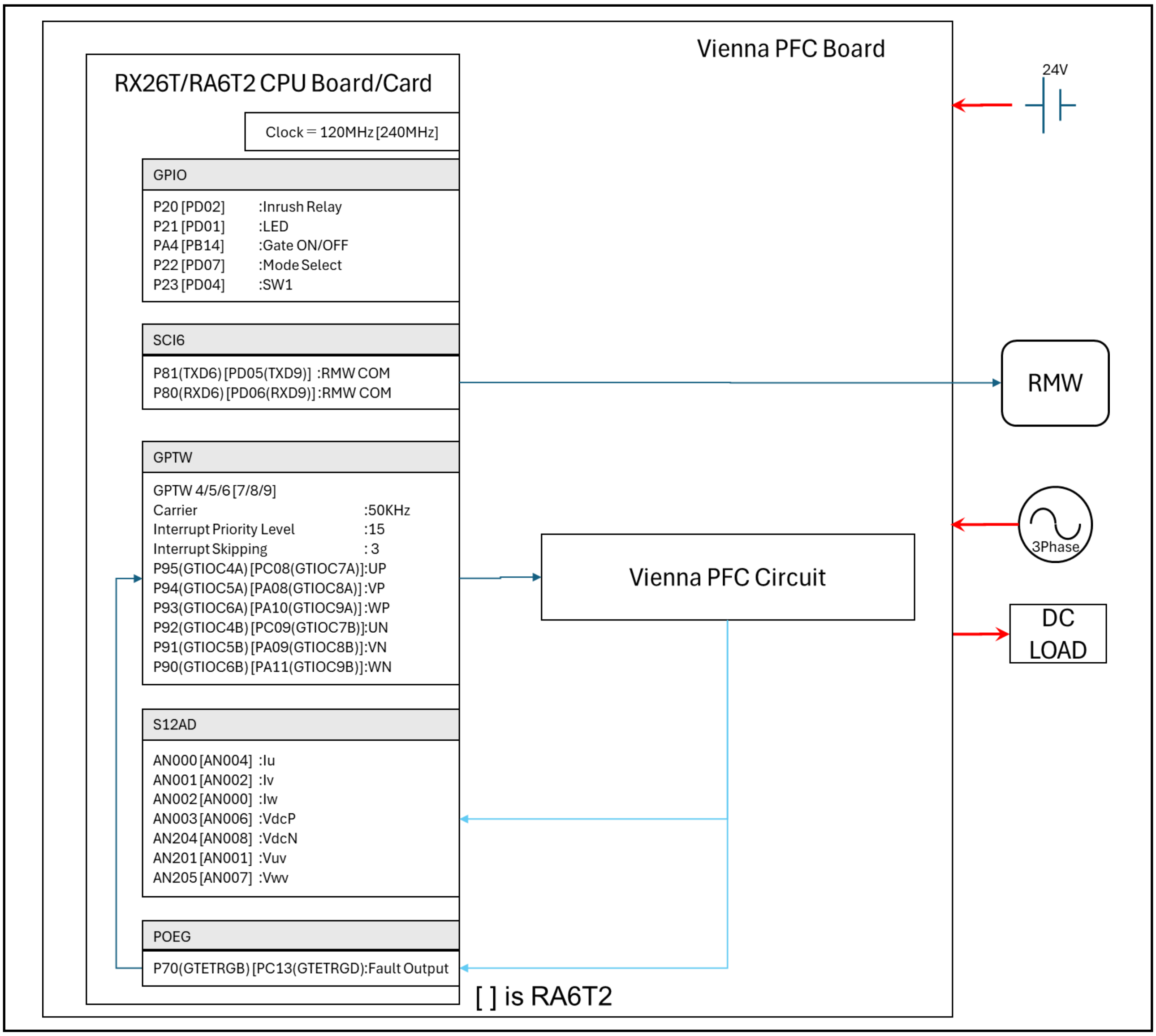


Figure 6 MCU Function Connection Configuration Diagram

3.3 MCU Peripheral Function

Table 6 shows the peripheral functions of RX26T/RA6T2 used in this system.

Table 6 List of Peripheral Functions Used

MCU modular	Function
12-bit AD (S12AD)	Input Current : S12AD0 : AN000/AN001/AN002 [S12AD0 : AN004/AN002/AN000] Input Voltage : S12AD2 : AN201/AN205 [S12AD0 : AN001/AN007] Output voltage : S12AD0/2 : AN003/AN204 [S12AD0 : AN006/AN008]
PWM output timer (GPTW)	50kHz Complementary PWM Output : GPTW4/5/6 [GPTW7/8/9] (Interrupt Thinning : 3-interrupt thinning)
Port Output Enable (POEG)	External Input Trigger (GTETRGB [GTETRGD]) stops Vienna PFC drive (GPTW's GPTW4/5/6 [GPTW7/8/9])

[ ] is RA6T2.

3.4 Port Interface

Table 7 lists the port interfaces of RX26T/RA6T2 used in this system.

Table 7 RX26T/RA6T2 Port Interfaces

Module name	Used resources	RX26T Port name	RA6T2 Port name	Function
GPIO		P20	PD02	Inrush Relay
		P21	PD01	LED
		P22	PD07	Mode Selection
		P23	PD04	SW1 (ON/OFF SW)
		PA4	PB14	Gate Enable (Gate ON/OFF)
SCI	SCI6 [SCI9]	P80(RXD6)	PD06(RXD9)	RMW communication (receive)
		P81(TXD6)	PD05(TXD9)	RMW communication (send)
GPTW	GPTW4/5/6 [GPTW7/8/9]	P90(GTOPC6B)	PA11(GTIOC9B)	PFC WN
		P91(GTIOC5B)	PA09(GTIOC8B)	PFC VN
		P92(GTIOC4B)	PC09(GTIOC7B)	PFC UN
		P93(GTIOC6A)	PA10(GTIOC9A)	PFC WP
		P94(GTIOC5A)	PA08(GTIOC8A)	PFC VP
		P95(GTIOC4A)	PC08(GTIOC7A)	PFC UP
S12AD	S12AD0	P40(AN000)	PA04(AN004)	Iu
		P41(AN001)	PA02(AN002)	Iv
		P42(AN002)	PA00(AN000)	Iw
		P43(AN003)	PA06(AN006)	VdcP
	S12AD2 [S12AD0]	P50(AN204)	PB00(AN008)	VdcN
		P51(AN205)	PA07(AN007)	Vuv
		P53(AN201)	PA01(AN001)	Vwv
POEG		P70(GTETRGB)	PC31(GTETRGD)	Fault Output

[ ] is RA6T2.

3.5 User Interface

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

Table 8 List of User Interfaces

Item	Interface component	Function
Operation switch	ON/OFF switch (SW1)	RUN/STOP command ON : RUN operation OFF: STOP operation
Operation Mode Indicator	LED1	Operation Mode Indicator Light : STOP mode Flash : RUN mode Off : ERROR mode
Power Status Indicator	LED2	Light when control power is ON.
Relay Status Indicator	LED3	Light when relay is ON
High Voltage Output Status Indicator	LED4	Light when High Voltage Output is ON

Table 9 Error contents

Error contents	Set value	Error flag **(g_u2_ErrorFlag_CurLoop)**
Output Overvoltage Protection	750V	0x0001
Input Overcurrent Protection	10A	0x0002
Fault Output Hardware Protection	Adjustable	0x0010
A/D Conversion Error	Default	0x0020

The value of the error flag (variable name: g_u2_ErrorFlag_CurLoop) can be confirmed via RMW.

3.6 Operation Procedure

① Set the input and output modes using resistors R70 and R71 near SW1.

If R70 is installed, the input is 200Vac and the output is 350Vdc/1.5kW.

If R71 is installed, the input is 400Vac and the output is 700Vdc/3kW.

② Connect the connectors shown in Table 5.

③ When power is supplied, LED1 lights up and the software waits in STOP mode.

④ Pressing SW1 on the board controls start/stop.

The behavior when pressing SW1 is as follows.

LED1 State	Mode after transition when SW1 pressed and LED1 state
LED1 ON (STOP mode)	LED1 flashes and enters RUN mode.
LED1 Flash (RUN mode)	LED1 ON and enters STOP mode.
LED1 OFF (ERROR mode)	LED1 ON and enters STOP mode.

When an error occurs, LED1 turns off and enters ERROR mode regardless of the current mode.

4. Software Description

Software-process of this application note is divided into AC-DC converter control block (Vienna PFC converter) and user interface control block. The user interface controls set the parameters required to control Vienna PFC converter and communicate with Renesas Motor Workbench. Vienna PFC converter performs complementary PWM to switch the switching devices according to the loading conditions. The software module configuration is shown in Figure 7.

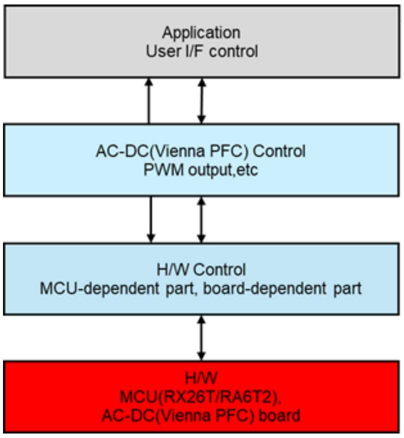


Figure 7 Module Configuration

4.1 Software Configuration

Table 10 shows the folder and file structure for the RX26T group. Table 10 shows the folder and file structure for the RA6T2 group.

Table 10 Folder and File Structure for RX26T group

Folder name	File name	Description
src	main.c	Main functions, user interface control
	intprg.c	Interrupt handler
	r_pwr_control.c	Initialization process
	r_pwr_interrupt.c	Interrupt process
	r_pwr_Sequence.c	Sequence control
	r_pwr_pfc_ctrl.c	PFC control software
	r_pwr_control.h	Initialization related defined
	r_pwr_interrupt.h	Control parameter defined
	r_pwr_Sequence.h	Sequence parameter related defined
	r_pwr_pfc_ctrl.h	PFC parameter defined
src\REL_src	resetprg.c	Process at power-on
	dbsct.c	B, R section-setting
	sbrk.c	Memory allocation process
	vecttbl.c	Vector table initialization process
	iodefine.h	IO register defined
	sbrk.h	Allocation size defined
	stacksct.h	Stack area size defined
	typedefine.h	Type defined
	vect.h	Vector defined
src\PWR_IOLIB	r_pwr_IOLIB_AD.c	S12AD related process
	r_pwr_IOLIB_CLOCK.c	Operation clock setting process
	r_pwr_IOLIB_CMT.c	CMT related process
	r_pwr_IOLIB_INV_GPT_PWM.c	GPTW related process
	r_pwr_IOLIB_IO.c	I/O related process
	r_pwr_IOLIB_IWDT.c	IWDT related process
	r_pwr_IOLIB_POE.c	POEG related process
	r_pwr_MATHLIB.c	Arithmetic operation related process
	r_pwr_IOLIB.h	MCU dependent part defined
	r_pwr_MATHLIB.h	Arithmetic operation related defined
src\ICS_LIB	ICS2_RX26T.h	Communication related defined for RMW tools
	ICS2_RX26T.lib	Communication library for RMW tools

Table 11 Folder and File Structure for RA6T2 group

Folder name	File name	Description
src	hal_entry.c	main function entry point
	r_pwr_control.c	Initialization process
	r_pwr_interrupt.c	Initialization process
	r_pwr_Sequence.c	Sequence control
	r_pwr_pfc_ctrl.c	PFC control software
	r_pwr_IOLIB.c	Additional Definitions for MCU Dependency Section
	r_pwr_MATHLIB.c	Arithmetic operation related process
	headers.h	Header File
	r_pwr_control.h	Initialization related defined
	r_pwr_interrupt.h	Control parameter defined
	r_pwr_Sequence.h	Sequence parameter related defined
	r_pwr_pfc_ctrl.h	PFC parameter defined
	r_pwr_IOLIB.h	MCU dependent part defined
	r_pwr_MATHLIB.h	Arithmetic operation related defined
ra ra_gen ra_cfg	-	FSP Generation Folder
ics_map_csv	-	RMW CSV File Generator
.\	ics_sample.dtlsp	Debug SP Project

4.2 Control overview

The software processing in this application note configures the GPTW4/5/6 (GPTW7/8/9 for RA6T2) of the RX26T group and RA6T2 group to triangle wave PWM mode 1, outputting PWM waveforms corresponding to the U, V, and W phases of the three-phase input.
It operates synchronized to the commercial power supply frequency (50/60Hz in Japan). Figure 8 shows the control signal wiring diagram.

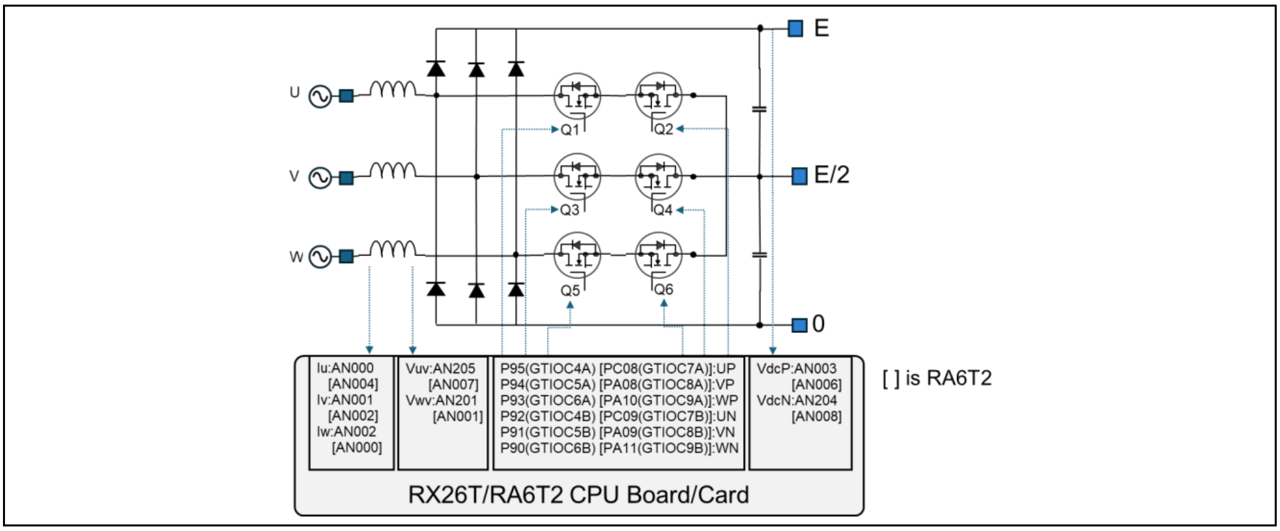
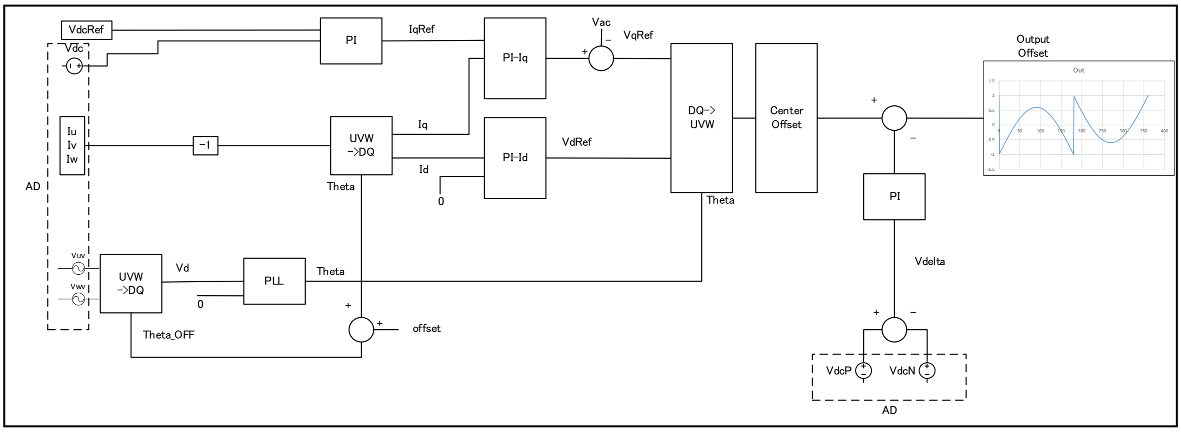


Figure 8 Circuit Configuration and Control Signal Wiring Diagram of Vienna PFC Converter Control Unit

4.3 Control logic

Figure 9 shows the control logic diagram. The Vienna PFC driver uses digital control, combining feedforward control and PI control to calculate the duty cycle. This control performs synchronous rectification during operation to improve efficiency. Based on the complementary PWM output, it modifies the phase output required for synchronous rectification.



Vdc、VdcP、VdcN、Iu、Iv、Iw、Vuv、Vwv is A/D data

VdcRef	: Voltage Command
IqRef	: Q-axis current command
Iq、Id	: q-axis current and d-axis current calculated from the phase current
Theta	: PLL output phase angle corresponding to phase voltage
Theta_OFF	: PLL output angle corresponding to line-to-line voltage
Offset	: Phase difference between phase voltage and line-to-line voltage
VdRef, VqRef	: d-axis output voltage, q-axis output voltage
Vac	: Input voltage
Vdelta	: Difference between VdcP and VdcN

Figure 9 Vienna PFC Control Logic Diagram

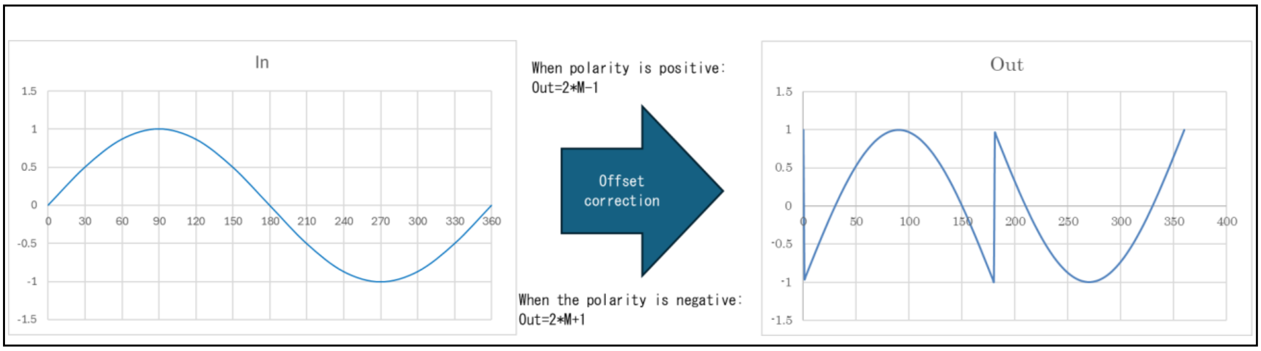
- PWM Period and Control Period
  The PWM period is 50kHz, and the control period is 12.5kHz (tripled). Due to the three-phase input, three-phase coordinate transformation is performed, and voltage and current control are executed in the dq rotating axis.

- Voltage Phase
  The input voltage is sampled as line-to-line voltage, so the angle is determined using a PLL. The phase of the phase voltage is obtained with a 30-degree offset.

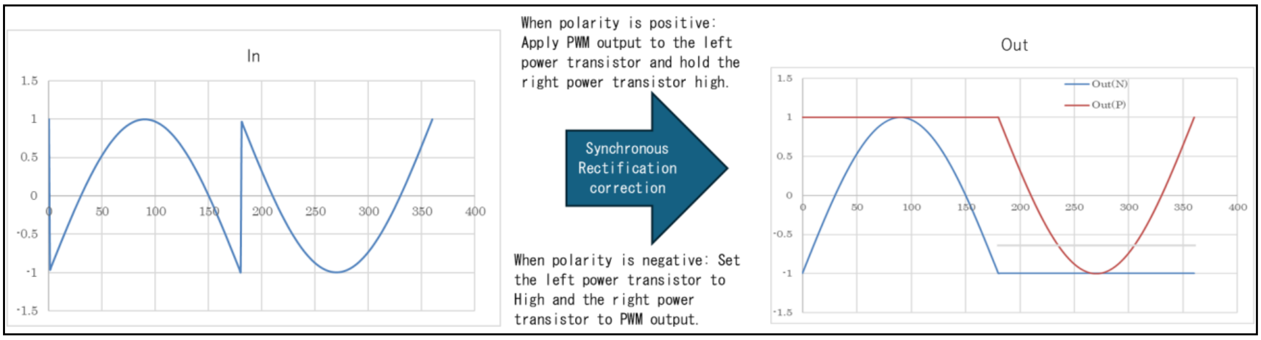
- Voltage and Current Control
  PI control of the voltage determines the q-axis current command, controlling the d-axis current to zero. PI control is also applied to the dq-axis currents to determine the output Vd and Vq. Adding the current voltage feedforward term to the q-axis output accelerates output tracking.

- Voltage Balance Control
  To maintain balance between the P and N components of the output voltage, the zero-phase output is added to the final modulation rate output, achieving P/N output balance. The zero-phase output is controlled via PI control based on the difference between the PN voltages.

- PWM Definition
  The PWM output is a three-phase complementary PWM output using GPTW's triangular wave PWM Mode 1. Coordinate transformation from Vd and Vq yields a sinusoidal output, to which the following output offset is applied based on voltage polarity.
  • When polarity is positive : Actual output modulation rate = 2 x Modulation rate (M) - 1
  • When polarity is negative : Actual output modulation rate = 2 x Modulation rate (M) + 1



- Synchronous Rectification
  To improve efficiency, one of the power transistors connected in series is driven by a PWM output, while the other is driven by a High output. This reduces switching losses in the devices. The switching pattern over one voltage cycle is as follows.



4.4 State Transition

Figure 10 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.

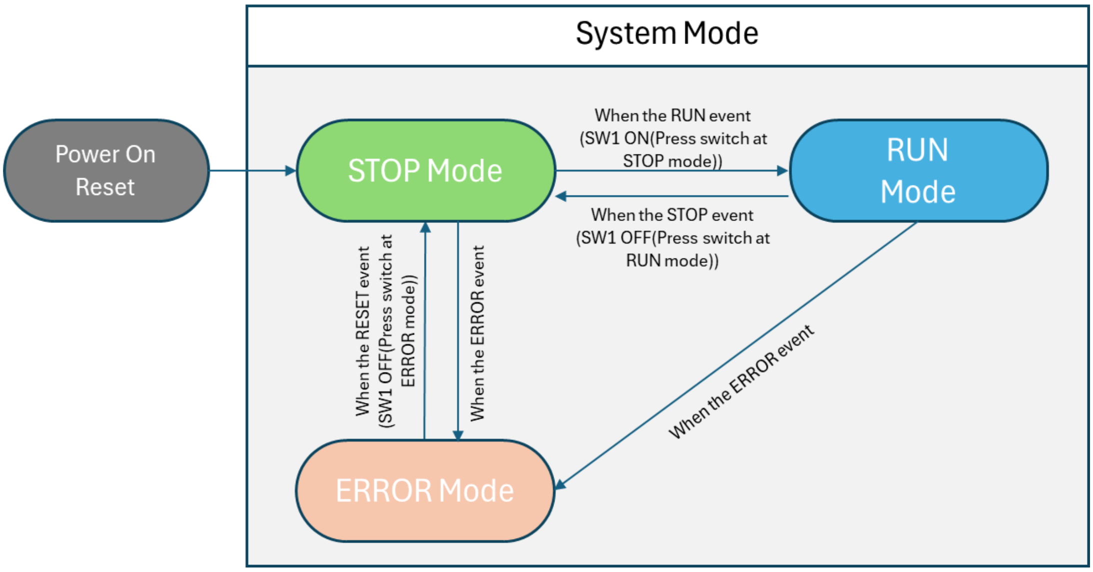
(2)Switch to "RUN Mode" in SW1 ON and execute AC-DC converter control (Vienna PFC converter). (LED1 is flash)

(3)All process are terminated by SW1 OFF, the status changes to "STOP Mode", and the system enters the standby status (LED1 ON).

■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 details of the error.

(2)By resetting SW1 OFF, it changes to "STOP Mode" and enters the standby status.



		Current Mode		
		STOP	RUN	ERROR
EVENT	STOP		STOP	STOP
	RUN	RUN		ERROR
	ERROR	ERROR	ERROR	

Figure 10 State Transition Diagram

4.5 List of Functions

The function list of this control program is shown below. 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 12 Functions for RX26T group

File		Function				Note
Path	Name	Name	Arguments	Return Type	Overview	
src	main.c	main	void	void	Main function	
	r_pwr_control.c	r_pwr_User_Ctrl_Init	void	void	Parameter Initialization	
	r_pwr_interrupt.c	interrupt_GPT4_carrier	void	void	12.5 kHz interrupt, A/D value get, PWM output configuration, error checking, user input, mode setting	
		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 handler 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 Triggering Process	
		r_pwr_Seq_Init	void	void	Sequence Initialization	Not used
	r_pwr_pfc_ctrl.c	r_pwr_Vpfc_control	void	void	PFC Control Function	
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	Not used
		r_pwr_ad_S12AD2_init	uint16_t mode	void	S12AD2 Initialization	
		r_pwr_ad_S12AD0_set_channel	uint32_t ch_list	void	S12AD Channel Settings	
		r_pwr_ad_S12AD1_set_channel	uint32_t ch_list	void	S12AD1 Channel Settings	Not used

		r_pwr_ad_S12AD2_set_channel	uint32_t ch_list	void	S12AD2 Channel Settings	
		r_pwr_ad_S12AD0_set_range	int16_t ch, int16_t offset, float range	void	S12AD Offset, Range Setting	
		r_pwr_ad_S12AD1_set_range	int16_t ch, int16_t offset, float range	void	S12AD1 Offset, Range Setting	Not used
		r_pwr_ad_S12AD2_set_range	int16_t ch, int16_t offset, float range	void	S12AD2 Offset, Range Setting	
	r_pwr_IOLIB_CLOCK.c	r_pwr_CLOCK_init	Void	void	Operating Clock Settings	
	r_pwr_IOLIB_CMT.c	r_pwr_interval_CMT0_init	uint16_t freq	void	CMT0 Initialization	Not used
		r_pwr_interval_CMT1_init	uint16_t freq	void	CMT1 Initialization	Not used
		r_pwr_interval_CMT2_init	uint16_t freq	void	CMT2 Initialization	Not used
		r_pwr_interval_CMT3_init	uint16_t freq	void	CMT3 Initialization	Not used
	r_pwr_IOLIB_INV_GPT_PWM.c	r_pwr_tppfc_GPT456_init	uint32_t usFreqCarrier, uint32_t usDeadtime, uint32_t usDecimation	void	Initialization for GPTW4/5/6 for AC-DC (PFC) Controlled PWM	
		r_pwr_tppfc_GPT456_set_uvw_3shunt	float refu, float refv, float refw	void	AC-DC (PFC) Control PWM GPTW4/5/6 Compare Value Setting	
	R_pwr_IOLIB_POE.c	r_pwr_tppfc_POEG_init	void	void	POEG Initialization	
	r_pwr_IOLIB_IO.c	r_pwr_User_CustomIO_init	void	void	Initialization of IO Ports	
	r_pwr_IOLIB_IWDT.c	r_pwr_IWDT_init	void	void	IWDT Initialization	Not used
	r_pwr_MATHLIB.c	r_pwr_uvw2dq	float iu, float iv, float iw, float theta, float *id, float *iq	void	uvw-dq conversion	
		r_pwr_dq2ab	float vd, float vq, float theta, float *va, float *vb	void	dq-αβ conversion	

		r_pwr_ab2uvw	float va, float vb, float *u, float *v, float *w	void	αβ-uvw conversion	
		r_pwr_calc_svpwm	float *refu, float *refv, float *refw	void	Spatial Vector Modulation	
		r_pwr_limit_PN_int16	int16_t data, int16_t limitp, int16_t limitn	float	Data Range Restriction Processing(int16)	Not used
		r_pwr_limit_PN	float data, float limitp, float limitn	void	Positive, Negative Data Range Restriction Processing	
		r_pwr_limit	float data, float limit	float	Data Range Restriction 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 Process	

Table 13 Functions for RA6T2 group

File		Function				Note
Path	Name	Name	Arguments	Return Type	Overview	
src	hal_entry.c	hal_entry	void	void	Main Function Actual Processing	
	r_pwr_control.c	r_pwr_User_Ctrl_Init	void	void	Parameter Initialization	
	r_pwr_interrupt.c	g_CarrierInterrupt	args_t	void	12.5 kHz interrupt, A/D value get, PWM output configuration, error checking, user input, mode setting	
		r_pwr_check_error_curloop	void	void	Error Checking	
		r_pwr_error_stop	void	void	Error handling	
	r_pwr_pfc_ctrl.c	r_pwr_Vpfc_control	void	void	PFC Control Function	
	r_pwr_Sequence.c	r_pwr_SEQ_Exec_Event	Uint8	void	Sequence Control Function	
		r_pwr_SEQ_Act	Uint8	void	RUN Event Handling	

		_Run				
		r_pwr_SEQ_Act_Stop	Uint8	void	STOP Event Handling	
		r_pwr_SEQ_Act_None	Uint8	void	NONE Event Handling	
		r_pwr_SEQ_Act_Reset	Uint8	void	RESET Event Handling	
		r_pwr_SEQ_Act_Error	Uint8	void	ERROR Event Handling	
		r_pwr_SEQ_Init_Start	void	void	Event Triggering Process	
		r_pwr_Seq_Init	void	void	Sequence Initialization	
	r_pwr_IOLIB.c	r_pwr_ad_set_range	int32_t ch, int32_t offset, float range	void	A/D Offset, Range Setting	
		r_pwr_tppfc_GPT789_set_uvw	float refu, float refv, float refw	void	AC-DC (PFC) Control PWM GPTW7/8/9 Compare Value Setting	
		r_pwr_tppfc_GPT789_stop_pwm	void	void	AC-DC (PFC) Control PWM GPTW7/8/9 Stop Processing	
		r_pwr_tppfc_GPT789_start_pwm	void	void	AC-DC (PFC) Control PWM GPTW7/8/9 Start Processing	
		r_pwr_tppfc_GPT7B_PWM_7A_HO	void	void	AC-DC (PFC) Control PWM GPTW7 Control Switching Process (GTIOC7A=High, GTIOC7B=PWM)	
		r_pwr_tppfc_GPT7B_HO_7A_PWM	void	void	AC-DC (PFC) Control PWM GPTW7 Control Switching Process (GTIOC7A=PWM, GTIOC7B=High)	
		r_pwr_tppfc_GPT8B_PWM_8A_HO	void	void	AC-DC (PFC) Control PWM GPTW8 Control Switching Process (GTIOC8A=High, GTIOC8B=PWM)	
		r_pwr_tppfc_GPT8B_HO_8A_PWM	void	void	AC-DC (PFC) Control PWM GPTW8 Control Switching Process (GTIOC8A=PWM, GTIOC8B=High)	
		r_pwr_tppfc_GPT9B_PWM_9A_HO	void	void	AC-DC (PFC) Control PWM GPTW9 Control Switching Process (GTIOC9A=High, GTIOC9B=PWM)	
		r_pwr_tppfc_GPT9B_HO_9A_PWM	void	void	AC-DC (PFC) Control PWM GPTW9 Control Switching Process (GTIOC9A=PWM, GTIOC9B=High)	
	r_pwr_MATHLIB.c	r_pwr_uvw2dq	float iu, float iv, float iw,	void	uvw-dq conversion	

			float theta, float *id, float *iq			
		r_pwr_dq2ab	float vd, float vq, float theta, float *va, float *vb	void	dq-αβ conversion	
		r_pwr_ab2uvw	float va, float vb, float *u, float *v, float *w	void	αβ-uvw conversion	
		r_pwr_calc_svp wm	float *refu, float *refv, float *refw	void	Spatial Vector Modulation	
		r_pwr_limit_PN	float data, float limitp, float limitn	void	Positive, Negative Data Range Restriction Processing	
		r_pwr_limit	float data, float limit	float	Data Range Restriction Processing	
		r_pwr_Inv_Calc _Lpf	float * input_lpf, float input, float k_filter	void	LPF calculation processing	

4.6 List of Variables

The following table lists the global variables used in this control program.

Table 14 List of Variables

File Name	Variable Name	Overview
r_pwr_interrupt.c	g_u1_Error_Status	Command Input Error Display Flag
	g_u2_ModeSystem	Driving Mode Display 0: STOP 1: RUN 2: ERROR
	g_u2_ModeSystem_Request	Command Acceptance (Controls the operating mode) 0 : STOP 1 : RUN 2 : ERROR
	g_u2_TimeSetting_Offset	Calibration time setting variable at startup
	g_u2_TimeCnt_Offset	Countdown for calibration time at startup
	g_f_ErrLevel_OV_pfc	PFC Overvoltage Protection Level
	g_f_ErrLevel_OC_pfc	PFC Overcurrent Protection Level

	g_u2_ErrorFlag_CurLoop	Error flag
	g_f_LpfFactor_CurrentOff	Filter Coefficient for Offset Calculation
	g_ics_cnt	RMW Thinning count
	g_f_Iu g_f_Iv g_f_Iw	Three-phase input current
	g_f_VdcP g_f_VdcN	Output voltage
	g_f_Vuv g_f_Vwv g_f_Vwu	Three-phase input phase-to-phase voltage
	g_f_VdcAll	Total output voltage
	g_f_VdcDelta	Output voltage difference
	g_f_Iu_Off g_f_Iv_Off g_f_Iw_Off	Current offset
	g_f_VdcP_Off g_f_VdcN_Off	Output voltage offset
	g_f_Vuv_Off g_f_Vwv_Off	Input voltage offset
	g_f_Mu_Ref g_f_Mv_Ref g_f_Mw_Ref	Modulation Rate Calculation Value
	g_f_Mu_Temp g_f_Mv_Temp g_f_Mw_Temp	Modulation Rate Buffer Value
	g_f_Mu_RefOut g_f_Mv_RefOut g_f_Mw_RefOut	Modulation Rate Final Output
	g_f_Ref_Limit	Modulation Rate Limit
	g_f_M_Off	Zero-phase offset
	g_u2_relay	Relay control variable
	g_u2_gate	GB Control Variable
	g_u2_relayflag	Relay Control Flag
	g_u2_relay_cnt	Counter for relay activation
	g_f_Vdc_relay	Relay activation voltage
	g_u2_syncOut	Synchronous Rectification Flag
	g_u2_flag_vdcOver	Overvoltage Flag
	g_u2_fo	Fault Output Input Detection

	g_u2_sw1 g_u2_sw2	SW1/2 Input Level
	g_u2_sw1_old	SW1 previous cycle value
	g_u2_sw1_cntP g_u2_sw1_cntN	SW1 Filter Count
	g_u2_sw1_value	SW1 level after filtering
	g_u2_sw1_value_old	The previous cycle value of the SW1 level after filtering
	g_u2_led_cnt	LED1 Flashing Counter
r_pwr_pfc_ctrl.c	g_f_Vd g_f_Vq	dq-axis voltage
	g_f_Id g_f_Iq	dq-axis current
	g_f_theta g_f_thetaPLL	PLL Output Angle
	g_f_theta_Off	Angle offset
	g_f_Kp_PLL g_f_Ki_PLL	Kp and Ki coefficients for PLL
	g_f_I_PLL_Refi	PLL integral value
	g_f_PLL_Ref	PLL output
	g_f_VdcRef	Output Voltage Command Value
	g_f_VdcRef_Ripple	Voltage ripple during discontinuous control
	g_f_I_Limit	Current limit
	g_f_Kp_Vdc g_f_Ki_Vdc	Kp, Ki for voltage control
	g_f_I_Refi	Voltage-Controlled Output Integral Value
	g_f_I_RefOver	Over-voltage Control Output Value
	g_f_I_Ref	Current command value
	g_f_Vdq_Limit	Output Voltage Limit
	g_f_Kp_Id g_f_Ki_Id	d-axis current control Kp, Ki
	g_f_Vd_Refi	d-axis voltage output integral value
	g_f_Vd_RefOver	D-axis voltage overvalues
	g_f_Vd_Ref	d-axis voltage command calculated value
	g_f_Vd_RefOut	d-axis voltage output value
	g_f_Kp_Iq g_f_Ki_Iq	q-axis current control Kp, Ki
	g_f_Vq_Refi	Q-axis voltage output integral value
	g_f_Vq_RefOver	Q-axis voltage overvalues

	g_f_Vq_Ref	Calculated Q-axis voltage command value
	g_f_Vq_RefOut	Q-axis voltage output value
	g_f_Va_Ref g_f_Vb_Ref	αβ-axis voltage
	g_f_Vu_Ref g_f_Vv_Ref g_f_Vw_Ref	Three-phase output voltage
	g_f_RevVdc	Inverse of the output voltage
	g_f_Kp_Vdiff g_f_Ki_Vdiff	Zero-phase control Kp, Ki
	g_f_Vdiff_Refi	Zero-sequence output integral value
	g_f_Mdiff_Limit	Zero-phase output limit value

4.7 Macro Defined List

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

Table 15 Macro Defined List

File	Defined	Set value	Unit	Remarks
r_pwr_interrupt.h	REF_VOL_H	700	V	Output voltage at 400Vac setting
	REF_VOL_L	350	V	Output voltage at 200Vac setting
	RELAY_ON_VOL_H	500	V	Relay activation voltage threshold at 400Vac setting
	RELAY_ON_VOL_L	220	V	Relay activation voltage threshold at 200Vac setting
	CALI_TIME	25000	s	Calibration time after control power is turned on (2 seconds)
	CALI_FILTER	0.001		Calibration filter
	RELAY_TIME	12500	s	Relay activation time (1 seconds)
	ERR_LEVEL_OV_H	750	V	Overvoltage level at 400Vac
	ERR_LEVEL_OV_L	400	V	Overvoltage level at 200Vac
	ERR_LEVEL_OC	10	A	Overcurrent Level
	CNT_SETTING_SW1	250	s	Filter time for SW1 (20ms)
	CNT_SETTING_LED1	12500	s	LED1 flashing cycle (1 secounds)
	CARRIER_FREQ_PFC	50000	Hz	PFC carrier cycle For RA6T2, configure via FSP.
	DEADTIME_PFC	0		Dead Time Setting For RA6T2, configure via FSP.
	ICS_DECI	1	time	RMW Thinning count
	FLAG_ERROR_OV	0x0001		Overvoltage Flag
	FLAG_ERROR_OC	0x0002		Overcurrent Flag
	FLAG_ERROR_POE	0x0010		POE Protection Status Flag
	FLAG_ERROR_ADERR	0x0020		A/D Conversion Error RA6T2 is cleared by a power reset.

4.8 Control Flow

4.8.1 Main Process

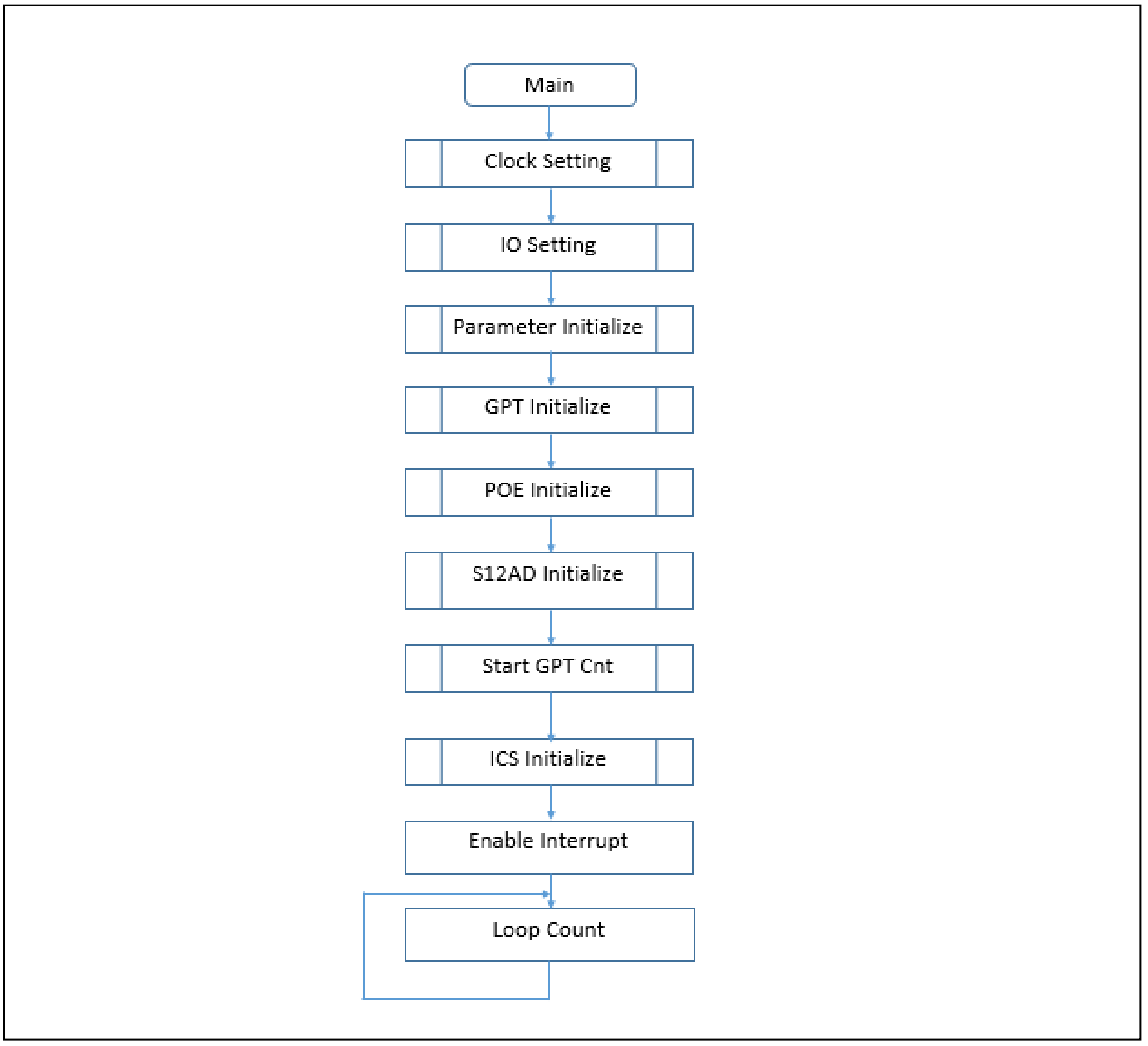


Figure 11 Main Process

4.8.2 12.5kHz Cycle Sequence

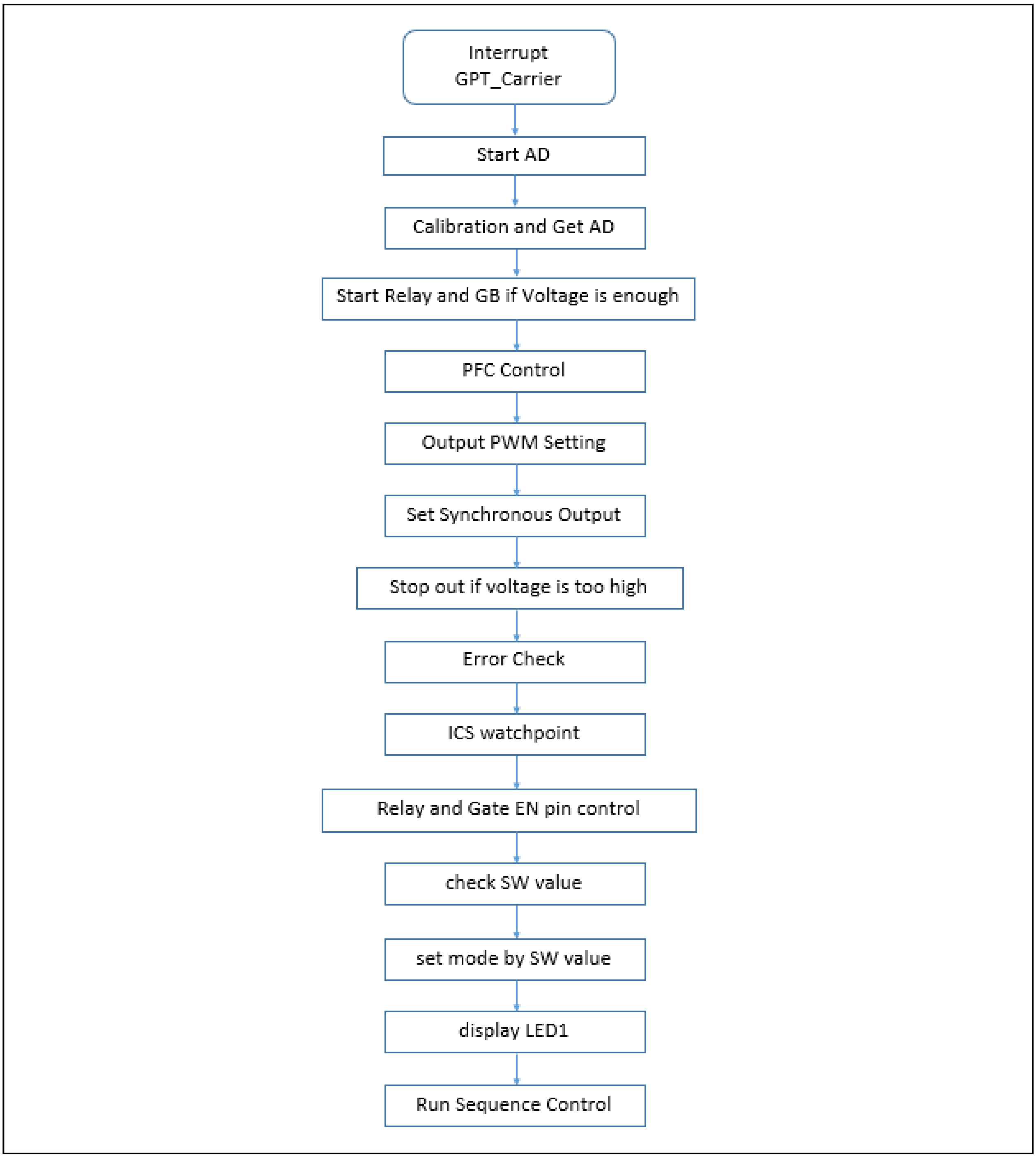


Figure 12 12.5kHz Cycle Sequence (GPTW4[GPTW7] U phase valley Interrupt Process)

4.8.3 Vienna PFC Control Process

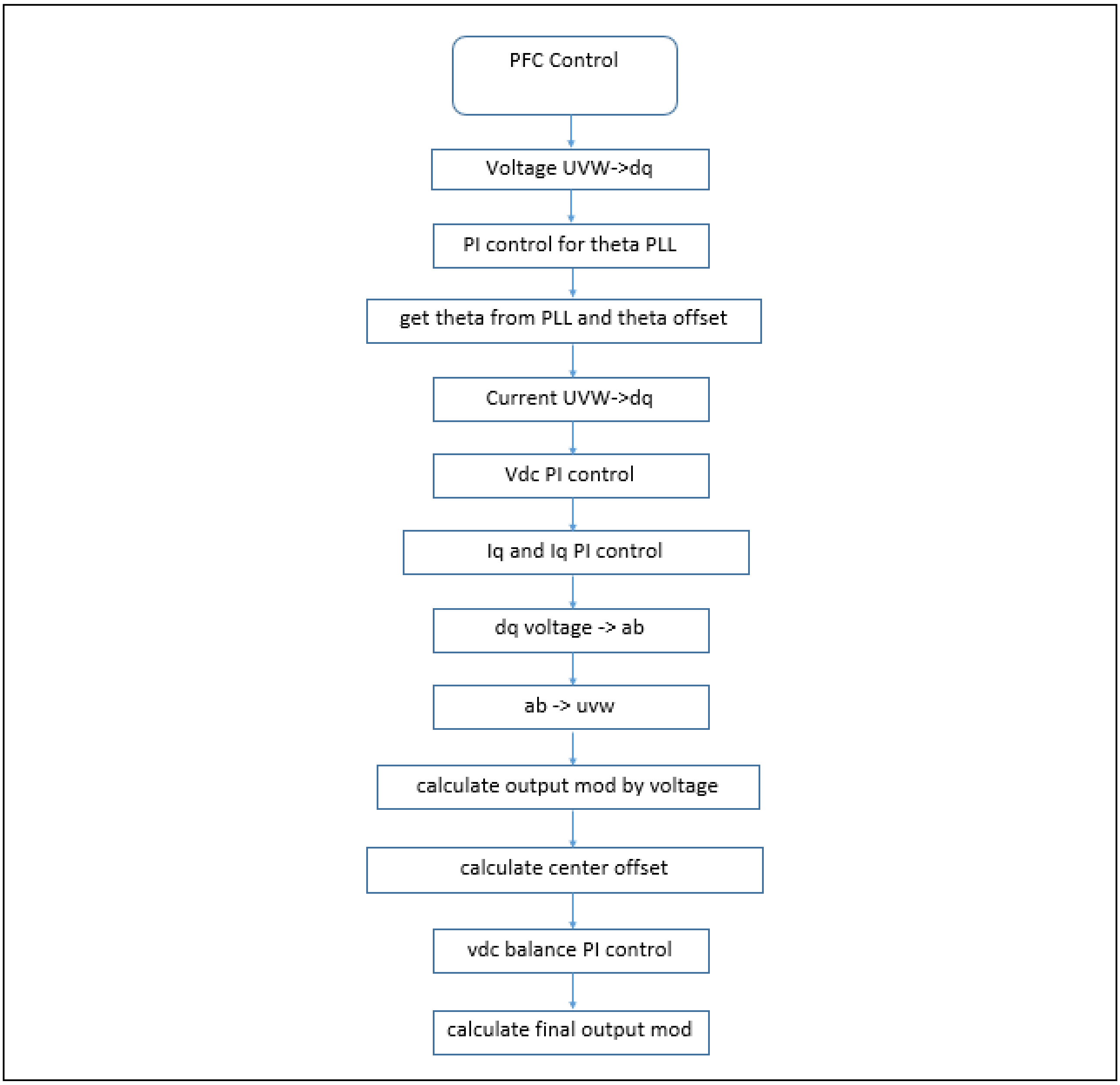


Figure 13 Vienna PFC Control Process

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 4.6 Variable List. Figure 14 shows the operating environment of "Renesas Motor Workbench" and Figure 15 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.

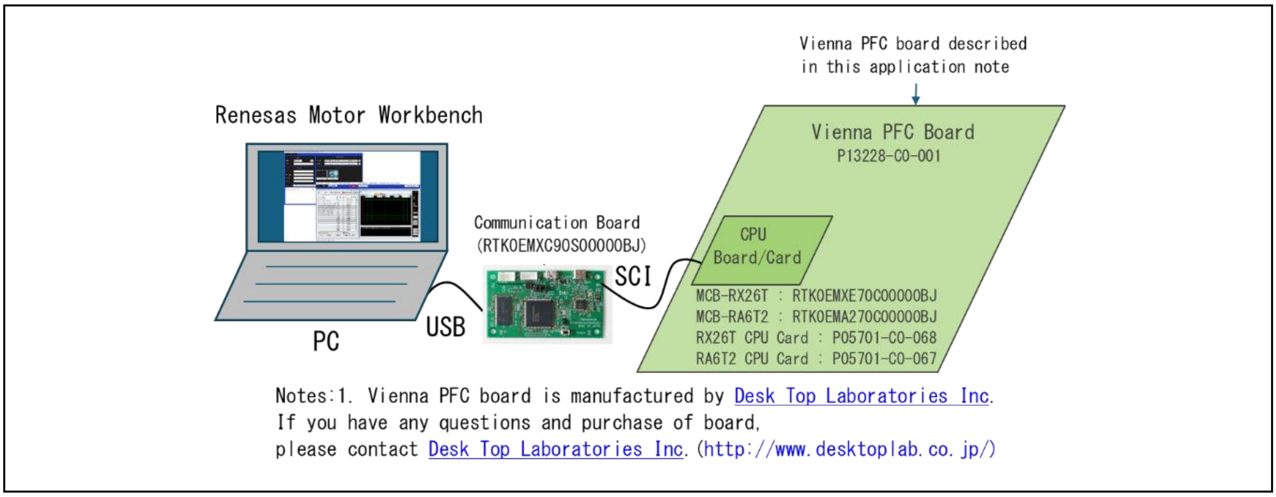


Figure 14 Renesas Motor Workbench Operating Conditions

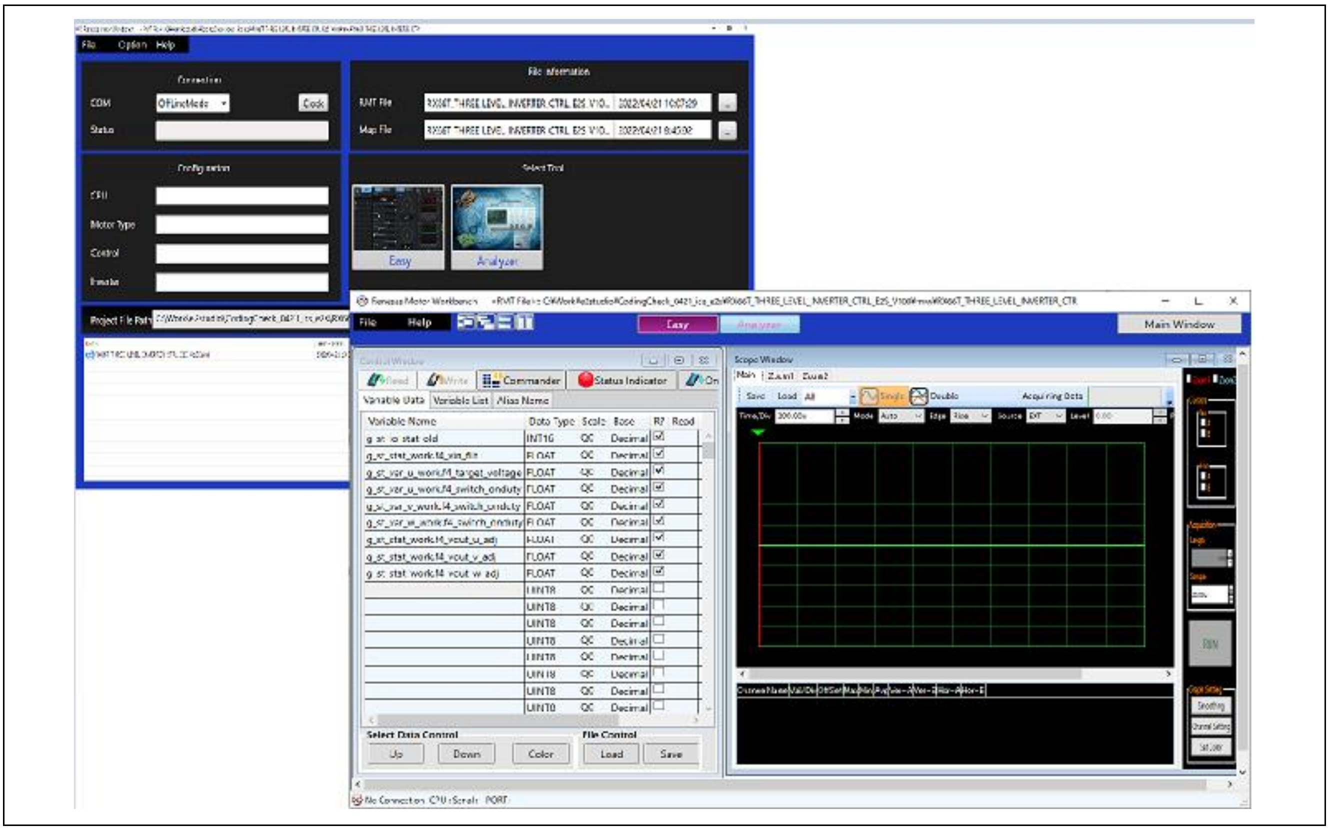
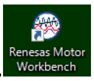


Figure 15 View of Renesas Motor Workbench

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 14 Variable List for the target variables.

6. Measurement Data

Section 6.1 shows the efficiency and power factor measurement results for the Vienna PFC in this application note, while Section 6.2 shows the execution time.

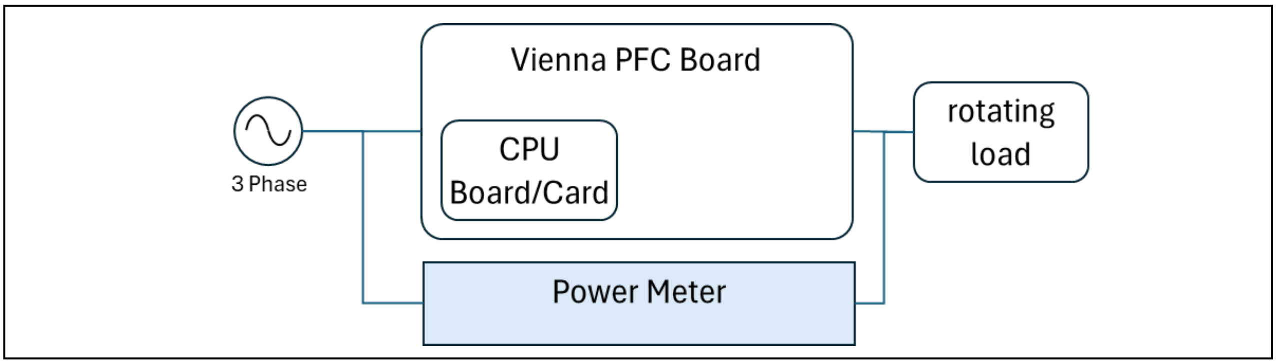


Figure 16 Measurement Environment

6.1 Efficiency and Power Factor Measurement Results

■Measurement Conditions

- The load is a regenerative load.
- Measure the voltage generated by the regenerative load as the output voltage.

- At 200Vac input (350Vdc output)
  At an input power of 624W, the output power is approximately 616W, achieving an efficiency of 98.78%. The efficiency measurement results are shown in Table 16 and Figure 17, and the power factor measurement results are shown in Figure 18.

Table 16 Efficiency measurement results at 200Vac input

Input voltage (V)	Output voltage (V)	Output current (A)	Efficiency
216.0	331.90	212.0	98.15
421.0	331.30	413.8	98.29
624.0	325.48	616.4	98.78
826.8	319.60	811.5	98.15
1029.1	318.83	1009.7	98.11
1231.7	318.44	1207.7	98.05
1433.9	317.95	1403.6	97.89
1534.8	319.02	1501.7	97.84

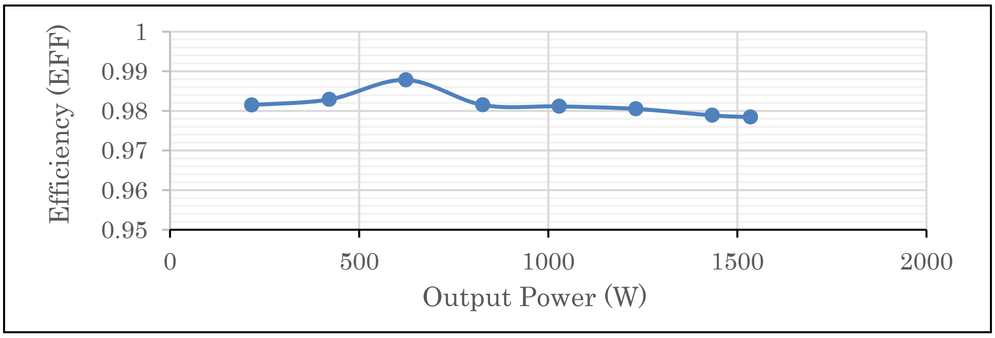


Figure 17 Efficiency relative to output power at an input voltage of 200Vac

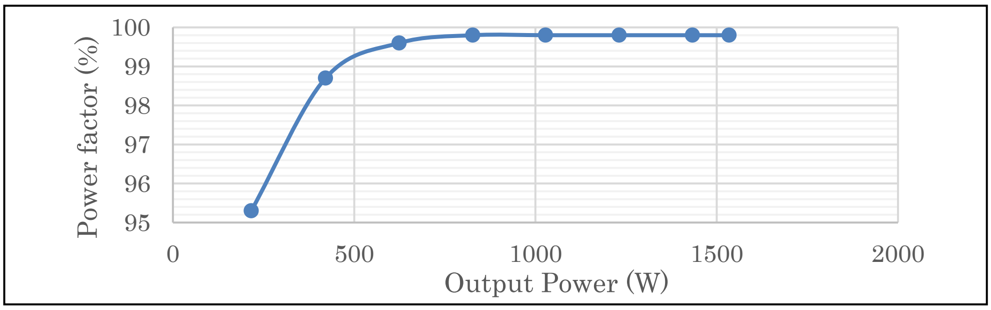


Figure 18 Power factor relative to output power at an input voltage of 200Vac

- At 400Vac input (700Vdc output)
  At an input power of 2857W, the output power is approximately 2808W, achieving an efficiency of 98.28%. The efficiency measurement results are shown in Table 16 and Figure 17, and the power factor measurement results are shown in Figure 18.

Table 17 Efficiency measurement results at 400Vac input

Input voltage (V)	Output voltage (V)	Output current (A)	Efficiency
433.8	699.03	416.8	96.08
841.8	699.37	821.0	97.53
1248.9	698.68	1224.3	98.03
1651.7	698.89	1621.8	98.19
2050.9	698.97	2014.5	98.23
2453.4	699.00	2409.8	98.22
2857.4	699.38	2808.3	98.28
3061.7	699.19	3008.2	98.25
3072.2	695.79	3018.3	98.25

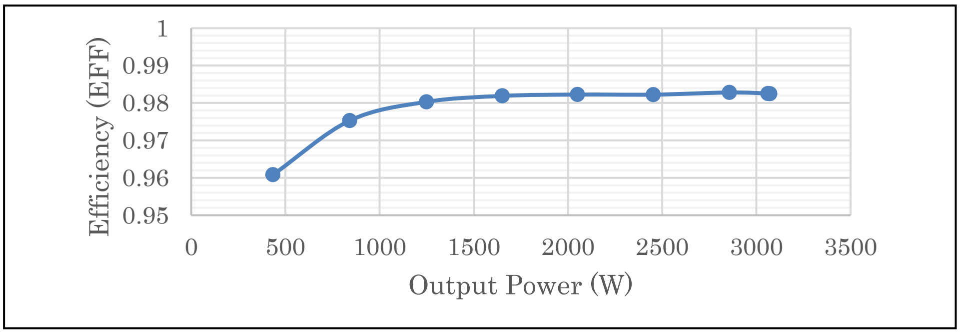


Figure 19 Efficiency relative to output power at an input voltage of 400Vac

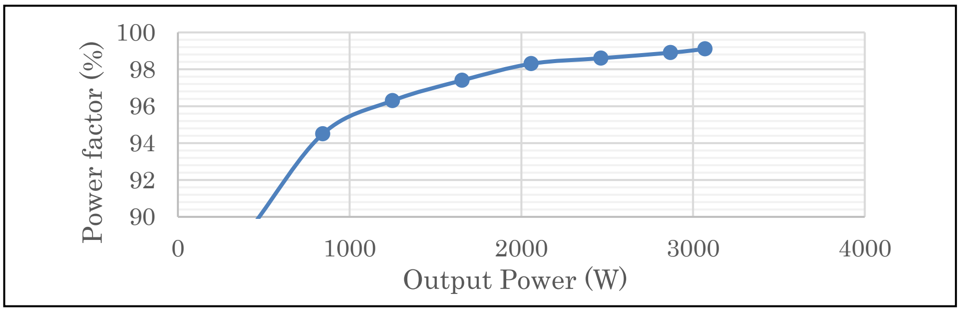


Figure 20 Power factor relative to output power at an input voltage of 400Vac

6.2 Execution Time

Table 18 shows the execution times for the RX26T group and RA6T2 group.

Table 18 Execution Time

Grope Name	RUN (us)
RX26T (RXv3 core, maximum operating frequency 120MHz)	19.5
RA6T2 (Arm® Cortex®-M33 core, maximum operating frequency 240MHz)	30.5

7. Important Notes

① First, wire the inputs and outputs according to the connector list in Table 5 Vienna PFC Board.

② Check the input and output voltages at R70 and R71. Refer to Section 3.6 Operation Procedure for details.

③ Before startup, confirm that the output voltage is 0 (LED4 is completely off).

④ Turn on the control power first, wait at least 2 seconds, then turn on the three-phase power.

Ensure the three-phase power supply is applied with no load connected.

⑤ After applying the three-phase power supply, verify the relay is ON (LED3 is lit).

If the input voltage is too low, the relay may not activate. Always confirm the relay is ON.

⑥ After startup, verify all LEDs (LED1 to LED4) are lit.

⑦ During load testing, ensure cooling fans are available.

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Oct.7.25	-	First Edition

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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(Rev.5.0-1 October 2020)

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