3-Phase AC 400 V Input
PFC Converter

SW Guide

RD044-SWGUIDE-01

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

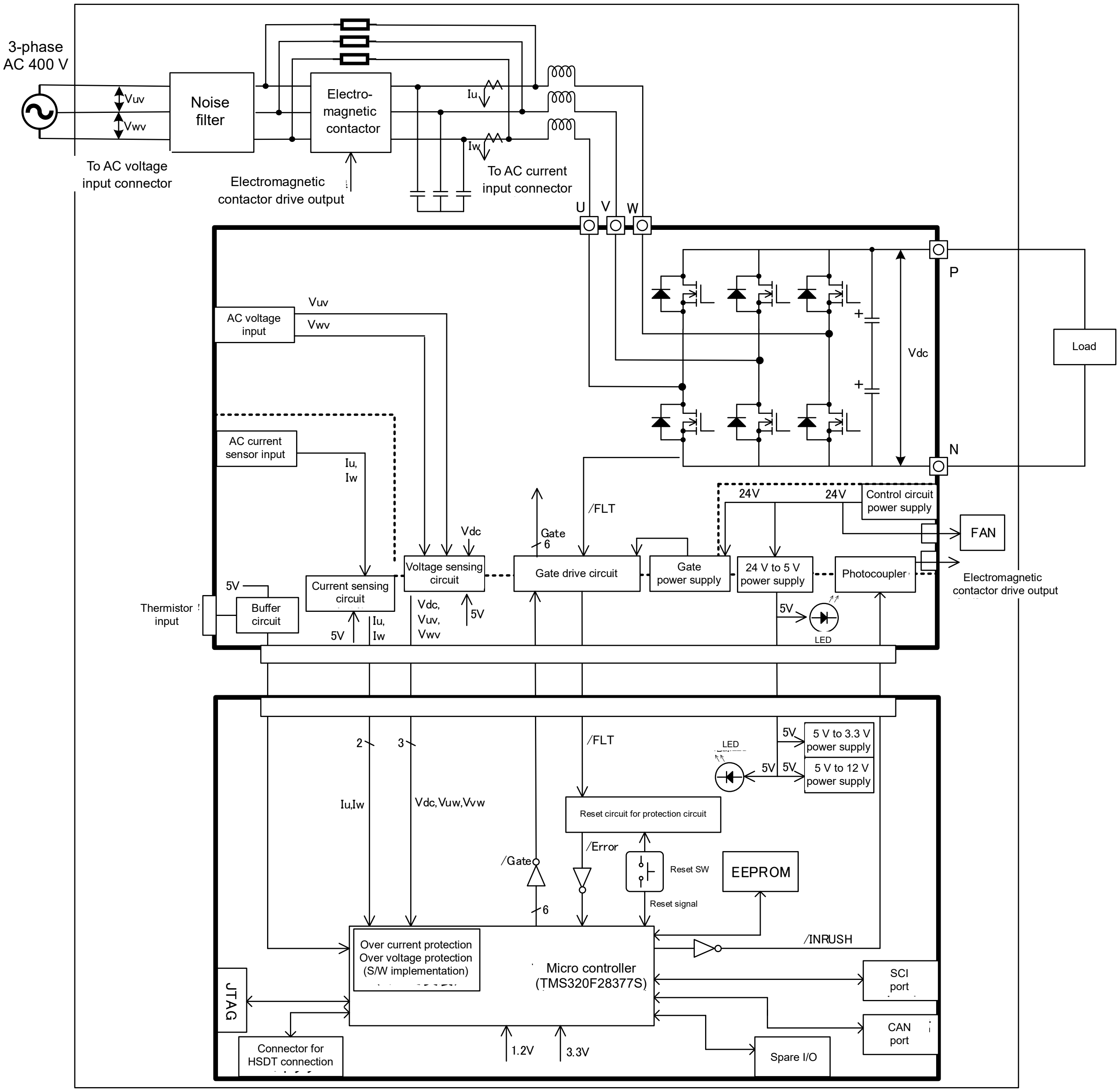
Contents

1. Introduction

1.1. Overview

This guide defines the software (SW) specifications for the power controller of the 3-phase AC 400 V input PFC power supply (this power supply) . The hardware (HW) to be controlled by the SW specified in this guide is outlined as shown below.

<Overview of HW>



1.2. How to Use

・Procedure for use

1. Turn on the control power 24 V.
2. Turn on the 3-phase AC power supply.

・Procedure for resetting and reusing from Error status

1. Disconnect the connection with the 3-phase AC power supply.
2. Press the reset switch or turn on the control power again.
   (The reset switch is lacated on the control board.)

The following is an overview of the power controller used with this power supply.

<Power Controller>

Use TMS320F28377SPTP as the power controller.

1. Features

Item	Description
Manufacturer	Texas Instruments
Model number	TMS320F28377SPTP
Package	176pin, HLQFP, Pin-to-Pin 0.5 mm Pitch
Memory capacity	ROM : 1 MB (1 word = 16 bit) RAM : 328 kB (1 word = 16 bit)
Maximum operating frequency	200 MHz (XIN = 20 MHz)
Timer	32-bit timer counter × 3 channels
	Watchdog Timer (WDT)
PWM signal generation function	6ch (of which 3ch is used) Operating frequency 100 MHz
Comparator function	8 channels (3 of which are used) U-phase current-overcurrent protection W-phase current vs. overcurrent protection DC voltage-overvoltage protection
Communication Function	I2C × 1ch (used as interface with EEPROM) CAN × 1 ch (not used with this power supply standard SW) SCI ×2ch (1ch is used for communication with HSDT-DP made by Head Spring. The other channel is not used with the standard switch of this power supply.)
A/D conversion	12-bit sample-and-hold method × 4 modules (8 channels for input channels to the A/D conversion module)
EEPROM function	Manufacturer: Micronchip Technology, Model number: OOCI/SM (Not used with this power supply standard SW)
IO Voltage	3.3 V
Core voltage	1.2 V

2. Clock

The power controller uses the following clocks:

External transmitter
20 MHz

3. Development environment

Code-development tools: Texas Instruments Code Composer Studio

OS:Windows,Mac OS,Linux

Debug tool: HSDT-DP, HSDT-GUI made by Head Spring

OS:Windows

2. Input/Output Signal

I/O signals are defined as follows.

Port	Pin	Signal name	Function	I/O (Form)	Initial value	Other
GPIO0	160	PWM1A_DSP160	U-phase high-side PWM gate signal	O (CMOS)	0	
GPIO1	161	PWM1B_DSP161	U-phase low-side PWM gate signal	O (CMOS)	0	
GPIO2	162	PWM2A_DSP162	V-phase high-side PWM gate signal	O (CMOS)	0	
GPIO3	163	PWM2B_DSP163	V-phase low-side PWM gate signal	O (CMOS)	0	
GPIO4	164	PWM3A_DSP164	W-phase high-side PWM gate signal	O (CMOS)	0	
GPIO5	165	PWM3B_DSP165	W-phase low-side PWM gate signal	O (CMOS)	0	
GPIO6	166	PWM4A_DSP166	PWM signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO7	167	PWM4B_DSP167	PWM signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO8	18	PWM5A_DSP18	PWM signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO9	19	PWM5B_DSP19	PWM signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO10	1	PWM6A_DSP1	PWM signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO11	2	PWM6B_DSP2	PWM signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO12	4	No signal assignment	-	-	-	
GPIO13	5	No signal assignment	-	-	-	
GPIO14	6	No signal assignment	-	-	-	

GPIO15	7	No signal assignment	-	-	-	
GPIO16	8	DO0_DSP8	For gate driver error signal short circuit Digital signal output	O (CMOS)	0	
GPIO17	9	DO1_DSP9	Digital signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO18	10	DO2_DSP10	Digital signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO19	12	DO3_DSP12	Digital signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO20	13	DO4_DSP13	Digital signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO21	14	DO5_DSP14	Digital signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO22	22	DO6_DSP22	Digital signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO23	23	DO7_DSP23	Digital signal output function (Not used with this power supply)	O (CMOS)	0	
GPIO24	24	No signal assignment	-	-	-	
GPIO25	25	No signal assignment	-	-	-	
GPIO26	27	No signal assignment	-	-	-	
GPIO27	28	No signal assignment	-	-	-	
GPIO28	64	No signal assignment	-	-	-	
GPIO29	65	No signal assignment	-	-	-	
GPIO30	63	No signal assignment	-	-	-	

GPIO31	66	No signal assignment	-	-	-	
GPIO32	67	No signal assignment	-	-	-	
GPIO33	69	No signal assignment	-	-	-	
GPIO34	70	No signal assignment	-	-	-	
GPIO35	71	No signal assignment	-	-	-	
GPIO36	83	CANRX_A_DSP83	CAN communication reception function	I (CMOS)	1	
GPIO37	84	CANTX_A_DSP84	CAN communication transmission function	O (CMOS)	0	
GPIO38	85	No signal assignment	-	-		
GPIO39	86	No signal assignment	-	-		
GPIO40	87	No signal assignment	-	-		
GPIO41	89	No signal assignment	-	-		
GPIO42	130	SDA_A_DSP130	I2C communication data signal function	O/I (CMOS)	1	IFs to EEPROM
GPIO43	131	SCL_A_DSP131	I2C communication clock signal function	O (CMOS)	1	IFs to EEPROM
GPIO44	113	No signal assignment	-	-		
GPIO45	115	No signal assignment	-	-		
GPIO46	128	No signal assignment	-	-		
GPIO47	129	No signal assignment	-	-		
GPIO48	90	No signal assignment	-	-		
GPIO49	93	No signal assignment	-	-		

GPIO50	94	DIO08_DSP94	General purpose digital input/output function (Not used with this power supply)	I (CMOS)	1	Function can be changed by SW
GPIO51	95	DIO09_DSP95	General purpose digital input/output function (Not used with this power supply)	I (CMOS)	1	Function can be changed by SW
GPIO52	96	DIO10_DSP96	General purpose digital input/output function (Not used with this power supply)	I (CMOS)	1	Function can be changed by SW
GPIO53	97	DIO11_DSP97	General purpose digital input/output function (Not used with this power supply)	I (CMOS)	1	Function can be changed by SW
GPIO54	98	No signal assignment	-	-		
GPIO55	100	No signal assignment	-	-		
GPIO56	101	No signal assignment	-	-		
GPIO57	102	No signal assignment	-	-		
GPIO58	103	SSO_DSP103	Head Spring HSDT-DP For SCOPE function SPI Communication-Data Output	O (CMOS)		
GPIO59	104	SSI_DSP104	Head Spring HSDT-DP For SCOPE function SPI Communication-Data Input	I (CMOS)		
GPIO60	105	SSCK_DSP105	Head Spring HSDT-DP For SCOPE function SPI Communication-Clock Output	O (CMOS)		
GPIO61	107	SPISTEA_DSP107	Head Spring HSDT-DP For SCOPE function SPI communication-Sync signal output	O (CMOS)		

GPIO62	108	No signal assignment	-	-		
GPIO63	109	No signal assignment	-	-		
GPIO64	110	No signal assignment	-	-		
GPIO65	111	No signal assignment	-	-		
GPIO66	112	No signal assignment	-	-		
GPIO67	132	DI0_DSP132	U-phase gate driver error signal Input function	I (CMOS)	0	
GPIO68	133	DI1_DSP133	V-phase gate driver error signal Input function	I (CMOS)	0	
GPIO69	134	No signal assignment	-	-		
GPIO70	135	No signal assignment	-	-		
GPIO71	136	No signal assignment	-	-		
GPIO72	139	BOOT1_DSP139	Boot mode selector	I	-	
GPIO73	140	DI2_DSP140	W-phase gate driver error signal Input function	I (CMOS)	0	
GPIO74	141	DI3_DSP141	Digital signal input function (Not used with this power supply)	I (CMOS)	0	
GPIO75	142	DI4_DSP142	Digital signal input function (Not used with this power supply)	I (CMOS)	0	
GPIO76	143	DI5_DSP143	Digital signal input function (Not used with this power supply)	I (CMOS)	0	
GPIO77	144	DI6_DSP144	Digital signal input function (Not used with this power supply)	I (CMOS)	0	
GPIO78	145	DI7_DSP145	Digital signal input function (Not used with this power supply)	I (CMOS)	0	

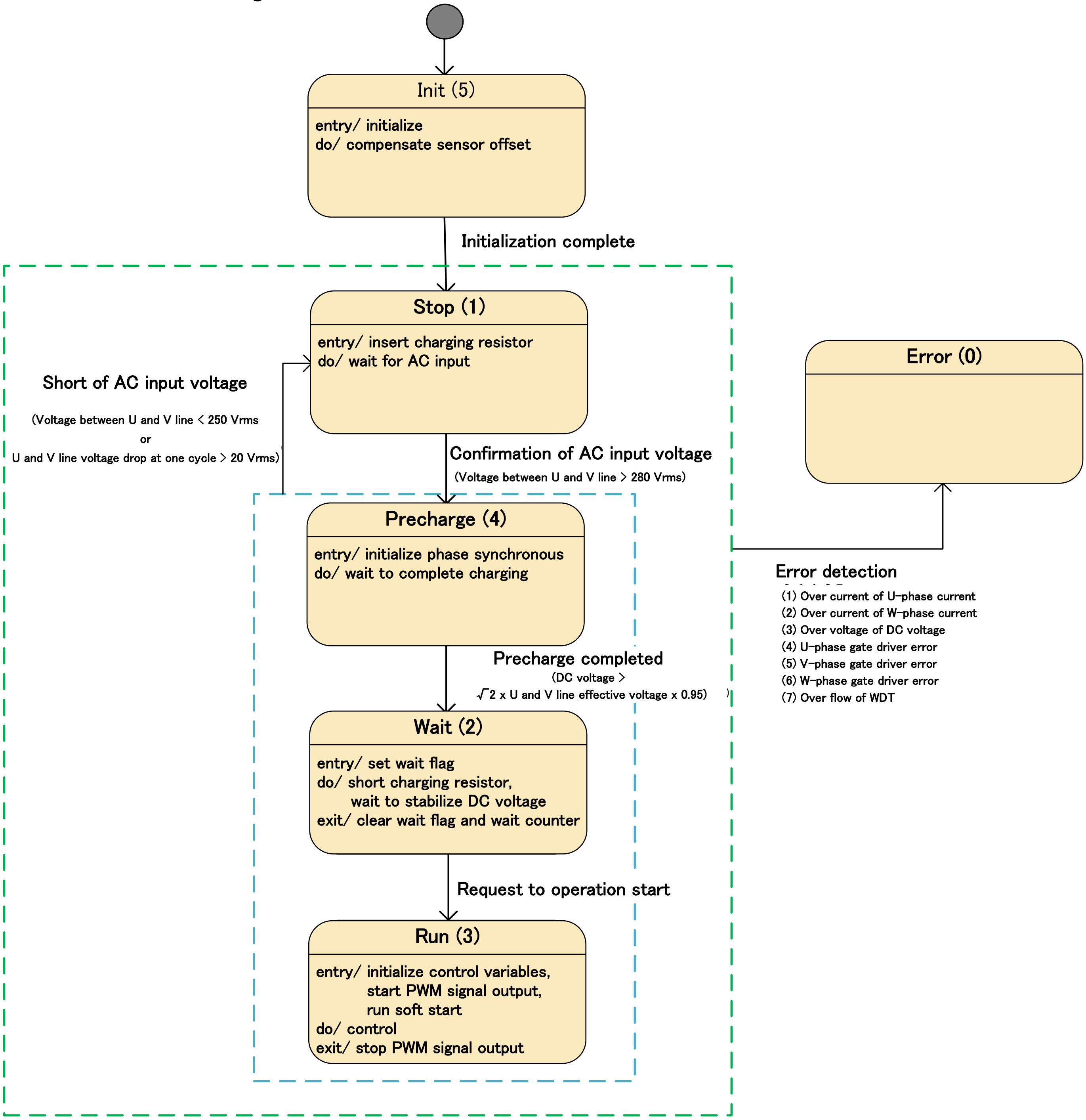
GPIO79	146	No signal assignment	-	-		
GPIO80	148	No signal assignment	-	-		
GPIO81	149	No signal assignment	-	-		
GPIO82	150	No signal assignment	-	-		
GPIO83	151	No signal assignment	-	-		
GPIO84	154	SCITXDA_ DSP154	Head Spring HSDT-DP Debug communication function			
GPIO85	155	SCIRXDA_ DSP155	Head Spring HSDT-DP Debug communication function			
GPIO86	156	SCITX_B_ DSP156	General purpose serial communication function (Not used with this power supply)			
GPIO87	157	SCIRX_B_ DSP157	General purpose serial communication function (Not used with this power supply)			
GPIO88	170	No signal assignment	-	-	-	-
GPIO89	171	DIO12_DSP171	General purpose digital input/output function (Not used with this power supply)	I (CMOS)	1	Function can be changed by SW
GPIO90	172	DIO13_DSP172	General purpose digital input/output function (Not used with this power supply)	I (CMOS)	1	Function can be changed by SW
GPIO91	173	No signal assignment	-	-		
GPIO92	174	No signal assignment	-	-		

GPIO93	175	DIO14_DSP175	General purpose digital input/output function (Not used with this power supply)	I (CMOS)	1	Function can be changed by SW
GPIO94	176	DIO15_DSP176	General purpose digital input/output function (Not used with this power supply)	I (CMOS)	1	Function can be changed by SW
GPIO 133	118	No signal assignment	-	-		

3. State Transition

3.1. State Transition Diagram

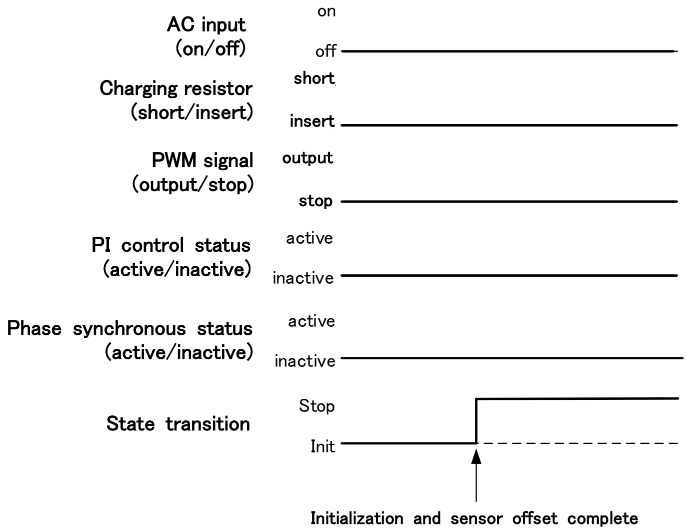
The state transition diagram of this SW is shown below.



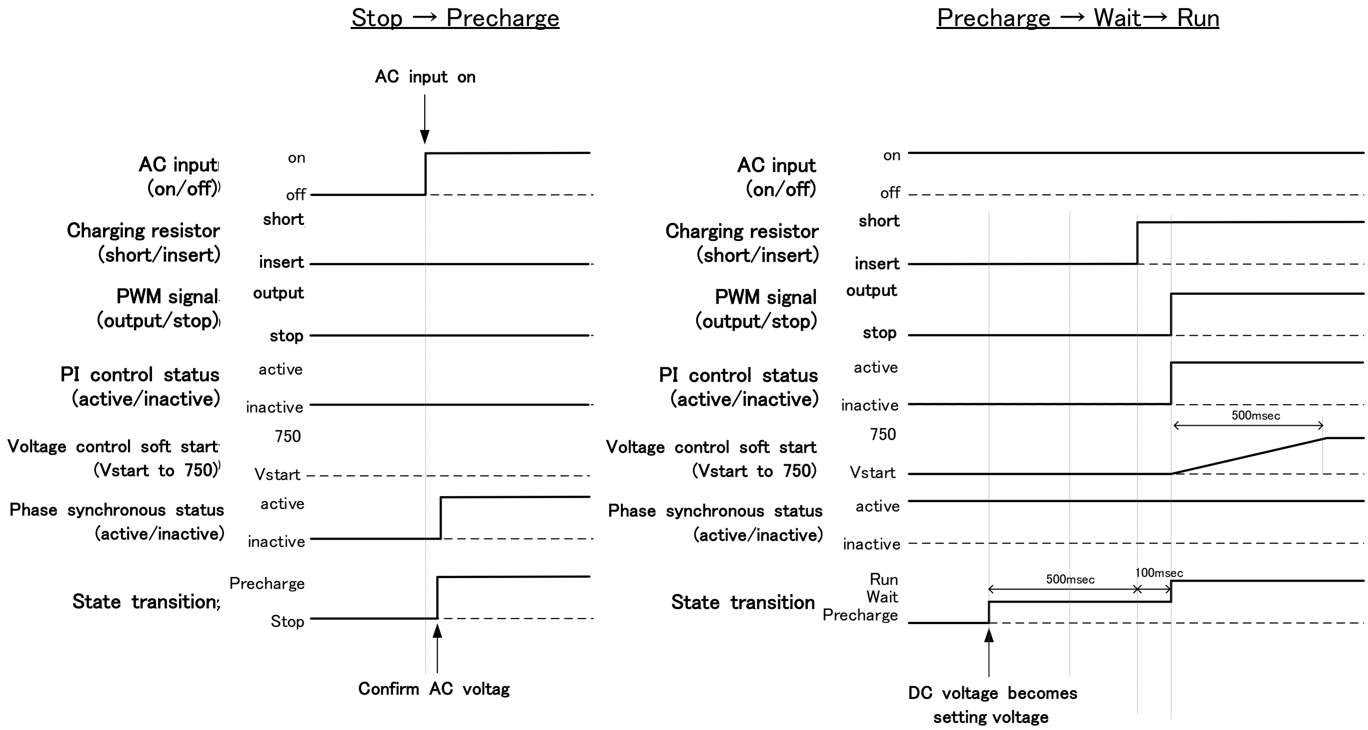
3.2. Timing Chart

The timing chart of this SW is shown below.

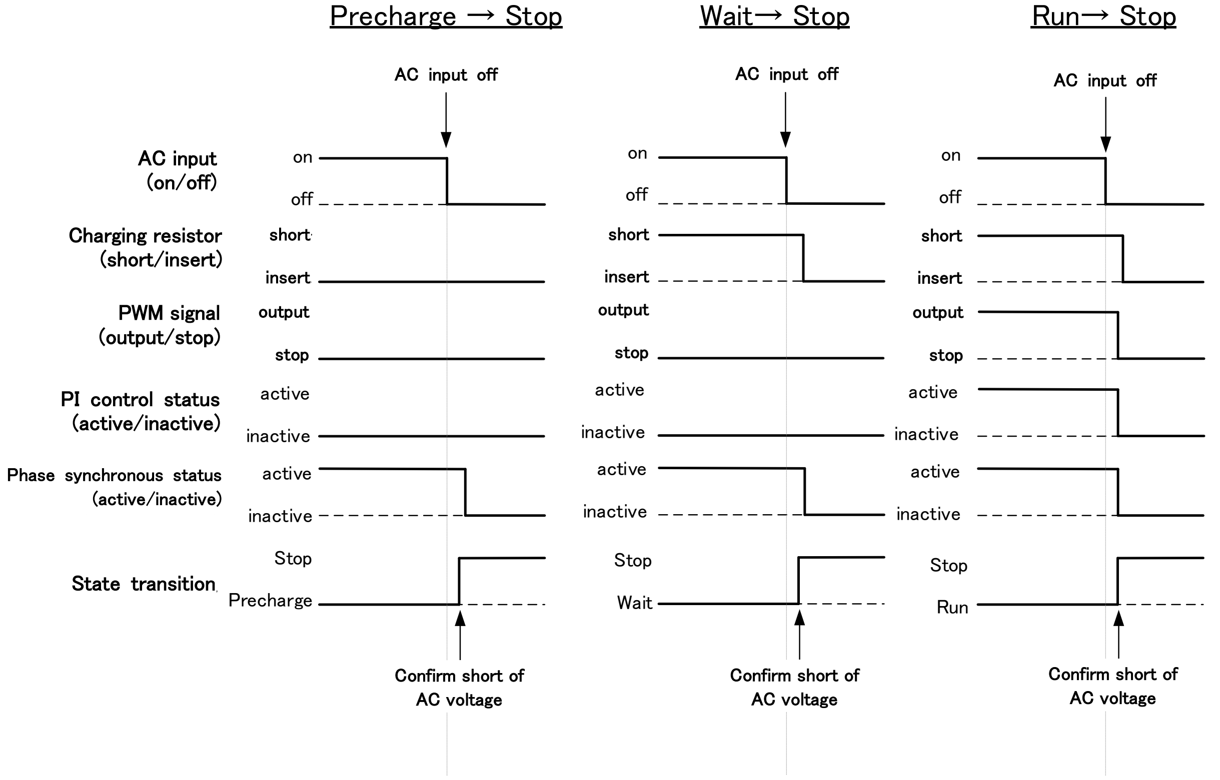
1. Transition from Init status to Stop status



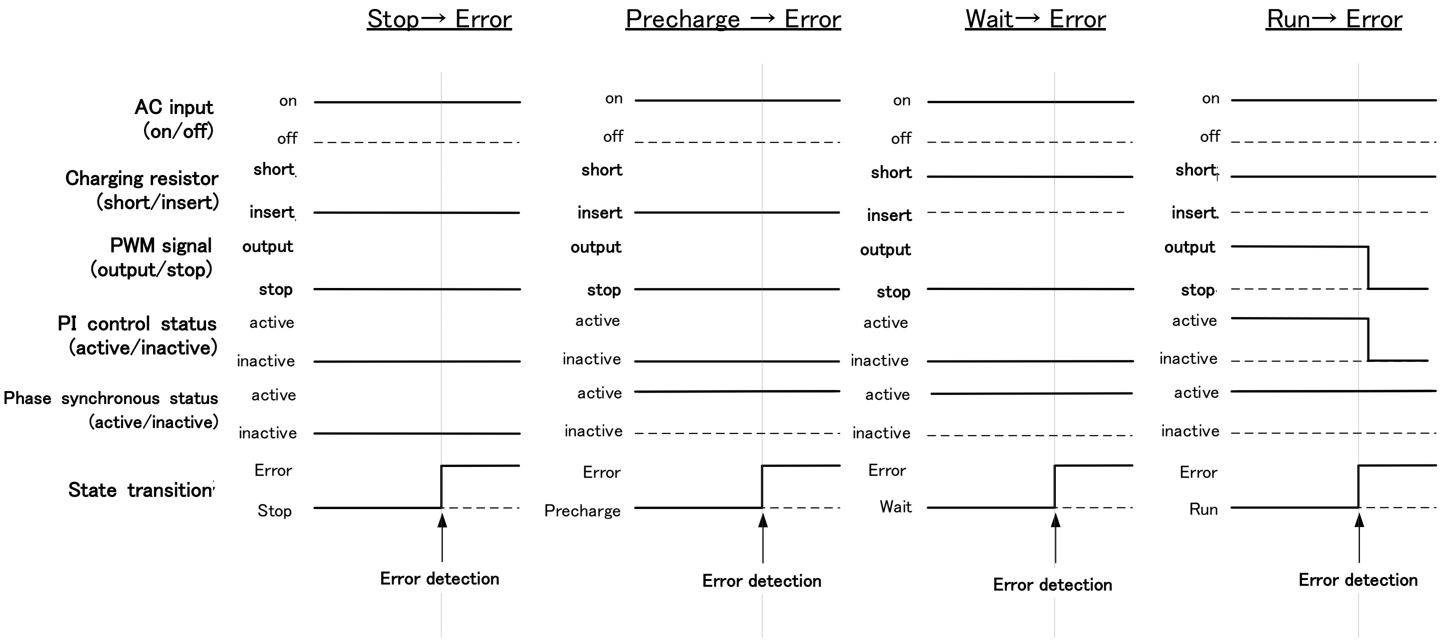
2. Transition from Stop status to Run status through Precharge status



3. Transition from Precharge status, Wait status, and Run status to Stop status



4. Transition from Stop status, Precharge status, Wait status, and Run status to Error status



4. Constant and Variable Definition

4.1. Constant Definition

Define the constants as follows:

1. Constant for PWM function setting

Constant name	Details
CARRIERFREQ_KHZ	Defines the frequency of the PWM signal in kHz.
CARRIERFREQ_HZ	Defines the frequency of the PWM signal in Hz.
INTERRUPT_MASK	Defines the execution cycle of the general control routine (see below).
DEADTIME_NSEC	Defines the dead time of the PWM signal in ns units.

2. Constant for timer interrupt routine cycle setting

Constant name	Details
TIMER0INTERVAL_US	Defines the execution period of the timer interrupt routine in μs units.

3. Constant for sensor value setting

Constant name	Details
VUV_GAIN VUV_OFFSET	Set the reading voltage range of the U-to-V line voltage sensor circuit as follows. ((-VUV_GAIN) + VUV_OFFSET) ～ (VUV_GAIN + VUV_OFFSET) Refer to 13.A/D transformation list for more information.
VWV_GAIN VWV_OFFSET	Set the read voltage range of the W-V line voltage sensor circuit as follows. ((-VWV_GAIN) + VWV_OFFSET) ～ (VWV_GAIN + VWV_OFFSET) Refer to 13.A/D transformation list for more information.
IU_GAIN IU_OFFSET	Set the reading current range of the U-phase current sensor circuit as follows. ((-IU_GAIN) + IU_OFFSET) ～ (IU_GAIN + IU_OFFSET) Refer to 13.A/D transformation list for more information.
IW_GAIN IW_OFFSET	Set the reading current range of the W-phase current sensor circuit as follows. ((-IW_GAIN) + IW_OFFSET) ～ (IW_GAIN + IW_OFFSET) Refer to 13.A/D transformation list for more information.
VDC_GAIN VDC_OFFSET	Set the read voltage range of the DC voltage sensor circuit as follows. ((-VDC_GAIN) + VDC_OFFSET) ～ (VDC_GAIN + VDC_OFFSET) Refer to 13.A/D transformation list for more information.

4. Constant for control

Constant name	Details
VQKP	Defines the value of proportional gain in PI control operation for PLL.
VQKI	Defines the value of the integral gain in the PI control operation for the PLL.
IDKP	Defines the value of proportional gain in PI control calculation of d-axis current.
IDKI	Defines the value of integral gain in PI control calculation of d-axis current.
IQKP	Defines the value of proportional gain in PI control calculation of q-axis current.
IQKI	Defines the value of integral gain in PI control operation of q-axis current.
VDCKP	Defines the value of proportional gain in PI control calculation of DC voltage.
VDCKI	Defines the value of integral gain in PI control calculation of DC voltage.
IDLIMIT	Defines the limit value for the d-axis current command value, which is the PI control calculation output of the DC voltage.
MRATELIMIT	Modulation factor calculation

4.2. State Definition

1. System-state constants (type name: SystemState)

Constant name	Details
State_Error	State constant indicating that the system is in an error state
State_Stop	State constant indicating that the system is stopped
State_Wait	State constant indicating that the system is in standby status
State_Run	State constant indicating that the system is in operating state
State_Precharge	State constant indicating that the system is in the precharge state
State_Init	State constant indicating that the system is in the initialization state

2. Protected status constants (type name: ErrState)

Constant name	Details
Err_IU	Status constant indicating that the overcurrent of the U-phase current has been detected and the protection function has been activated
Err_IW	Status constant indicating that the overcurrent of the W-phase current has been detected and the protection function has been activated
Err_VDC	A state constant that detects an overvoltage of the DC voltage and indicates that the protection function has activated.
Err_FLTU	Status constant indicating that the U-phase gate driver error signal has been detected and the protection function has been activated

Err_FLTV	Status constant that detects the error signal of the V-phase gate driver and indicates that the protection function has been activated
Err_FLTW	Status constant indicating that the W-phase gate driver error signal has been detected and the protection function has been activated
Err_WDT	State constant indicating that the protection function of the watchdog timer has been activated
Err_TRIP	State constant indicating that PWM is tripped

4.3. Variable Definition

1. Variables for sensor reading display

Variable name	Details
Vuv	Indicates the sensor (analog) value of the U-to-V line voltage.
Vwv	Indicates the sensor (analog) value of the W-V line voltage.
Iu	Indicates the sensor (analog) value of the U-phase current.
Iw	Indicates the sensor (analog) value of the V-phase current.
Vdc	Indicates the DC voltage sensor (analog) value.

2. Variables for sensor calculations

Variable name	Details
Vu	Indicates the U-phase voltage value calculated from the values of Vuv and Vwv.
Vv	Indicates the V-phase voltage value calculated from the values of Vuv and Vwv.
Vw	Indicates the W-phase voltage value calculated from the values of Vuv and Vwv.
Va	αβ conversion is performed for Vu, Vv, and Vw, and the obtained α-axis voltage value is shown.
Vb	αβ conversion is performed for Vu, Vv, and Vw, and the obtained β-axis voltage value is shown.
Vd	The dq conversion is performed for Va and Vb, and the obtained d-axis voltage is shown.
Vq	The dq conversion is performed for Va and Vb, and the obtained q-axis voltage is shown.
Ia	α-β conversion is performed for Iu and Iw, and the obtained α-axis current value is shown.
Ib	Executes αβ conversion for Iu and Iw, and shows the obtained β-axis current value.
Id	The dq conversion is performed for Ia and Ib, and the obtained d-axis current value is shown.
Iq	Executes dq conversion for Ia and Ib, and indicates the obtained q-axis current value.
VdLPF	With a low-pass filter at the cutoff frequency VdFc relative to the sensor value Vd Indicates.
VdFc	Indicates the cutoff frequency of the low-pass filter applied to the sensor value Vd.
VqLPF	Indicates the low-pass filter applied at the cutoff frequency VqFc with respect to the sensor value Vq.

VqFc	Indicates the cutoff frequency of the low-pass filter applied to the sensor value Vq.
VqLPF2	Indicates the low-pass filter applied at the cutoff frequency VqFc2 with respect to the sensor value Vq.
VqFc2	Indicates the cutoff frequency of the low-pass filter applied to the sensor value Vq.
VdcLPF	Indicates the output when low-pass filter is applied at the cutoff frequency VdcFc with respect to the sensor value Vdc.
VdcFc	Indicates the cutoff frequency of the low-pass filter applied to the sensor value Vdc.
IdLPF	Indicates the output when low-pass filtering is applied at the cutoff frequency IdFc with respect to the sensor value Id.
IdFc	Indicates the cutoff frequency of the low-pass filter applied to the sensor value Id.
IqLPF	Indicates the output of a low-pass filter applied at the cutoff frequency IqFc with respect to the sensor value Iq.
IqFc	Indicates the cutoff frequency of the low-pass filter applied to the sensor value Iq.
IuLPF	Indicates the output when low-pass filtering is applied at the cutoff frequency IuFc with respect to the sensor value Iu.
IuFc	Indicates the cutoff frequency of the low-pass filter applied to the sensor value Iu.
IwLPF	Indicates the output when low-pass filtering is applied at the cutoff frequency IwFc for the sensor value Iw.
IwFc	Indicates the cutoff frequency of the low-pass filter applied to the sensor value Iw.
IvLPF	Indicates the V-phase current obtained by (-IuLPF) + (-IwLPF).
OffsetVuv	Indicates the offset correction value of the U-to-V line voltage sensor value.
OffsetVwv	Indicates the offset correction value of the W-V line voltage sensor value.
OffsetIu	Indicates the offset correction value of the U-phase current sensor value.
OffsetIw	Indicates the offset correction value of the W-phase current sensor value.
FlagCalibEnd	0: Indicates that the offset error correction process for each sensor has not been completed. 1:Indicates that the offset error correction process for each sensor is completed.

3. Variables for protection and error status display

Variable name	Details
ErrorState	Indicates a protection, error state (not latched). Bit0: U-phase current overcurrent protection status Bit1: W-phase current overcurrent protection status Bit2: DC voltage overvoltage protection status Bit3: U-phase gate driver error signal detection status Bit4: Error signal detection status of V-phase gate driver Bit5: W-phase gate driver error signal detection status Bit6: Watchdog timer overflow status Bit7: Trip status of PWMs
ErrorState_Latch	Indicates protection, error status (latch). Bit0: U-phase current overcurrent protection status Bit1: W-phase current overcurrent protection status Bit2: DC voltage overvoltage protection status Bit3: U-phase gate driver error signal detection status Bit4: Error signal detection status of V-phase gate driver Bit5: W-phase gate driver error signal detection status Bit6: Watchdog timer overflow status Bit7: Trip status of PWMs
ErrThrVdcHi_V	Indicates the overvoltage threshold of DC voltage.
ErrThrIac_Apk	Indicates the overcurrent threshold (peak value) of the AC voltage.
FlagWDT	Indicates the overflow occurrence status of the watchdog timer.

4. State transition variables

Variable name	Details
State	Indicates the status of the system. It is assigned in the timer interrupt routine. Type: SystemState
PreState	This bit indicates the status of the system assigned by the timer interrupt routine one cycle ago. Type: SystemState
InitEnd	Indicates whether the initialization is complete. 0:Indicates that the initialization has not finished. 1:Indicates that the initialization is completed.
StopThrVac_Vrms	Indicates the AC voltage lower limit (rms value) for the system to operate.
RunStartStopReq	Becomes a variable that manipulates the transition between the standby state and the operating state.
FlagEntryWait	Indicates that the unit is in standby mode.
TimerEntryWait	Indicates the time after the transition to the standby state in ms.

5. Variables for calculating the effective value

Variable name	Details
Vuv_Vrms	Indicates the effective value of the U-to-V line voltage.
Vuv_Vrms0	Indicates the effective value of the U-to-V line voltage one cycle before.
VuvSum_V	Indicates the sum of squares of the U-V line voltage used for root-mean-square value calculation.
SignVuv	Indicates the sign of the U-to-V line voltage.
SignVuv0	Indicates the sign of the U-to-V line voltage one cycle before.
PeriodCount	Indicates the value that is added at the switching period from the U-to-V line voltage zero crossing.

6. Variables for phase calculation

Variable name	Details
VqRef	Indicates q-axis voltage command value.
ErrVq	Indicates the deviation between VqLPF2 and the q-axis voltage command.
VqKp	Indicates the proportional gain value in PI control calculation (PLL) of q-axis voltage.
VqKi	Indicates the value of the integral gain in PI control calculation (PLL) of the q-axis voltage.
VqTi	Indicates the time constant in PI control calculation (PLL) of q-axis voltage.
VqPElement	Indicates the proportional component of the PI control calculation (PLL) of the q-axis voltage (proportional control output).
VqIElement	Indicates the integral component of the PI control operation (PLL) of the q-axis voltage (integral control output).
VqPIElement	Indicates the sum of the proportional and integral components of the PI control operation (PLL) of the q-axis voltage.
Phase_rad	Indicates the phase information obtained by the PI control calculation (PLL) of the q-axis voltage.
RefPhase_rad	Indicates the reference phase generated based on the U-to-V line voltage zero crossing.
RefDeltaPhase_rad	Indicates the reference phase change amount to be added in the switching period.

7. AC current control variable

Variable name	Details
IdRef	Indicates d-axis current command value.
ErrId	Indicates the deviation between IdLPF and the d-axis current command.
IdKp	Indicates the value of proportional gain in PI control calculation of d-axis current.
IdKi	Indicates the value of integral gain in PI control calculation of d-axis current.
IdTi	Indicates the time constant in PI control calculation of d-axis current.
IdPElement	Indicates the proportional component of PI control calculation of d-axis current (proportional control output).
IdIElement	Indicates the integral component of the PI control operation of d-axis current (integral control output).
IdPIElement	Indicates the sum of the proportional and integral components of the PI control operation of d-axis current.
VdOut	Indicates d-axis voltage command value obtained by PI control calculation of d-axis current.
IqRef	Indicates q-axis current command value.
ErrIq	Indicates the deviation between IqLPF and the q-axis current command.
IqKp	Indicates the value of proportional gain in PI control calculation of q-axis current.
IqKi	Indicates the value of integral gain in PI control calculation of q-axis current.
IqTi	Indicates the time constant in PI control calculation of q-axis current.
IqPElement	Indicates the proportional component of PI control calculation of q-axis current (proportional control output).
IqIElement	Indicates the integral component of PI control operation of q-axis current (integral control output).
IqPIElement	Indicates the sum of the proportional and integral components of the PI control operation of the q-axis current.
VqOut	Indicates q-axis voltage command value obtained by PI control calculation of q-axis current.

8. DC voltage control variable

Variabale name	Details
IdLimitHi	Indicates the upper limit of d-axis current command value.
IdLimitLo	Indicates the lower limit of d-axis current command value.
VdcRef	Indicates DC voltage command value.
ErrVdc	Indicates the deviation between VdcLPF and VdcRef.

VdcKp	Indicates the value of proportional gain in PI control calculation of DC voltage.
VdcKi	Indicates the value of integral gain in PI control calculation of DC voltage.
VdcTi	Indicates the time constant in PI control calculation of DC voltage.
VdcPElement	Indicates the proportional component of the PI control operation of the DC voltage (proportional control output).
VdcIElement	Indicates the integral component of the PI control operation of the DC voltage (integral control output).
VdcPIElement	Indicates the sum of the proportional and integral components of the PI control operation of the DC voltage. This value is substituted into IdRef as the d-axis current command value.
ConstVdcRef	Indicates the target voltage for constant DC voltage control.
FlagVdcRefRamp	Indicates that DC voltage control is in soft start.
DeltaVdcRefRamp	Indicates the DC voltage command value that increases every 1ms when DC voltage control is soft-starting.

9. Variable for calculating the modulation factor

Variable name	Details
VaRef	The dq inverse transform is performed on VdOut,VqOut, and the obtained α-axis voltage command is shown.
VbRef	The dq inverse transform is performed on VdOut,VqOut, and the obtained β-axis voltage command is shown.
VuRef	Two-phase three-phase transformation is performed on VaRef,VbRef, and the resulting U-phase voltage is superimposed on the third harmonic.
VvRef	Two-phase three-phase transformation is performed on VaRef,VbRef, and the resulting V-phase voltage is superimposed on the third harmonic.
VwRef	Two-phase three-phase transformation is performed on VaRef,VbRef, and the resulting W-phase voltage is superimposed on the third harmonic.
Vmax	Indicates the max. of VuRef, VwRef, VvRef.
Vmin	Indicates the smallest VuRef, VwRef, VvRef.
Vavr	Indicates the mean of Vmax and Vmin.
PhaseUDeadTimeComp	Indicates the dead time compensation to be added to the modulation factor of the U-phase gate.
PhaseVDeadTimeComp	Indicates the dead time compensation to be added to the modulation factor of the V-phase gate.

PhaseWDeadTimeComp	Indicates the dead time compensation to be added to the modulation factor of the W-phase gate.
KDeadTime	Indicates the value to adjust the dead time compensation amount near AC zero crossing.
LimitDeadTimeComp	Indicates the value to limit dead time compensation.
MuRateOut	Indicates the modulation ratio of the U-phase PWM.
MvRateOut	Indicates the modulation factor of the V-phase PWM.
MwRateOut	Indicates the modulation ratio of the W-phase PWM.
MRateLimHi	Indicates the upper limit of the modulation ratio.
MRateLimLo	Indicates the lower limit of the modulation factor.

4. Initialization

4.1. Initialization Routine Execution Condition

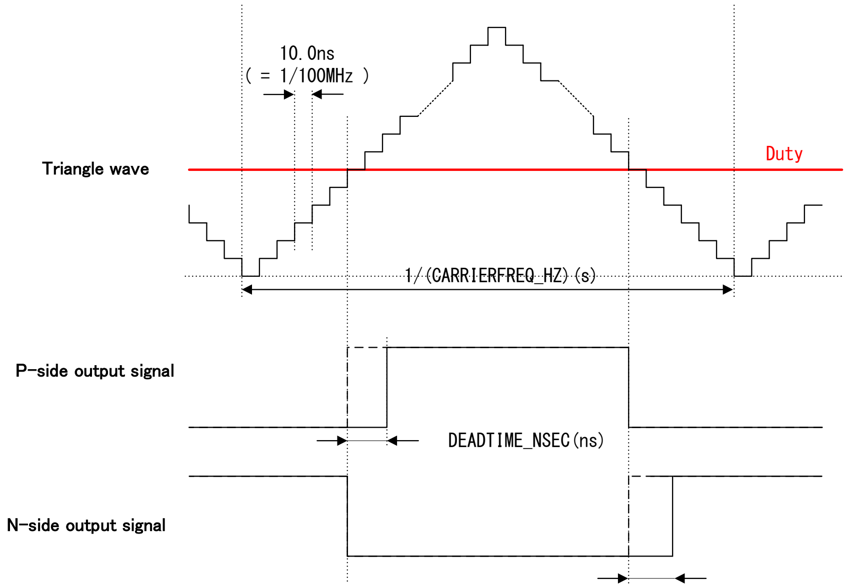
The initialization routine is executed when the following conditions are established.

1. When the power is turned on for the first time
2. When the reset switch is pressed

4.2. Initialization Routine

The initialization routine is executed by executing function Init(). The following processing is performed.

Processing order	Details of processing	Details of processing
1	Of TMS320F28377SPTP Initialization pin setting	Initialize TMS320F28377SPTP and set the pins. For pin setting, refer to the I/O signals described in 2 above.
2	Head Spring HSDT-DP SCOPE function initialization and setting	Initialize and configure the settings so that SCOPE function of Head Spring HSDT-DP can be used.
3	AD conversion function initialization and setting AD conversion value-range, offset setting	Initialize the AD conversion function and set the AD conversion start timing to start upon receiving a conversion start trigger output from the PWM function. For the range and offset settings, refer to 4.1 Constants for Sensor Value Setting in Constant Definition.4.1
4	Comparator function initialization and setting	Initializes the comparator function and sets the operation to stop when any of U-phase overcurrent, W-phase overcurrent, or DC overvoltage is detected.
5	Watchdog timer initialization, setting	The watchdog timer function was initialized and ClearWDT() function was last executed. Set to stop the operation if it is not executed again within 13.1ms from the timing.
6	Timer function initialization, setting	Initializes the timer function and sets the interrupt routine to be executed at 1ms intervals.

7	Initialization and setting of PWM function	Initialize the PWM function and set as follows. ・PWM frequency Same as CARRIERFREQ_HZ (Hz) ・Dead time Set to the same number as DEADTIME_NSEC(ns) ・Shape of the comparison carrier Chopping sea  ・Protective function Output of PWM signal is stopped when any of U-phase current overcurrent, W-phase current overcurrent, or DC voltage overvoltage is detected by the comparator. ・AD conversion start trigger output function A/D conversion start trigger is output at the timing of the trough of the triangle-wave carrier.
8	Waiting for system stabilization	After processing 1 to 7 is completed, wait for 1ms for system stabilization.
9	Interrupt function setting	Enables execution of general control routines and timer interrupt routines.

5. Main Routine

This section describes the main routine process that is executed after the initialization function Init() is completed.
This SW generates interrupt processing at regular intervals and executes each subroutine.
If no interrupt processing has occurred, the main loop is executed.

Subroutine name	Interrupt Function Name	Execution trigger, cycle	Details of processing
General control routine	PWMIntFunc	Trigger: PWM function Cycle: 50 μs (at 20kHz operation) 20 μs (at 50kHz operation) 10 μs (at 100kHz operation)	・Read sensor value ・Root-mean-square value calculation ・Dq Conversion ・Low-pass filter processing ・Line voltage-> phase voltage conversion ・Phase calculation ・AC current control ・Modulation factor calculation
Timer interrupt routine	Timer0IntFunc	Trigger: Timer function cycle: 1 ms	・Measurement of standby time in standby mode ・Soft start processing at start of operation ・Error detection ・State transition ・Low-pass filter processing ・DC voltage control ・Sensor offset correction

5.1. Main Loop

This section shows the main loop processing of this SW.

Processing order	Details of processing	Details of processing
1	Watchdog timer processing	Reset the watchdog timer counter and check the flag of the watchdog timer function. The watchdog timer counter was not reset for more than 13.1ms. In this case, stop the operation.
2	Digital signal input check	Check the input status of DI0, 1 and 2.
3	Head Spring HSDT-DP SCOPE function updating process	Perform the process for updating HSDT-DP SCOPE function from Head Spring.

5.2. General Control Routine

This SW has the following general control routines.

The generic control routine is executed by function PWMIntFunc().

Processing order	Details of processing	Details of processing
1	Read sensor value	U-to-V line voltage, W-to-V line voltage, U-phase current, W-phase current, DC voltage Loads the sensor value.
2	AC voltage phase calculation AC voltage execution value calculation	AC voltage phase information obtained in the previous general control routine and general control The phase difference corresponding to one cycle of the routine is added to update the AC voltage phase information. In addition, the rms value of the AC voltage is calculated from the sensor value.
3	IuwOOBIdq transformation Id,Iq,Iu,Iw low-pass filter treatment	The d-axis current value Id and the q-axis current value Iq are calculated from the values of Iu and Iw, and low-pass filtering is performed on Iu,Iw,Id,Iq.
4	Phase voltage calculation VuvwOOCVdq transformation Vd, Vq low-pass filter processing	To calculate the d-axis voltage Vd and q-axis voltage Vq, Vu, Vw, and Vv (each phase voltage) are calculated from the values of Vuv and Vwv. The resulting Vu, Vv, and Vw are subjected to dq conversion and low-pass filtering.
5	Phase calculation	To synchronize the AC voltage phase information with the phase information on the switch, PI control operation is performed on VqLPF and VqRef (PLL-processing).
6	Id, Iq control	To calculate VuRef, VvRef, and VwRef, perform PI control for Id and Iq, and calculate the d-axis current control output VdOut and q-axis current control output VqOut.
7	Third harmonic superposition processing Dead time compensation Modulation factor calculation	Calculates the modulation ratio of the PWM waveform to be output. Dead-time compensation is performed after the third harmonic components are superimposed on VuRef, VvRef, and VwRef. The PWM waveform output is changed according to the calculated modulation factor.

5.3. Timer Interrupt Routine

This SW has the following timer interrupt routines:

The timer interrupt routine is executed by function Timer0IntFunc().

Processing order	Details of processing	Details of processing
1	Multiple interrupt enable processing	If a general control processing routine occurs during a timer interrupt routine, Set the general control processing routine to take precedence.
2	Time measurement in standby mode	Measure the DC voltage stabilization wait time after transitioning to the standby state. Short-circuit the charging resistor when the waiting time reaches 500ms.
3	Soft start processing at start of operation	The DC voltage is gradually increased to 750V by increasing the value of VdcRef, which is the DC voltage command value, from the DC voltage value at the moment when the system switches to the Run state to 750V over a period of 500ms, thereby suppressing the amount of inflow current.
4	Error determination processing	Status of DI0, 1, 2 (gate driver error signal), DC overvoltage, Check whether the U-or W-phase overcurrent is occurring and the status of the watchdog timer to determine the abnormal status. For details, see section 8, Error Judgment Processing.
5	State transition processing	Of the system status at the time of processing, the result of error determination processing, and various variables Changes the state of the system to match the state. For details, see section 3, State Transition Diagram.
6	Low-pass filter processing coefficient calculation processing DC voltage low-pass filter processing	The low-pass filter coefficients are calculated for Vd,Vq,Id,Iq,Iu,Iw,Vdc, and the low-pass filter is applied to the Vdc value.
7	DC voltage control processing	The d-axis current command value IdRef is calculated by calculating the deviation between the value of VdcRef, which is the DC voltage command value, and the value of VdcLPF, and performing the PI-control operation. This process is performed only when the system is in the Run state.

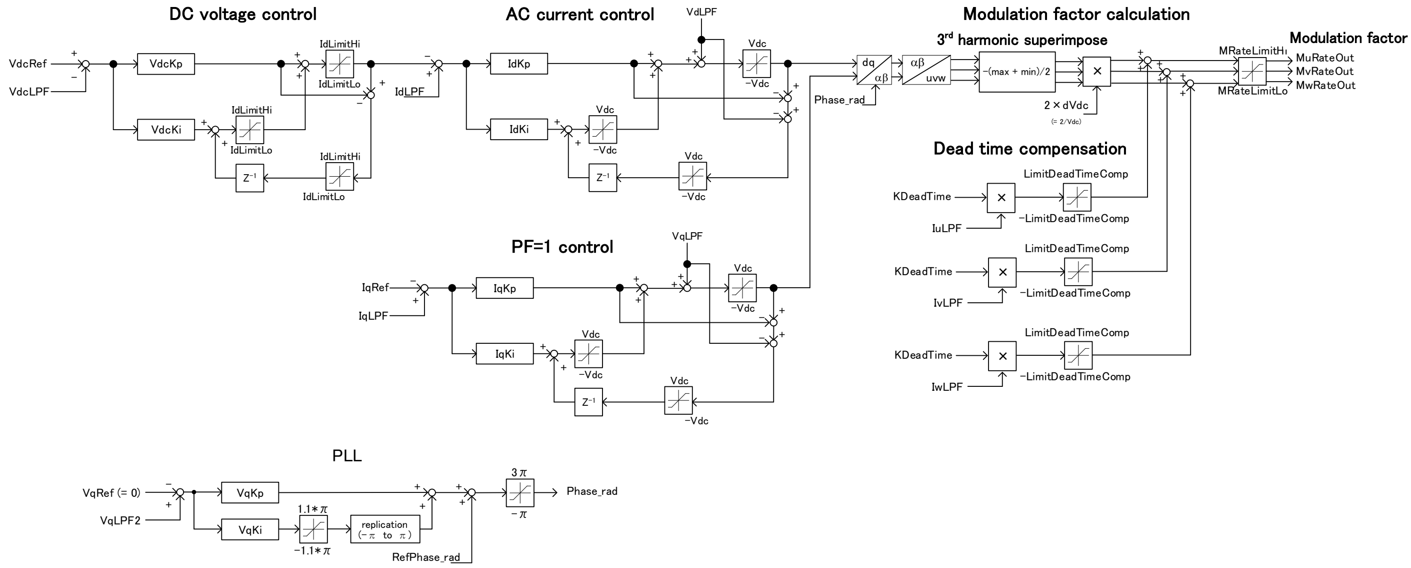
8	AD Conversion-Offset Error Correction Processing	When the system is in Init (initialization) status, the offset error is measured using the readings of the sensors prior to the three-phase AC power-on, and the compensation process is performed. When the correction process is completed, FlagCalibEnd is changed to 1. The above process is performed by CalibAdOffset(). If the status is not Init, the above process is not performed.
9	Multiple interrupt disable processing	If a general control processing routine occurs during a timer interrupt routine, Cancels the setting that gives priority to the general control processing routine.

The control block diagram of this SW is shown on the next page.

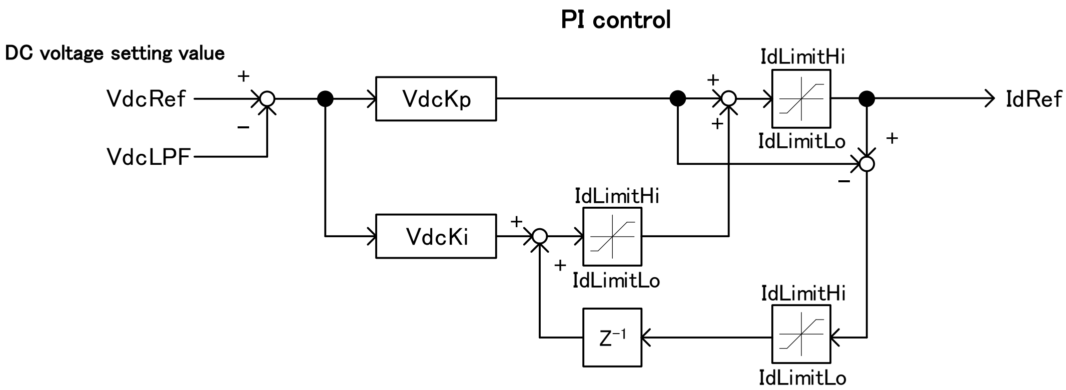
5.4. Control Block Diagram

The control block diagram of the entire power supply and the control block diagram for each function are shown below.

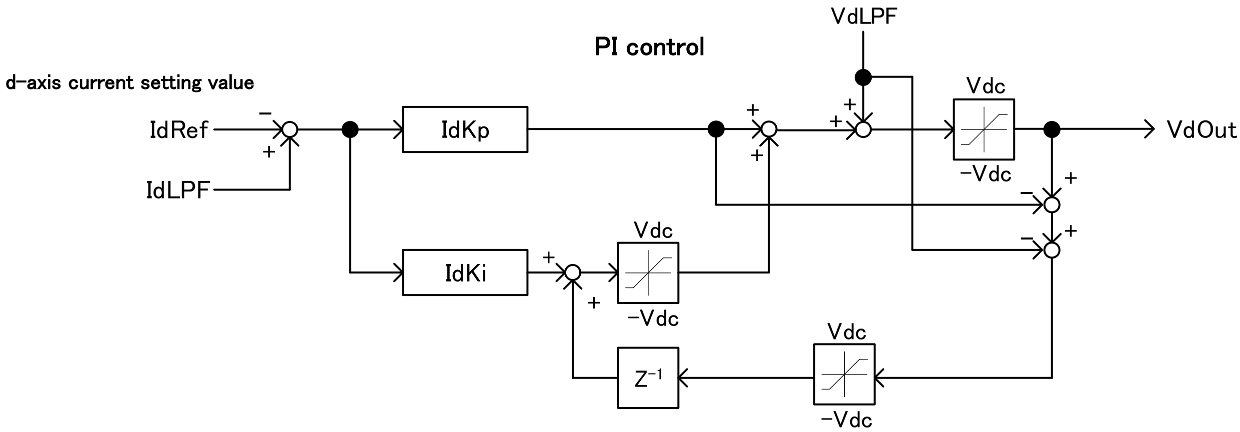
1. 3-phase PFC power supply control



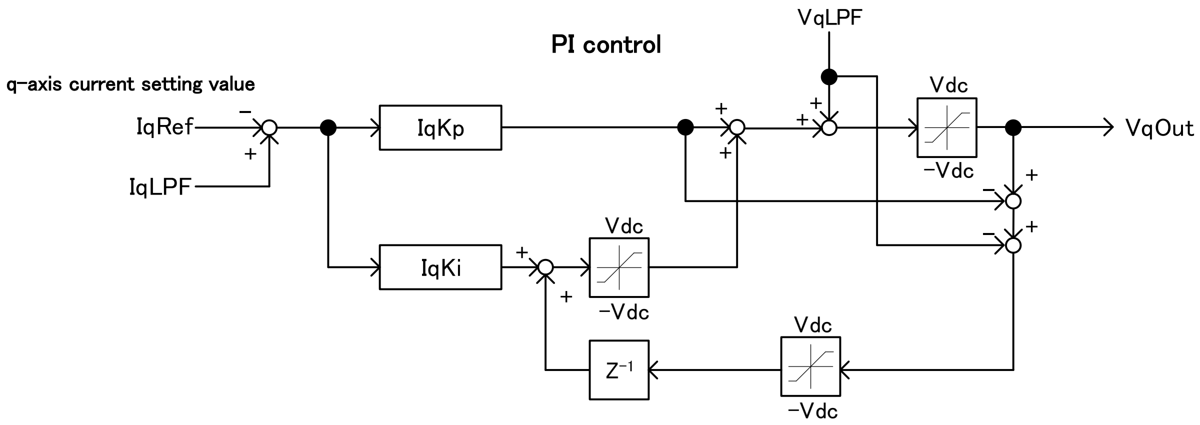
2. Fixed voltage operation



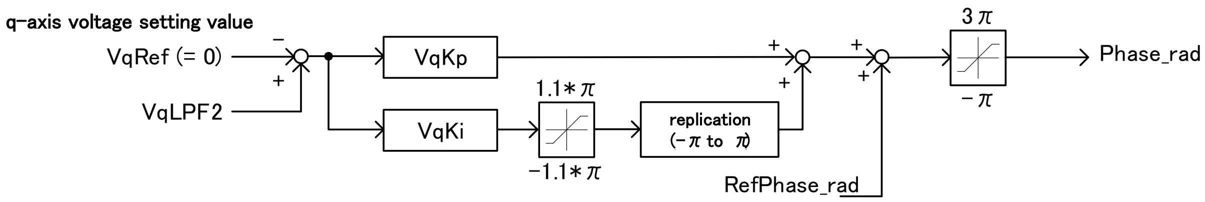
3. AC current control



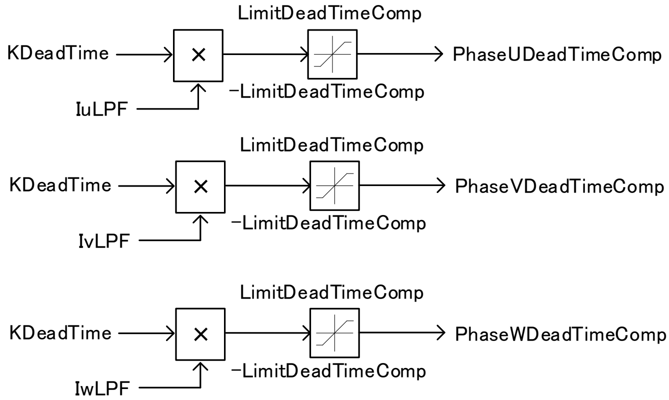
4. Power factor 1 control



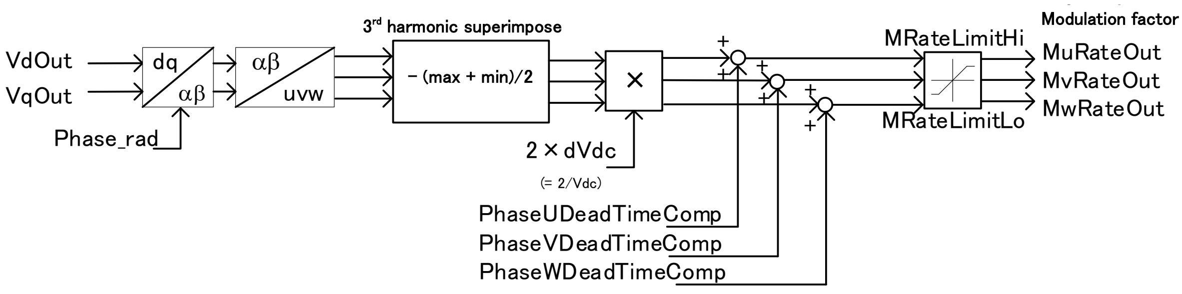
5. PLL



6. Dead time compensation



7. Modulation factor calculation



6. Abnormal Processing

This section describes the error processing of this SW. In this SW, when the overcurrent of the AC side current, the overvoltage of the DC side voltage, DESAT signal detection of the U, V, and W-phase gate drivers, and the watchdog timer overflow during Precharge status, Wait status, and Run status, Error status is activated, and the operation is stopped.

When the operation is stopped, the output of all PWM signals is stopped, and the operation is not restored until the reset SW is pressed or the control power is turned on again.

To return to operation, perform the operation return according to the following procedures.

1. Disconnect the connection with the 3-phase AC power supply.
2. Press the reset switch or turn on the control power again.

7. A/D Conversion List

The A/D conversion table is shown below.

Port	Pin	Measurement item	Data	A/D conversion Resolution	Filter processing
ADCINA2	41	U-V Line voltage	12bit	0.3977 (V/LSB)	Low-pass filter circuit implemented in the control circuit Cut-off frequency: 22 kHz
ADCINA4	39	W-V Line voltage	12bit	0.3977 (V/LSB)	Low-pass filter circuit implemented in the control circuit Cut-off frequency: 22 kHz
ADCINB2	48	U phase current	12bit	0.02441 (A/LSB)	Low-pass filter circuit implemented in the control circuit Cut-off frequency: 22 kHz
ADCIN14 (ADCIND14)	44	W phase current	12bit	0.02441 (A/LSB)	Low-pass filter circuit implemented in the control circuit Cut-off frequency: 22 kHz
ADCINC2	31	DC voltage	12bit	0.2285 (V/LSB)	Low-pass filter circuit implemented in the control circuit Cut-off frequency: 22 kHz

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