1.6 kW T-Type 3-Level PFC Power Supply

SW Guide

RD172-SWGUIDE-01

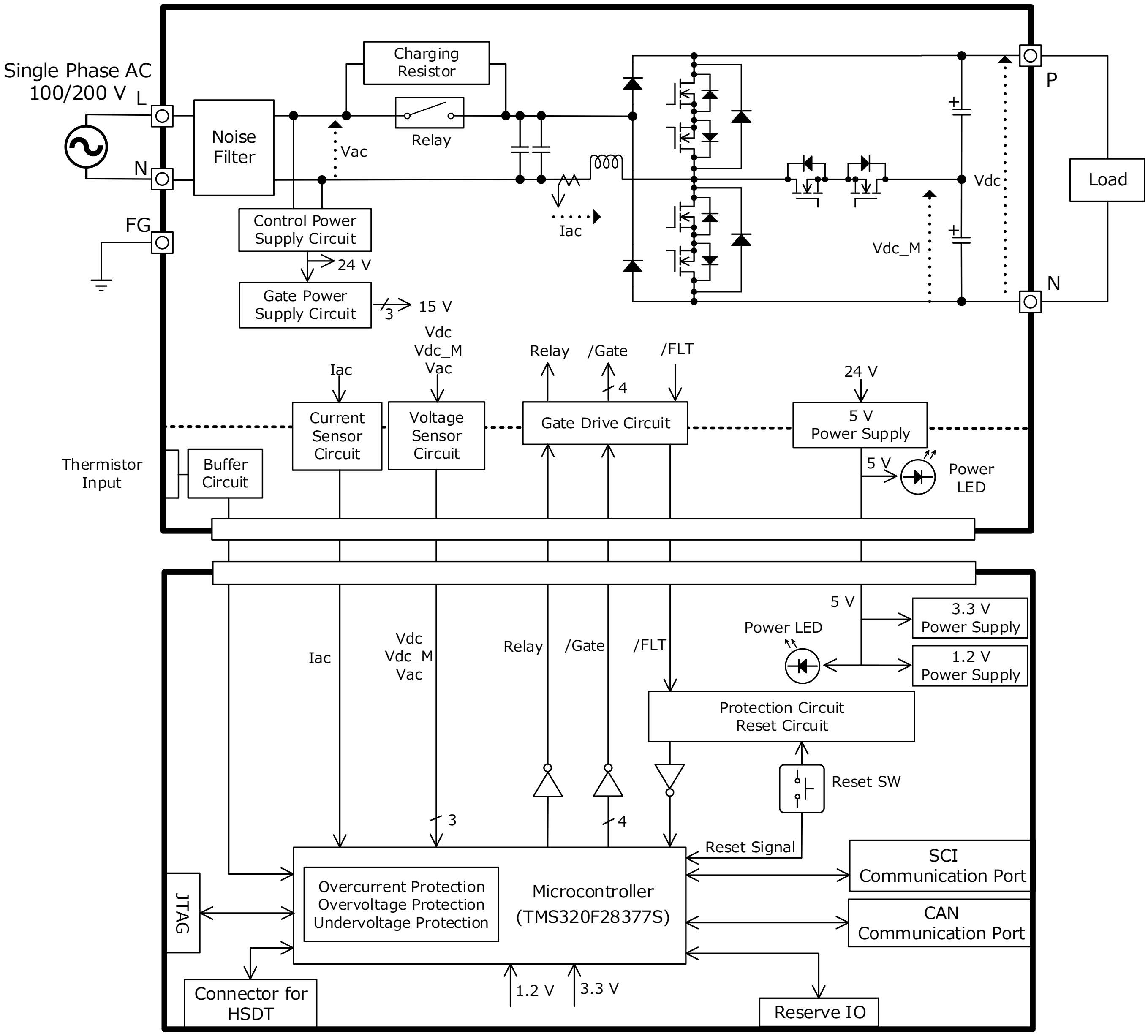
TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

Table of Contents

1. Introduction

1.1. Overview

This manual defines the firmware specifications of 1.6 kW T-Type 3-Level PFC Power Supply (hereafter referred to as this power supply). The hardware block diagram controlled by firmware specified in this manual is shown below.



1.2. How to Use

・Turn on the single-phase AC power supply.

・To recover from Error state, press the RESET switch or turn on the single-phase AC power supply again.

(The reset SW is located on the control board.)

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

<Power Supply Controller>

TMS320F28377SPTP is used as the power supply controller.

1. Features

Item	Description
Manufacturer	Texas Instruments
Model Number	TMS320F28377SPTP
Package	176 pin, 0.5 mm pitch (between pins), HLQFP
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	6 channels (2 of which are used for switching, and 1 channel is used for protection function) Operating frequency 100 MHz
Comparator Function	8 channels (4 of which are used) AC Current - Overcurrent Protection AC Voltage - Overvoltage Protection DC voltage - Overvoltage protection DC midpoint voltage - Overvoltage protection
Communication Function	I2C × 1 channel (used as interfaces with EEPROM) CAN × 1 channel (not used in this reference design standard firmware) SCI ×2 channel (1 channel is used for communication with HSDT-DP made by Headspring Inc. The other channel is not used in this reference design standard firmware.)
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: 24LC512-I/SM (Not used in this reference design standard firmware)
IO Voltage	3.3 V
Core Voltage	1.2 V

2. Clock

The power controller uses the following clock:

External Transmitter
20 MHz

3. Development environment

Code Development Tool: Texas Instruments's Code Composer Studio

OS: Windows, Mac OS, Linux

Debug Tool: HSDT–DP, HSDT-GUI made by Headspring Inc.

OS: Windows

2. Input/Output Signals

I/O signals are defined as follows.

Port	Pin	Signal Name	Function	I/O (Model)	Initial Value	Other
GPIO0	160	PWM1A_DSP160	N-phase high-side PWM gate signal	O (CMOS)	0	
GPIO1	161	PWM1B_DSP161	N-phase clamp PWM gate signal	O (CMOS)	0	
GPIO2	162	PWM2A_DSP162	N-phase clamp PWM gate signal	O (CMOS)	0	
GPIO3	163	PWM2B_DSP163	N-phase low-side PWM gate signal	O (CMOS)	0	
GPIO4	164	PWM3A_DSP164	PWM signal output function (not used in this reference design)	O (CMOS)	0	
GPIO5	165	PWM3B_DSP165	PWM signal output function (not used in this reference design)	O (CMOS)	0	
GPIO6	166	PWM4A_DSP166	PWM signal output function (not used in this reference design)	O (CMOS)	0	
GPIO7	167	PWM4B_DSP167	PWM signal output function (not used in this reference design)	O (CMOS)	0	
GPIO8	18	PWM5A_DSP18	PWM signal output function (not used in this reference design)	O (CMOS)	0	
GPIO9	19	PWM5B_DSP19	PWM signal output function (not used in this reference design)	O (CMOS)	0	
GPIO10	1	PWM6A_DSP1	PWM signal output function (not used in this reference design)	O (CMOS)	0	
GPIO11	2	PWM6B_DSP2	PWM signal output function (not used in this reference design)	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	Digital signal output function	O (CMOS)	0	

			(not used in this reference design)			
GPIO17	9	DO1_DSP9	For main relay drive signal Digital signal output	O (CMOS)	0	
GPIO18	10	DO2_DSP10	Digital signal output function (not used in this reference design)	O (CMOS)	0	
GPIO19	12	DO3_DSP12	For driver reset signal Digital signal output	O (CMOS)	1	
GPIO20	13	DO4_DSP13	Digital signal output function (not used in this reference design)	O (CMOS)	0	
GPIO21	14	DO5_DSP14	Digital signal output function (not used in this reference design)	O (CMOS)	0	
GPIO22	22	DO6_DSP22	Digital signal output function (not used in this reference design)	O (CMOS)	0	
GPIO23	23	DO7_DSP23	Digital signal output function (not used in this reference design)	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	Signal function for I2C communication Data	O/I (CMOS)	1	Interface with EEPROM
GPIO43	131	SCL_A_DSP131	Signal function for I2C Communication Clock	O (CMOS)	1	Interface with 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 in this reference design)	I (CMOS)	1	Function can be changed with firmware
GPIO51	95	DIO09_DSP95	General-purpose digital input/output function (not used in this reference design)	I (CMOS)	1	Function can be changed with firmware
GPIO52	96	DIO10_DSP96	General-purpose digital input/output function (not used in this reference design)	I (CMOS)	1	Function can be changed with firmware
GPIO53	97	DIO11_DSP97	General-purpose digital input/output function (not used in this reference design)	I (CMOS)	1	Function can be changed with firmware

GPIO54	98	No signal assignment	-	-		
GPIO55	100	No signal assignment	-	-		
GPIO56	101	No signal assignment	-	-		
GPIO57	102	No signal assignment	-	-		
GPIO58	103	SSO_DSP103	Headspring Inc. HSDT-DP For SCOPE function SPI Communication-Data Output	O (CMOS)		
GPIO59	104	SSI_DSP104	Headspring Inc. HSDT-DP For SCOPE function SPI Communication-Data Input	I (CMOS)		
GPIO60	105	SSCK_DSP105	Headspring Inc. HSDT-DP For SCOPE function SPI Communication-Clock Output	O (CMOS)		
GPIO61	107	SPISTEA_DSP107	Headspring Inc. 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	Collective gate driver ready signal Input function	I (CMOS)	0	
GPIO68	133	DI1_DSP133	Collective 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	Digital signal input function (not used in this reference design)	I (CMOS)	0	

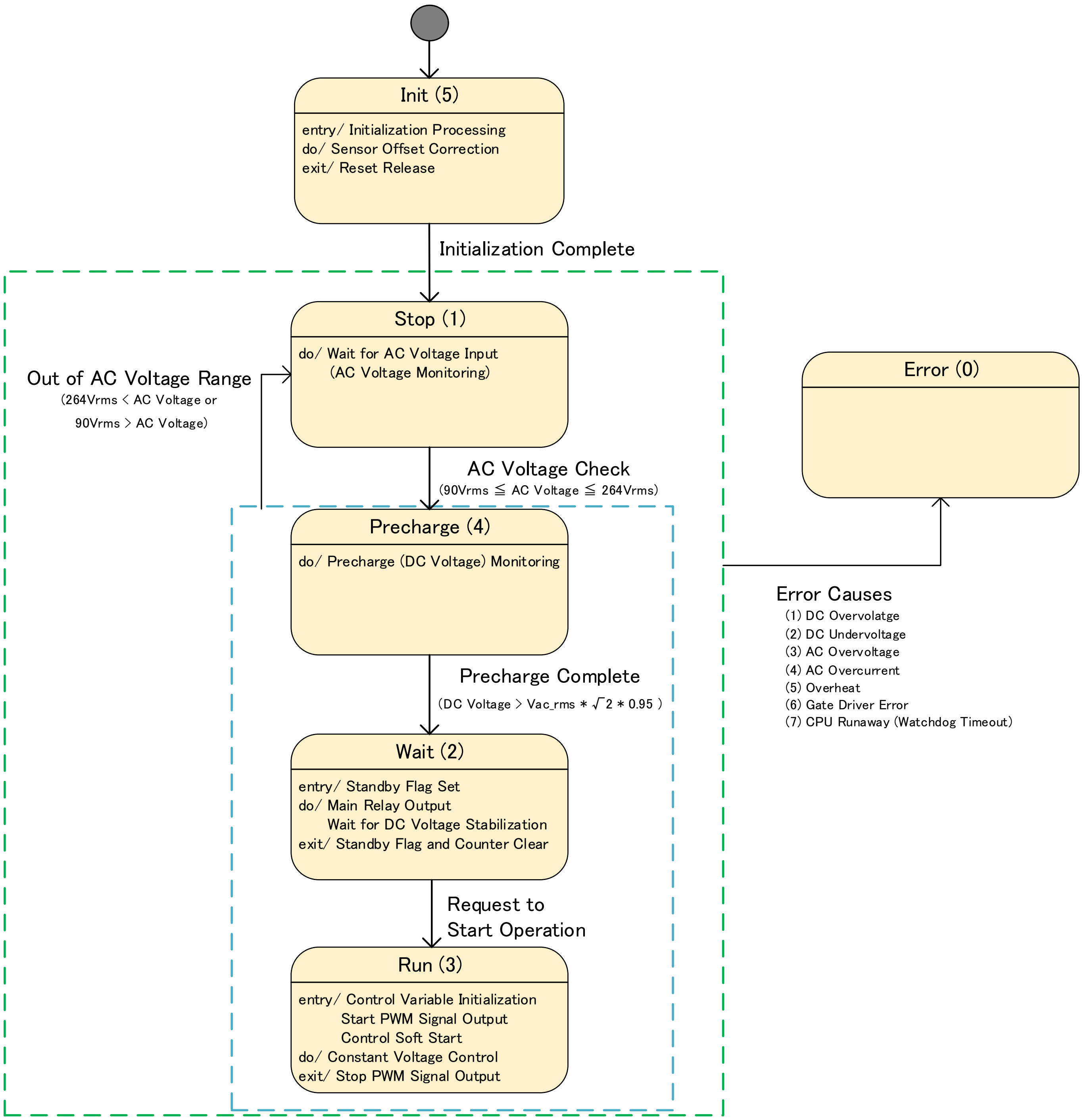
GPIO74	141	DI3_DSP141	Digital signal input function (not used in this reference design)	I (CMOS)	0	
GPIO75	142	DI4_DSP142	Digital signal input function (not used in this reference design)	I (CMOS)	0	
GPIO76	143	DI5_DSP143	Digital signal input function (not used in this reference design)	I (CMOS)	0	
GPIO77	144	DI6_DSP144	Digital signal input function (not used in this reference design)	I (CMOS)	0	
GPIO78	145	DI7_DSP145	Digital signal input function (not used in this reference design)	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	Headspring Inc. HSDT-DP Debug communication function			
GPIO85	155	SCIRXDA_ DSP155	Headspring Inc. HSDT-DP Debug communication function			
GPIO86	156	SCITX_B_ DSP156	General purpose serial communication function (not used in this reference design)			
GPIO87	157	SCIRX_B_ DSP157	General purpose serial communication function (not used in this reference design)			
GPIO88	170	No signal assignment	-	-	-	-
GPIO89	171	DIO12_DSP171	General-purpose digital input/output function (not used in this reference design)	I (CMOS)	1	Function can be changed with firmware
GPIO90	172	DIO13_DSP172	General-purpose digital input/output function (not used in this reference design)	I (CMOS)	1	Function can be changed

						with firmware
GPIO91	173	No signal assignment	-	-		
GPIO92	174	No signal assignment	-	-		
GPIO93	175	DIO14_DSP175	General-purpose digital input/output function (not used in this reference design)	I (CMOS)	1	Function can be changed with firmware
GPIO94	176	DIO15_DSP176	General-purpose digital input/output function (not used in this reference design)	I (CMOS)	1	Function can be changed with firmware
GPIO99	17	No signal assignment				
GPIO 133	118	No signal assignment	-	-		

3. State Transition

3.1. State Transition Diagram

The state transition diagram of this firmware is shown below.

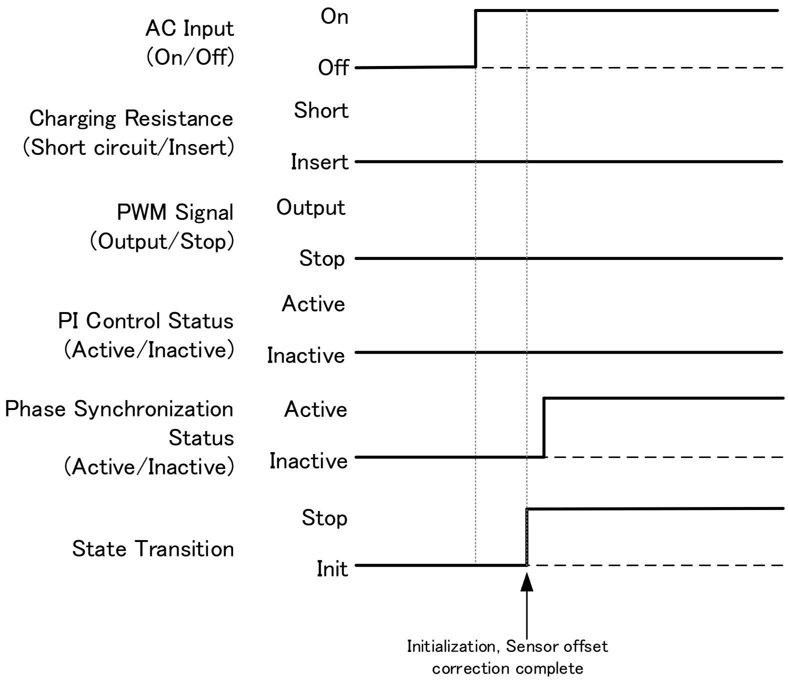


3.2. Timing Chart

The timing chart of this firmware is shown below.

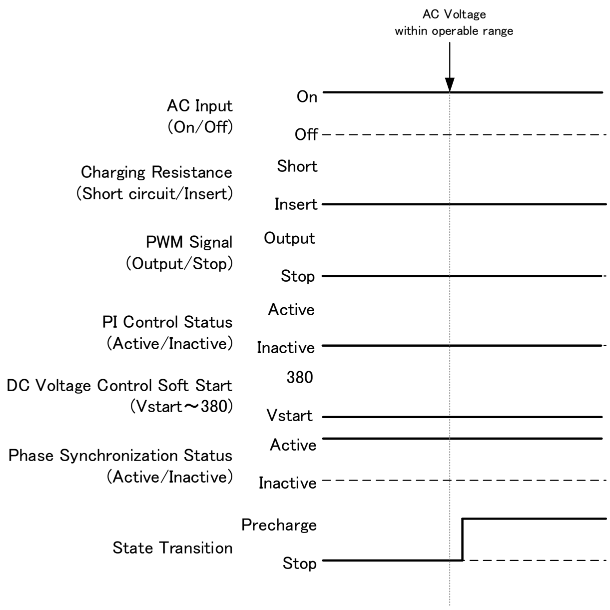
1. Transition from Init state to Stop state

Init → Stop

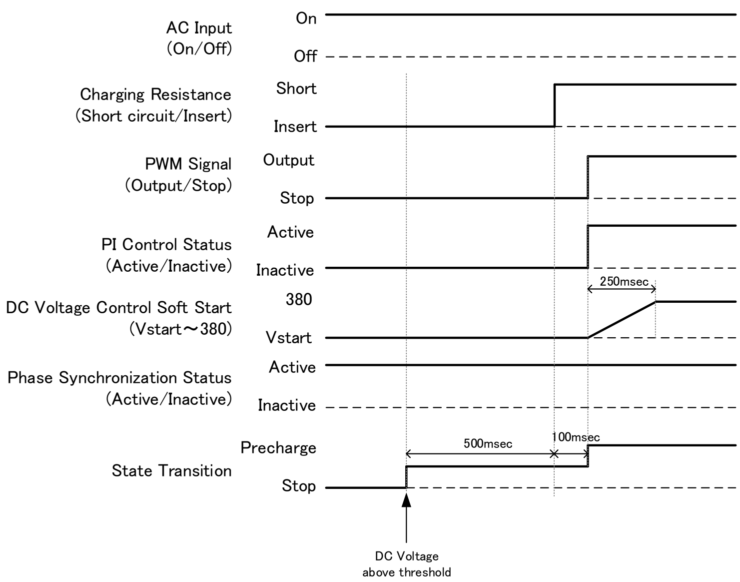


2. Transition from Stop state to Run state through Precharge state

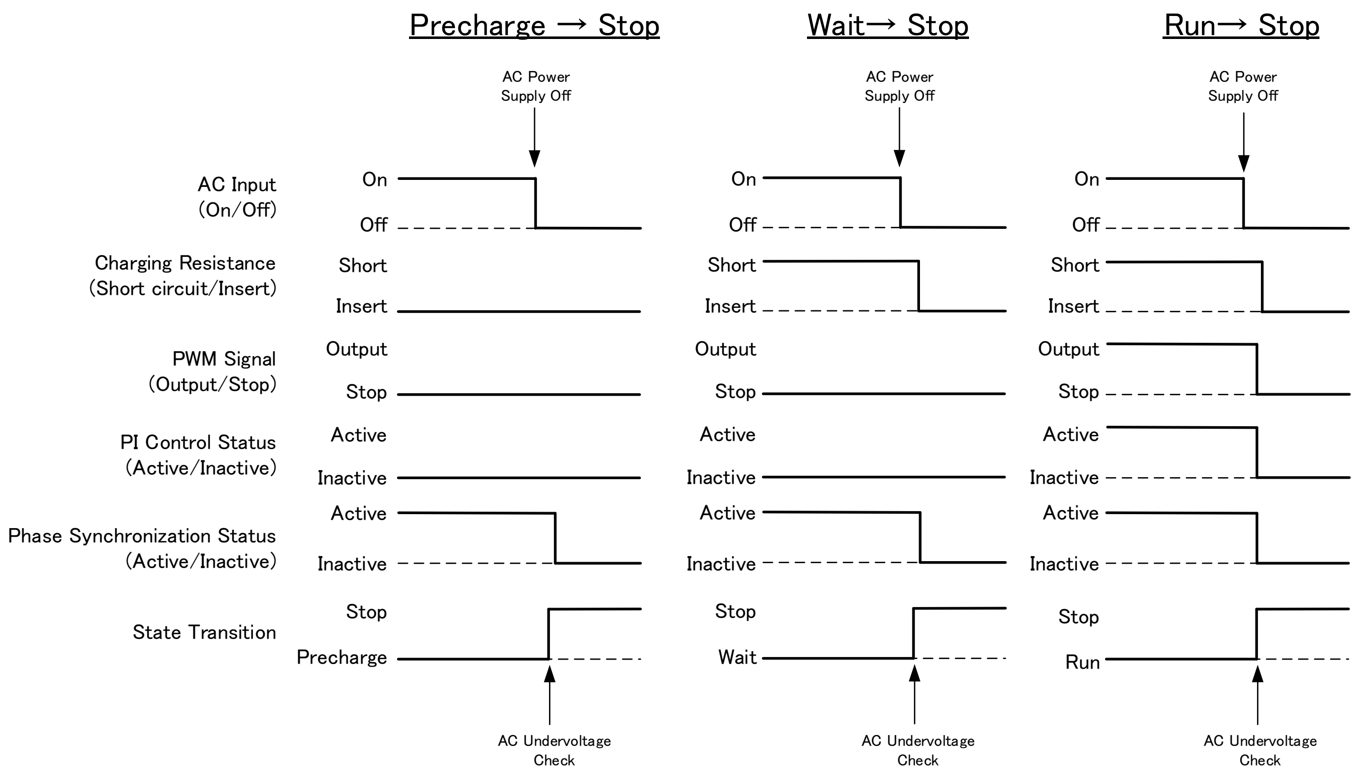
Stop → Precharge



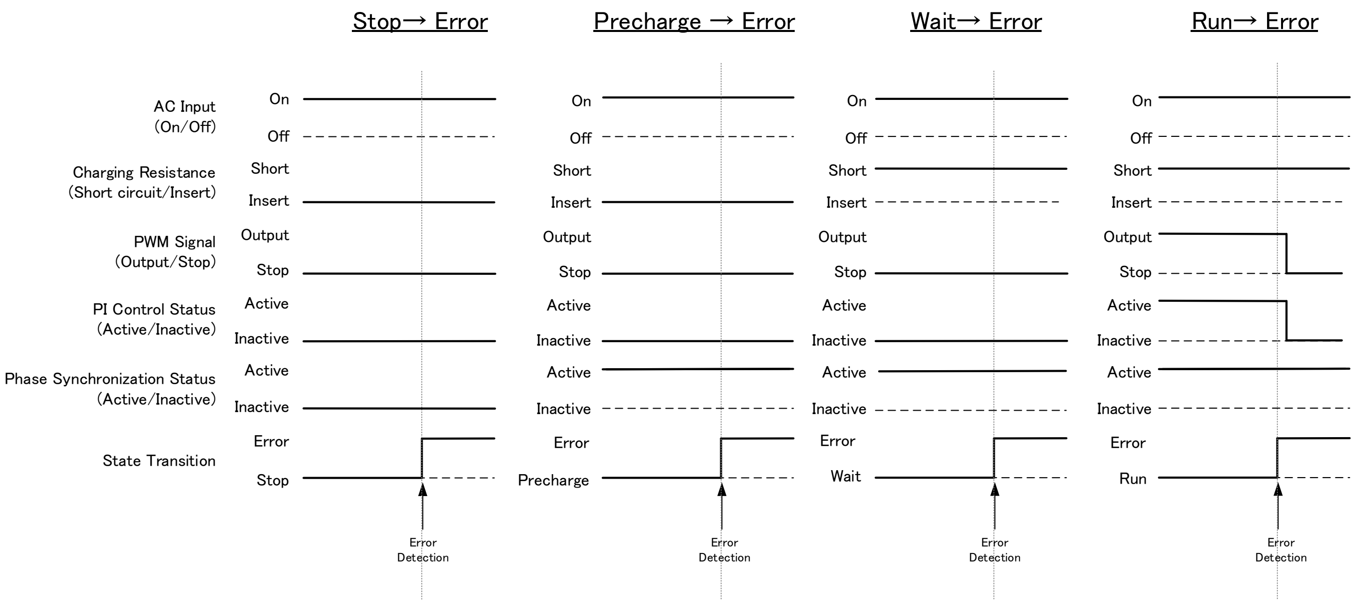
Precharge → Wait → Run



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



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



4. Constant, Variable Definition

4.1. Constant Definition

Definition of constants are as follows:

1. Constants for PWM function setting

Constant Name	Description
CARRIERPERIOD_NS	Defines the period of the PWM signal in ns.
CARRIERFREQ_HZ	Defines the frequency of the PWM signal in Hz.
INTERRUPT_MASK	Defines the execution cycle of the general control routine (described later).
DEADTIME_NS	Defines the dead time of the PWM signal in ns units.

2. Constant for timer interrupt routine cycle setting

Constant Name	Description
TIMER0INTERVAL_US	Defines the execution period of the timer interrupt routine in μs.

3. Constants for sensor value setting

Also refer to Section 7. A/D conversion list.

Constant Name	Description
VAC_GAIN VAC_OFFSET	Set the read voltage range of the AC voltage sensor circuit as follows. ((-VAC_GAIN) + VAC_OFFSET) to (VAC_GAIN + VAC_OFFSET)
IAC_GAIN IAC_OFFSET	Set the read current range of the current sensor circuit as follows. ((-IAC_GAIN) + IAC_OFFSET) to (IAC_GAIN + IAC_OFFSET)
VDC_GAIN VDC_OFFSET	Set the read voltage range of the DC voltage sensor circuit as follows. ((-VDC_GAIN) + VDC_OFFSET) to (VDC_GAIN + VDC_OFFSET)
VDC_M_GAIN VDC_M_OFFSET	Set the read voltage range of the DC midpoint voltage sensor circuit as follows. ((-VDC_M_GAIN)+VDC_M_OFFSET) to (VDC_M_GAIN+ VDC_M_OFFSET)
TH_GAIN TH_OFFSET	Set the read voltage range of the temperature sensor circuit as follows. ((-TH_GAIN) + TH_OFFSET) to (TH_GAIN + TH_OFFSET)

4. Constants for control

Constant Name	Details
IACKP1, IACKP2	Defines the value of proportional gain in PI control operation of input current.

IACKI	Defines the value of integral gain in PI control operation of input 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.
IACLIMIT	Defines the limit value for the current command value, which is the PI control calculation output of the DC voltage.
MRATELIMIT	Defines the upper limit of the modulation rate.

4.2. State Definition

1. System state parameter (Model: SystemState)

Constant Name	Details
State_Error	State constant indicating that the system is in error state
State_Stop	State constant indicating that the system is in stop state
State_Wait	State constant indicating that the system is in standby state
State_Run	State constant indicating that the system is in operating state
State_Precharge	State constant indicating that the system is in precharge state
State_Init	State constant indicating that the system is in initialization state

2. Protective State Constant (Model: ErrState)

Constant Name	Details
Err_IAC	State constant indicating that the overcurrent of the input current has been detected and the protection function has been activated
Err_VDC_OV	State constant indicating that the overvoltage of the DC voltage has been detected and the protection function has been activated.
Err_VDC_UV	State constant indicating that the undervoltage of the DC voltage has been detected and the protection function has been activated
Err_FLT	State constant indicating that the gate driver error signal has been detected and the protection function has been activated
Err_VAC	State constant indicating that the overvoltage of the input AC voltage 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 the PWM has tripped

4.3. Variable Definition

1. Variables for sensor measurement display

Constant Name	Details
Vac	Indicates the sensor (analog) value of the AC voltage.
Iac	Indicates the sensor (analog) value of the input current.
Vdc	Indicates the sensor (analog) value of the DC voltage.
Vdc_M	Indicates the sensor (analog) value of the DC midpoint voltage.
Th	Indicates the sensor (analog) value of the temperature.

2. Variables for sensor calculation value

Constant Name	Details
VacLPF	Indicates the output value when low-pass filter with the cutoff frequency VacFc is applied to the sensor value Vac.
VacFc	Indicates the cutoff frequency of the low-pass filter applied to the sensor value Vac.
VdcLPF	Indicates the output value when low-pass filter with the cutoff frequency VdcFc is applied to the sensor value Vdc.
Vdc_MLPF	Indicates the output value when low-pass filter with the cutoff frequency VdcFc is applied to the sensor value Vd_M.
VdcFc	Indicates the cutoff frequency of the low-pass filter applied to the sensor values Vdc and Vdc_M.
IacLPF	Indicates the output when a low-pass filter with the cutoff frequency IacFc is applied to the sensor value Iac.
IacFc	Indicates the cutoff frequency of the low-pass filter applied to the sensor value Iac.
OffsetVac	Indicates the offset correction value of the AC voltage sensor value.
OffsetIac	Indicates the offset correction value of the current sensor value.
OffsetVdc	Indicates the offset correction value of the DC voltage sensor value.
OffsetVdc_M	Indicates the offset correction value of the DC midpoint voltage 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 has been completed.

3. Variables for protection and error state display

Constant Name	Details
ErrorState	Indicates protection, error state (not latched). Bit0: Input overcurrent protection state Bit1: DC undervoltage protective state Bit2: DC overvoltage protection state

	Bit3: Gate driver error signal detection state Bit4: AC overvoltage (instantaneous) protection state Bit5: Overheat protection state Bit6: Watchdog timer overflow state Bit7: PWM trip state
ErrorState_Latch	Indicates protection and error state (latch). Bit0: Input overcurrent protection state Bit1: DC undervoltage protective state Bit2: DC voltage overvoltage protection state Bit3: Gate driver error signal detection state Bit4: AC overvoltage (instantaneous) protection state Bit5: Overheat protection state Bit6: Watchdog timer overflow state Bit7: PWM Trip state
ErrThrVdcHi_V	Indicates the overvoltage threshold of DC voltage.
ErrThrVdcLo_V	Indicates undervoltage threshold of DC voltage.
ErrThrVdc_MHi_V	Indicates the overvoltage threshold of the DC midpoint voltage.
ErrThrVac_Vpk	Indicates the overvoltage threshold (peak value) of the input voltage.
ErrThrIac_Apk	Indicates the overcurrent threshold (peak value) of the input current.
ErrThrTh_Deg	Indicates the heat sink overheat threshold.
FlagWDT	Indicates the overflow occurrence state of the watchdog timer.
FlagTZ	Indicates that a trip interrupt has occurred.
FlagWaitGB	Indicates the gate block wait state.

4. Variables for state transition

Constant Name	Details
State	Indicates the state of the system. It is assigned in the timer interrupt routine. Type: SystemState
PreState	Indicates the state 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 complete.
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.
FlagStateMainRelay	Indicates the state of the relay.

5. Variables for RMS calculation

Constant Name	Details
Vac_Vrms	Indicates the effective value of the AC voltage.
Vac_Vrms0	Indicates the effective value of the AC voltage one cycle before.
VacSum_V	Indicates the sum of squares of the AC voltage used for root-mean-square value calculation.
SignVac	Indicates the sign of AC voltage.
SignVac0	Indicates the sign of the AC voltage before one cycle.
PeriodCount	Indicates the value that is added in the switching period from the AC voltage zero crossing.
Iac_Arms	Indicates the rms value of the input current.
IacSum_A	Indicates the sum of squares of the input current used for root-mean-square value calculation.
FreqSys	Indicates the value of the input frequency.

6. Variables for averaging calculation

Constant Name	Details
VdcAVE	Indicates the average value of the DC voltage.
Vdc_MAVE	Indicates the average value of the DC midpoint voltage.
VdcSum_V	Indicates the sum of the DC voltages used for the average value calculation.
Vdc_MSum_V	Indicates the sum of the DC midpoint voltages used for the average value calculation.

7. Variables for phase calculation

Constant Name	Details
Phase_rad	Indicates phase information.
RefPhase_rad	Indicates the reference phase generated based on AC voltage zero crossing.
RefDeltaPhase_rad	Indicates the reference phase change amount to be added in the switching period.

8. Variables for AC current control

Constant Name	Details
IacRef	Indicates the input current command value.
ErrIac	Indicates the deviation between IacLPF and the input current command.
IacKp	Indicates the value of proportional gain in PI control calculation of input current.

IacKpComp	Indicates the correction value of proportional gain in PI control calculation of input current depending on input voltage.
IacKi	Indicates the value of integral gain in PI control calculation of input current.
IacTi	Indicates the time constant in PI control calculation of input current.
IacPElement	Indicates the proportional component of the PI control operation of the input current (proportional control output).
IacIElement	Indicates the integral component of the PI control operation of the input current (integral control output).
IacPIElement	Indicates the sum of the proportional and integral components of the PI control operation of the input current.
VacOut	Indicates the AC voltage command value obtained by PI control calculation of the input current.

9. Variables for DC voltage control

Constant Name	Details
IacLimit	Indicates the upper limit of the current command value.
VdcRef	Indicates the 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 PI control calculation of DC voltage (proportional control output).
VdcIElement	Indicates the integral component of the PI control operation of 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 IacRef as the input 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.

10. DC voltage balance control variable

Constant Name	Details
ErrVdc_M	Indicates the deviation between Vdc_MLPF and (VdcLPF×2).

Vdc_MKp	Indicates the value of proportional gain in PI control calculation of DC midpoint voltage.
Vdc_MKi	Indicates the value of integral gain in PI control calculation of DC midpoint voltage.
Vdc_MTi	Indicates the time constant in PI control calculation of DC midpoint voltage.
Vdc_MPElement	Indicates the proportional component of PI control calculation of DC midpoint voltage (proportional control output).
Vdc_MIElement	Indicates the integral component of PI control operation of DC midpoint voltage (integral control output).
Vdc_MPIElement	Indicates the sum of the proportional and integral components of the PI control operation of the DC midpoint voltage. This value is added to the input current command value IacRef calculated by DC voltage control.

11. Variable for calculating the modulation factor

Constant Name	Details
MRateOut1,2	Indicates the modulation ratio of PWM.

5. Initialization

5.1. Initialization Routine Execution Condition

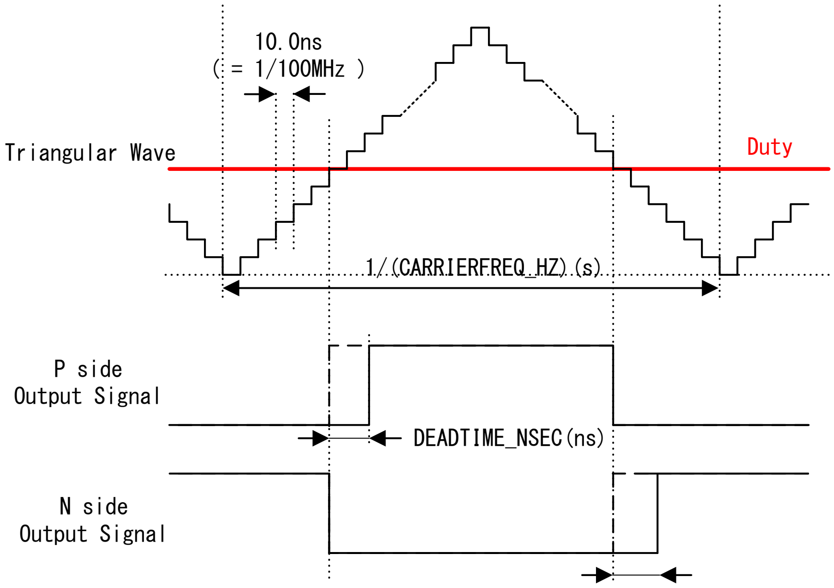
The initialization routine is executed when the following conditions are met.

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

5.2. Initialization Routine

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

Processing Order	Processing	Details of Processing
1	Pin setting initialization of TMS320F28377SPTP	Initializes the MCU (TMS320F28377SPTP) and sets pins. For pin setting, refer to the I/O signals described in Section 2 above.
2	Headspring Inc. HSDT-DP SCOPE function initialization and setting	Initializes and set so that SCOPE function of HSDT-DP made by Headspring Inc. can be used.
3	AD conversion function initialization and setting AD conversion value - range, offset setting	Initializes the AD conversion function and sets 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 Section 4.1.
4	Comparator function initialization and setting	Initializes the comparator function and sets the operation to stop when any of input overcurrent, DC overvoltage, or input overvoltage is detected.
5	Watchdog timer initialization, setting	Initializes the watchdog timer function. ClearWDT() sets the function to stop operation if it is not executed again within 13.1 ms from the timing of previous execution.
6	Timer function initialization and setting	Initializes the timer function and sets the interrupt routine to be executed at 1 ms intervals.
7	PWM function initialization and setting	Initializes the PWM function and performs following setting. ・PWM period (ns) Set to CARRIERPERIOD_NS ・Dead time (ns) Set to DEADTIME_NS

		・Shape of the comparison carrier Triangular wave  ・Protective function Output of the PWM signal is stopped when any of the input current overcurrent, DC voltage overvoltage, or AC 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 1ms for system stabilization.
9	Comparator latch mechanism reset Trip flag clear	Resets the latch mechanism at the comparator output section and clears the trip flag.
10	Interrupt function setting	Enables execution of general control routines, timer interrupt routines, and trip interrupts.

6. Main Routine

This section describes the main routine process that is executed after the initialization function Init() is completed.
This firmware generates interrupt processing at regular intervals and executes each subroutine. Interrupt processing also occurs when the trip zone function is activated.
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 Period : 20 μs	・Sensor value reading ・DC voltage control ・DC voltage balance control ・RMS value, average value calculation ・Low-pass filtering ・Phase calculation ・Input current control ・Modulation factor calculation
Timer Interrupt Routine	Timer0IntFunc	Trigger: Timer function Period : 1 ms	・Measurement of standby time in standby mode ・Soft start processing at start of operation ・Error detection ・State transition ・Low-pass filtering ・Temperature sensor value reading/conversion ・Sensor offset correction
Trip Interrupt Routine	TZIntFunc	Trigger: Trip zone function Cycle: When a trip occurs	Gate block

6.1. Main Loop

Indicates the main loop processing of this firmware.

Processing Order	Processing	Details of Processing
1	Watchdog Timer Processing	Resets the watchdog timer counter and checks the watchdog timer flag. If the watchdog timer counter is not reset for 13.1 ms, the operation is stopped.
2	Digital Signal Input Checking	Checks DI0, 1 entry state.

3	Headspring Inc. HSDT-DP SCOPE Function Updating Processing	Performs the HSDT-DP SCOPE function update process made by Headspring Inc.

6.2. General Control Routine

This firmware has the following general control routines.

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

Processing Order	Processing	Details of Processing
1	Multiple Interrupt Enable Processing	Set to prioritize trip interrupt when trip interrupt occurs during general control routine execution.
2	Sensor Value Reading	Reads each sensor value of AC voltage, AC current, DC voltage, and DC midpoint voltage.
3	AC Voltage Phase Calculation AC Voltage RMS Value Calculation DC Voltage Average Value Calculation	The AC voltage phase information obtained in the previous general control routine is added together with the phase difference corresponding to one cycle of the general control routine to update the AC voltage phase information. In addition, the rms value of the AC voltage and the average value of the DC voltage are calculated from each sensor value.
4	DC Voltage Control Processing	The deviation between the value of Vdc_MLPF is calculated using the ½ times value of VdcLPF as the command value, and the value calculated bu the PI control opration is added to the input current command value IacRef. It is executed during the routine immediately after zero crossing where the AC voltage goes from negative to positive.
5	DC Voltage Balance Control	The deviation of the value of Vdc_MLPF is calculated using the value 1/2 times VdcLPF as the command value, and the value calculated by the PI control operation is added to the input current command value IacRef. It is executed during the routine immediately after both zero crossings where the AC voltage goes from negative to positive and positive to negative.
6	Low-pass Filtering	Performs low-pass filter processing.
7	Input Current Control	Performs PI control for IacLPF and calculates the input-current control output VacOut.

8	Modulation Factor Calculation	Calculates the modulation ratio of the PWM waveform to be output. The PWM waveform output is changed according to the calculated modulation factor.
9	Multiple Interrupt Disable Processing	Cancels the setting that prioritizes trip interrupts.

6.3. Timer Interrupt Routine

This firmware has the following timer interrupt routines.

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

Processing Order	Processing	Details of Processing
1	Multiple Interrupt Enable Processing	If another interrupt occurs during timer interrupt routine execution, the corresponding interrupt is given priority.
2	Time Measurement in Standby Mode	Measures the DC voltage stabilization wait time after transitioning to the standby state. Short-circuit the charging resistor when the waiting time reaches 500 ms.
3	Soft Start Processing at Start of Operation	Gradually increases the DC voltage by increasing the DC voltage command value VdcRef, from the DC voltage value at the moment when the system switches to the Run state to 380 V over a period of 250 ms to reduce the amount of inrush current.
4	Temperature Sensor Value Reading, Conversion	Reads the temperature sensor value and converts it to temperature.
5	Error Determination Processing	Checks the status of DI1 (gate driver error signal) for DC overvoltage, input overcurrent, input overvoltage, and overheat status, and the status of the watchdog timer to determine the error state. For details, refer to Section 6, Error Processing.
6	State Transition Processing	The system state is changed according to the system state at the time of process execution, the result of error processing, and the state of various variables. For details, refer to Section 3, State Transition Diagram.
7	Low-pass Filter Processing Coefficient Calculation Processing	Calculates the coefficients of the low-pass filter.
8	AD Conversion-Offset Error Correction Processing	When the system is in Init (initialization) state, the offset error is measured using the readings of each sensor before the single-phase AC power is turned on, and the correction processing is performed. When the correction process is completed, FlagCalibEnd is changed to 1.

		The above process is performed by CalibAdOffset(). If the system state is not Init, the above process is not performed.
9	Multiple Interrupt Disable Processing	Cancels the setting that gives priority to other interrupts.

6.4. Trip Interrupt Routine

This firmware has the following trip interrupt routine.

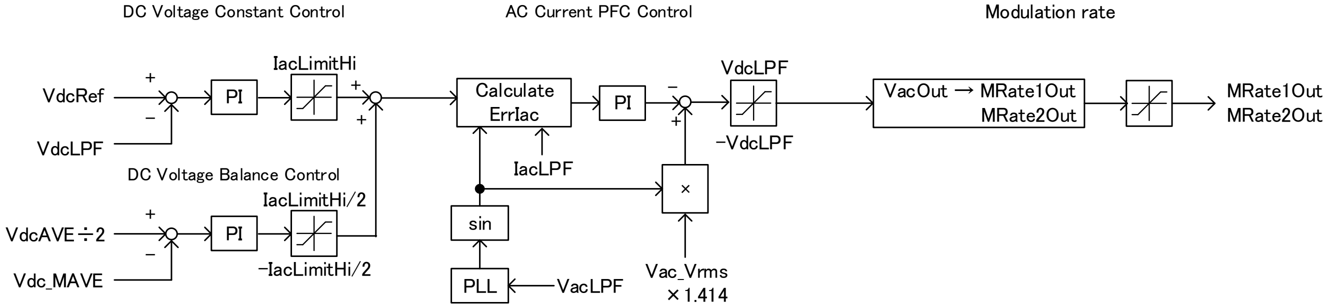
The trip interrupt routine is executed by TZIntFunc() function.

Processing Order	Processing	Details of Processing
1	Gate Block Processing	This bit disables the gate transmission of the upper and lower arms, and changes the flag FlagTZ to 1 to disable the gate transmission of the intermediate arm within the following general control routine.

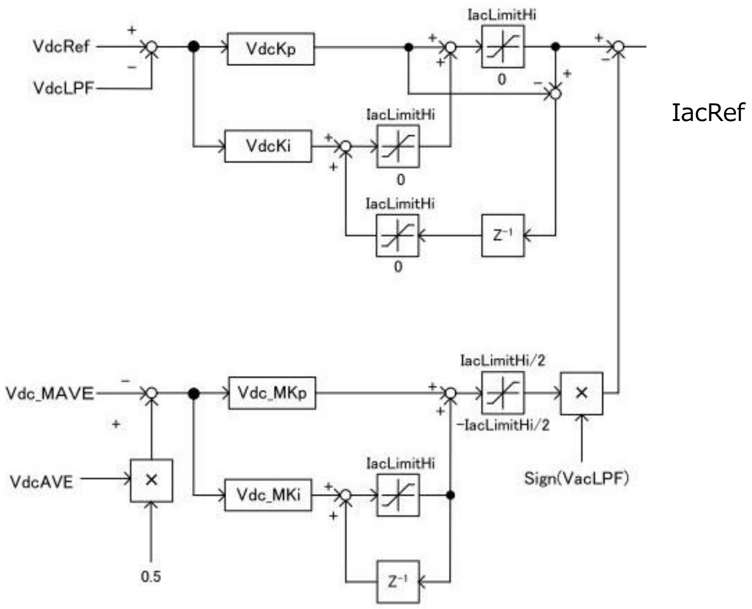
6.5. Control Block Diagram

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

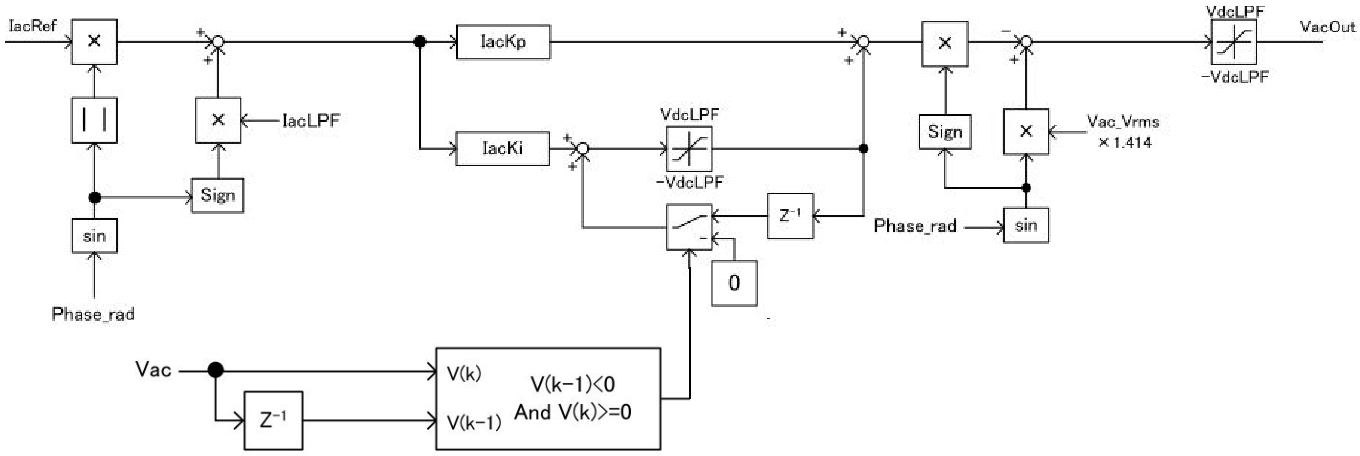
1. Overall



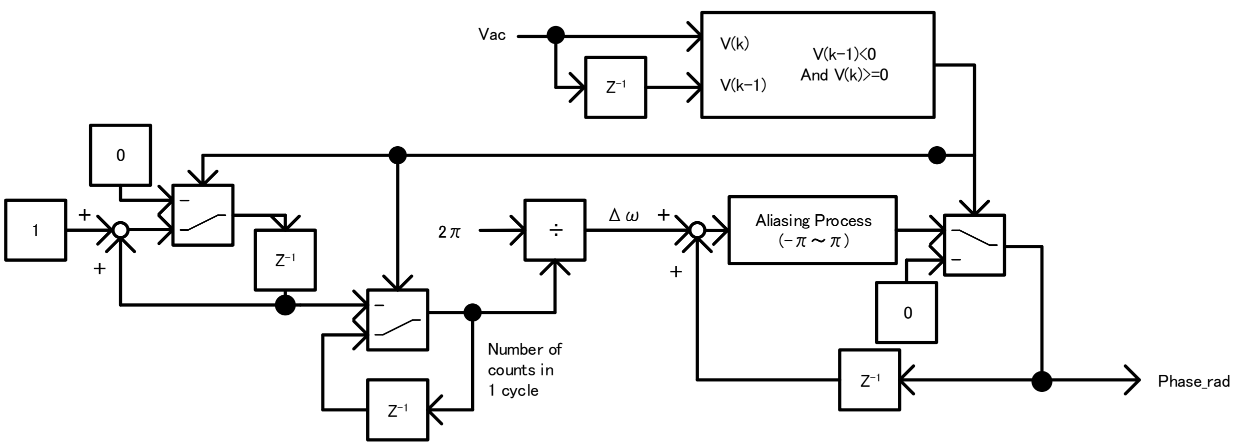
2. DC Voltage Constant Control and DC Voltage Balance Control



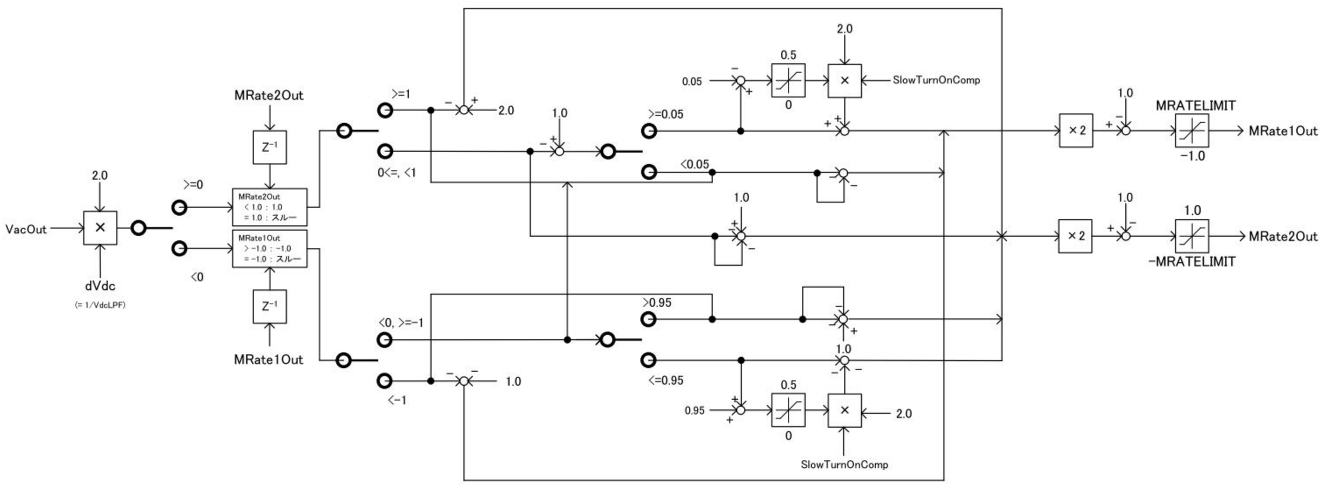
3. AC Current PFC Control



4. PLL



5. Modulation Factor Calculation



7. Error Processing

In this firmware Error state is set, and the operation is stopped if any of the following is detected; the overcurrent of the AC side current, the overvoltage of the AC side instantaneous voltage, the overvoltage of the DC side voltage, DESAT signal of the gate driver, and the watchdog timer overflow during Precharge state, Wait state, and Run state.

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 restore the operation, press the reset switch or turn the AC power OFF and then ON again.

8. A/D Conversion List

A/D conversion table is shown below.

Port	Pin	Measurement Item	Data	A/D Conversion Resolution	Filtering
ADCINA2	41	AC voltage	12bit	0.2588(V/LSB)	Low-pass filter circuit mounting in the control circuit Cut-off frequency: 17 kHz
ADCINA4	39	Temperature	12bit	0.00122(V/LSB)	Low-pass filter circuit mounting in the control circuit Cutoff frequency: 160 Hz
ADCINB2	48	AC current	12bit	0.01465(A/LSB)	Low-pass filter circuit mounting in the control circuit Cut-off frequency: 204 kHz
ADCIND0	56	DC voltage	12bit	0.1231(V/LSB)	Low-pass filter circuit mounting in the control circuit Cut-off frequency: 17 kHz
ADCINA3	40	DC midpoint voltage	12bit	0.0616(V/LSB)	Low-pass filter circuit mounting in the control circuit Cut-off frequency: 17 kHz

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