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Implementation of RTOS on STM32F4 Microcontroller to Control Parallel Boost for Photovoltaic Battery Charging Application

EkaPrasetyono*, Putra S Permana**
*(Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia)
**(Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya, Indonesia)

ABSTRACT
The DC-DC converter is operated with pulse width modulation (PWM) and controlled by modifying duty cycle. The PWM is easy developed on microcontroller system, but the problem become complex when some control algorithm implemented to determine duty cycle value. Multitasking is needed to handle sensor, control algorithm and user interface system. This paper discusses the application of Real Time Operating System (RTOS) to handle multitasking process on STM32F407 ARM Cortex M4 microcontroller to control parallel boost converter with load sharing algorithm for photovoltaic (PV) battery charging application. The first OS task is to run MPPT to get maximum energy from PV. This first OS task is implemented to control the first boost converter. Then, The second OS task to run fuzzy logic controller to control battery charging current with load sharing energy. This second OS task is task implemented to control second boost converter. The measurement of current and voltage of both converter side, display and user interface system also handled with OS task. As the result, each designed task could run well with recommended OS task priority for MPPT and Fuzzy is IRQ task and for TFT_LCD_displayosPriorityAboveNormal.
Keywords-Battery charging, Load Sharing Photovoltaic, RTOS, STM32F407.

I. INTRODUCTION

The PV energy is greatly influenced by environmental factors such as solar irradiation [1,2], so that many researcher have developed techniques to absorb PV energy in maximum stage used DC-DC power converter and controlled by maximum power point tracking algorithm (MPPT). The P&O method is the simplest and often used to control the MPPT [3]. This method is very simple to be implemented on microcontroller system

In the case of PV with MPPT algorithm for battery charging, the charging current is linear to intensity of solar irradiation [4]. The charging will be maximumat noon and morning. In the evening, the charging is not maximal. The charging method of battery depends on battery applications. The applications are roughly classified into main power application and stand-by/back-up power application [5]. In the main power battery application commonly used constant-current, constant-voltage, modified constant-voltage charging method [5-7]. For the reason, this paper proposes multi input battery charging with parallel boost converter for constant current battery charging system.

Conventionally, DC-DC converter application microcontroller is programed with procedural programming, when some control algorithm implemented on microcontroller application with procedural programming techniques is difficult for beginners, because it's requires multitasking process. Thus, This paper discusses the application of Real Time Operating System (RTOS) to handle multitasking process on STM32F407 ARM Cortex M4 microcontroller to control parallel boost converter with load sharing algorithm for PV battery charging application. Comparison software using RTOS and without RTOS illustrated on Table 1.

The discussion of this paper highlighted on RTOS Task ability to control each task algorithm for multi input parallel boost for battery charging application with load sharing algorithm. The load sharing algorithm described in this paper is PV as main energy source and existing grid electricity as secondary energy source. The charging current is emphasized on PV energy. Meanwhile, lack current from the demand charging current is taken from existing grid electricity. The RTOStaskis meant on this paper as OS task to running MPPT, OS task to running fuzzy logic controller and OS task tomeasurement of current and voltage display and user interface system for battery charging application.

Table 1. Comparison programming with RTOS and without RTOS [8].

NO RTOS	USING RTOS

void ADC_scaling()
{ //Processing ADC Value
}
 	
void LCD_display()
{ //Displaying data with LCD
}
 	
void TIMx_IRQHandler()
{ //Generating reference signal & PWM
}
 	
void TIMx_IRQHandler()
{ //schedule system
}
 	
int main(void)
{ keypad_io_init();
ADC_init();
LDC_io_init();
Timer_init();
while(1)
{ // call function
switch(schedule){
case a:
KeyPad();
break;
case b:
ADC_scaling();
break;
case c:
LCD_display();
break;
}
};
}
	void ADC_scaling()
	{ ADC_init();
	while(1)
	{ //Processing ADC Value
	};
	}
	
	void LCD_display()
	{ LDC_io_init();
	while(1)
	{ //Displaying data with LCD
	};
	}
	
	void TIMx_IRQHandler()
	{ //Generating reference signal & PWM
	}
	
	osThreadDef(KeyPad,osPriorityAboveNormal,1,0);
	osThreadDef(ADC_scaling,osPriorityNormal,1,0);
	osThreadDef(LCD_display,osPriorityNormal,1,0);
	
	int main(void)
	{ timer_init();
	osKernelInitialize (); // setup kernel
	osThreadCreate(osThread(KeyPad),NULL);
	osThreadCreate(osThread(ADC_scaling),NULL);
	osThreadCreate(osThread(LCD_display), NULL);
	osKernelStart (); // start kernel
	while(1)
	{
	//no code here
	};
	}

The battery charging system is not only hardware equipment, but also consist of hardware topology and requires software with some control algorithm. The main idea of this paper is to get easier way to handle multitasking process with RTOS system on multi input parallel boost for battery charging application with load sharing algorithm. There are many type of rechargeable batteries widely used in renewable energy systems to store electricity energy in the world[4], but in this paper discussion of rechargeable batteries focused on only sealed lead-acid (SLA) battery type. The charging of SLA batteries is not difficult process, a number of methods for charging lead-acid batteries have been developed to meet the rules for proper charging [5,6]. Common charging of SLA methods are known as the constant-current, constant-voltage, modified constant-voltage, float charging, and trickle charging method [5-7]. The characteristic of charging method of SLA battery can be seen on Figure 1 below.

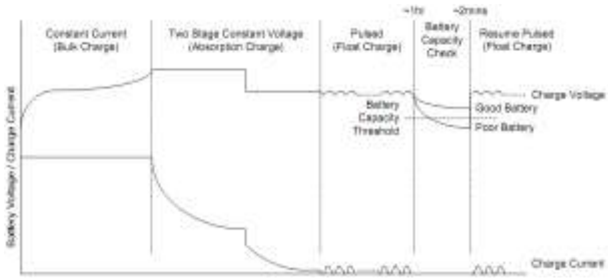

Figure 1.The characteristic of charging method of SLA battery [7].

The constant-current charging method is a fixed current applied for a certain time to recharge the battery. The charging current value is set to a low value, usually less than 10% from capacity or 0.1C for slow charging and 30% from capacity or 0.3C for fast charging. The constant-current charging method is not used for lead-acid batteries on long time charging, because of the gassing which is likely to occur when charging a battery too long [6].

The constant-voltage charging method is a fixed voltage applied to recharge the battery. The value of initial charging current (current value at the beginning of the battery charge) is in the maximum value according to the battery capacity and its level of charge. The initial charging current can reach higher values. It sometimes even exceed the maximum charge current prescribed by the battery manufacturer when the battery depth of discharge is high. For this reason, purely constant-voltage charging is infrequently used to charging lead-acid batteries that are used in cyclic charge-discharge applications. In this paper, for multi input parallel boost for battery charging with load sharing algorithm and the battery charging current is emphasized on PV energy. The constant-current charging method is selected as method of charging.

On the software part, there are many type of RTOS for microcontroller embedded application. In this paper the RTOS discussion is limited on the RTOS products RTX from KEIL uVision. This RTSO supports microcontroller ARM cortex M4F such as STM32F407 microcontroller. TheRTX (**R**eal **T**ime **E**xecutive) kernelbasedon theidea ofrunninga paralleltask, thetaskRTXkernel(number of programcodewith the purpose/specialized functions) in thesystem is splattedintosmallertasksthatcan berun simultaneously. The advantage of usingthe KeilRTX [8,9]:

- Task scheduling - tasks are called when needed ensuring better program flow and event response
- Multitasking - task scheduling gives the illusion of executing a number of tasks simultaneously
- Deterministic behaviour - events and interrupts are handled within a defined time

- Shorter ISRs - enables more deterministic interrupt behaviour
- Inter-task communication - manages the sharing of data, memory, and hardware resources among multiple tasks

RTX allows three kinds of scheduling options of *task*, they are :

Pre-emtive scheduling

The task will be stopped while it is running, when there is a task with a higher priority.

Round-Robin Scheduling

RTXwill beallocatedtotime slice for every task, duringaveryshorttime slice(in units of milli-second), then it appearsthe executionof eachtaskperformedsimultaneously

Cooperative Multitasking

It will allow a lower priority task to be executed when a completing task is done.

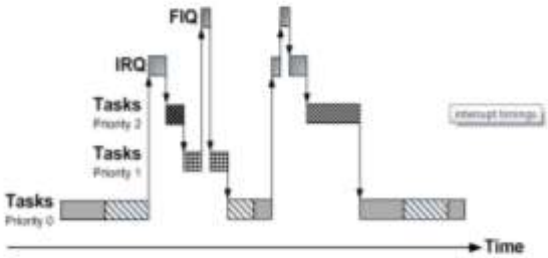

Figure 2. Task state on RTX [9].

The RTOS have been sucessful implemented on power converter application such as to control Switching Power Converters with LowCost Embedded Systems [10]. Also RTOS was applied in Power Quality Applications [11]. And some researcher on microcontroller and DSP sugest to used RTOS to improve performance of the control algorithm by scheduling these loops on RTOS[12].

II. METHOD AND DESIGN

The general block diagram of proposing multi input parallel boost for battery charging system is shown in Figure 3. The charging current is emphasized on PV energy. Meanwhile, lack current from the demand charging current is taken from existing grid electricity. To implement load sharing algorithm, the first boost converter is controlled by P&O MPPT algorithm and the second boost converter will be controlled with fuzzy logic to manage energy sharing. Both, control method in this paper are implemented on STM32F407 a 32 bit microcontroller with RTOS system.

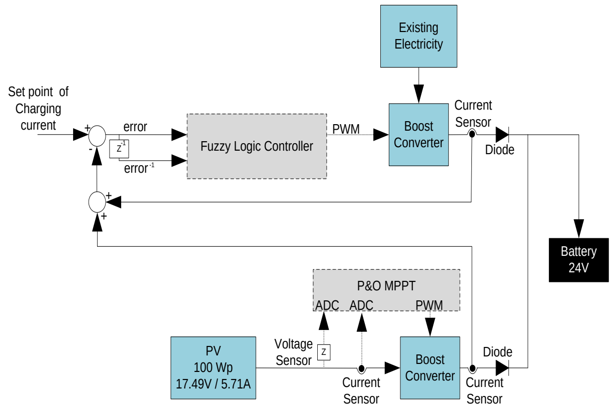

Figure 3. General block diagram for proposing battery charging system.

According to the general block diagram on Figure 3, the proposed system of multi input parallel boost for charging can be described as follows:

2.1. Design of Parallel Boost Converter.

A boost converter (step-up converter) is a DC-to-DC power converter to produce a higher output average voltage than the input voltage [13]. The basic schematic with the switching waveform of a boost converter is shown in Figure 4.

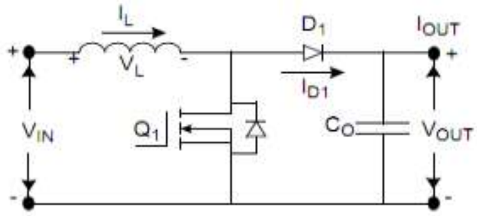

Figure 4.Boost converter and its signal of operation [13].

In a boost converter, an inductor (L) is placed in series with the input voltage source VIN. The input source feeds the output through the inductor and the diode D1. The output capacitor value should be large enough to supply the load with the minimum ripple in the output voltage. The relation between output and input voltage, as shown in Equation 1 below.

$$Vout = \frac{Vin}{(1-D)} \qquad ....(1)$$

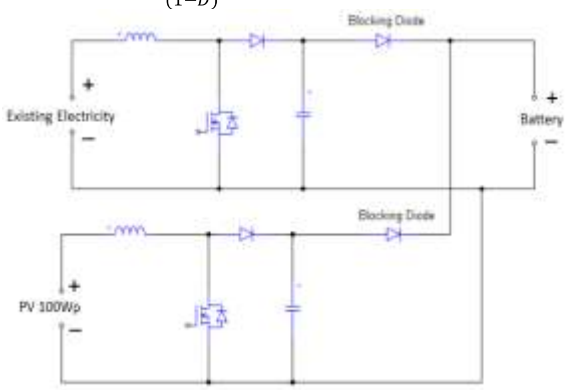

Figure 5.Proposed parallel boost converter circuit.

The paramater of designed parallelboost converter described on Table 2 below.

Table 2. Parameter of proposed parallel boost converter.

Parameter	Value
Switching ferquency	40Khz
Vin_min	8Volt
Vout_max	28.8Volt
Iin_max	5.88A
Iout_max	1.8 A
MOSFET	IRFP460
Diode	STTH60L06C
Capacitor	729,175 uF
Inductor	0,515 mH
Duty Cycle	0,584
Winding number of Inductor	39
Wire size of inductor	0.45 mm
Length of Wire	15 m

2.2. Design ofMPPT.

The P&O MPPT is one of the most discussed algorithms MPPT among PV researchers since it's basic MPPT algorithm and very simple. The algorithm worked on the PV panel by modifying the converter duty cycle [14]. To be able to implement P&O MPPT, the application needs to measure the panel voltage and current. To simplify the understanding on how P&O work look at Figure 6. The decreasing voltage on the left side of the MPP will increase power. Furthemore, increasing voltage on the right side of the MPP will raise the power. This is the main idea behind P&O. After performing an increase in the panel operating voltage, the algorithm compares the current power reading with the previous one. If the power has increased, it keeps the same direction (increase voltage), otherwise it changes direction (decrease voltage). This process is repeated at each MPP tracking step until the MPP is reached. After reaching the MPP, the algorithm naturally oscillates around the correct value. This P&O MPPT is designed to run under RTSO system. This task is implemented to control the first boost converter. The P&O MPPT algorithm will free running to get maximum energy from PV.

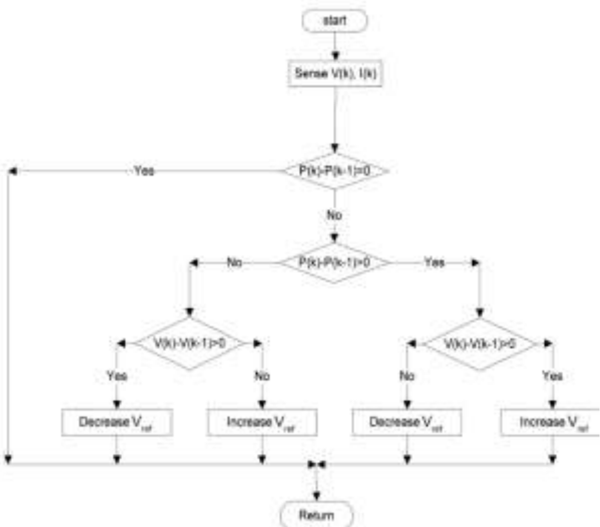

Figure 6.Flowchart of P&O MPPT [15].

2.3. Design of Fuzzy Logic Control.

The function of fuzzy logic controller is to control second boost converter with load sharing algorithm. This fuzzy logic controller is designed to run under RTSO system with highest priority. The fuzzy logic controller will manageenergy sharing between PV and existing grid electricity. The charging current is emphasized on PV energy. Meanwhile, lack current from the demand of set-point of charging current is taken from existing grid electricity. The input of fuzzy logic controller is taken from subtraction between set-point of charging current and summing of current sensor from both output of parallel boost converter. Then, current value processed as error and delta error. The design of membership function of error and delta error can be seen on Figure 7 and 8.

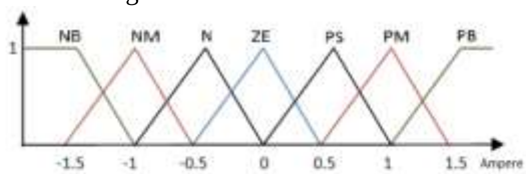

Figure 7.Membership function of input error

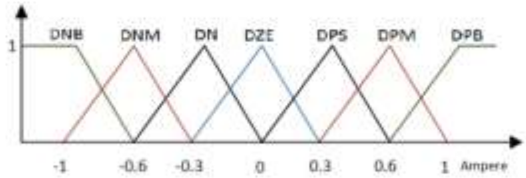

Figure 8.Membership function of input delta error

The inference system of fuzzy logic controller in this paper used 7x7 combination rule based on input error and input delta error. Detail of inference rule based can be seen on Table 3 below.

Table 3. Rule base of proposed fuzzy logic controller.

		Error						
		NB	NM	NS	ZE	PS	PM	PB
ΔError	DNB	DCB	DCB	DCB	DCB	DCS	DC	K
	DNM	DCB	DCB	DCB	DCS	DC	K	IC
	DNS	DCB	DCB	DCS	DC	K	IC	ICS
	DZE	DCB	DCS	DC	K	IC	ICS	ICB
	DPS	DCS	DC	K	IC	ICS	ICB	ICB
	DPM	DC	K	IC	ICS	ICB	ICB	ICB
	DPB	K	IC	ICS	ICB	ICB	ICB	ICB

The membership function of defuzzification in this paper use singleton type as shown on Figure 9.

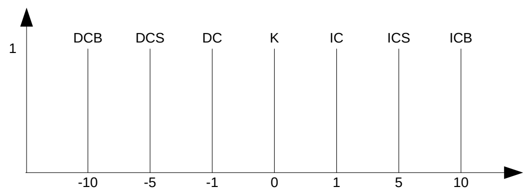

Figure 9.Membership function of output

The output value of defuzzification process can be calculated with weighted average formula as below.

$$\text{Defuzzification Output } = \frac{\sum_{n=i}^{n} \mathrm{W_i Z_i}}{\sum_{n=i}^{n} \mathrm{W_i}} \quad \text{…..(2)}$$

2.4. Design of RTOS Task.

The main idea of this paper is to get easier way to handle multitasking process with RTOS system on multi input parallel boost for battery charging application. The RTOS provided task priority from low to high level priority and allowed interrupt (IRQ) to handle time critical process. The design of RTOS task on this paper described on Table 4 below.

Table 4. Designed of proposed RTOS task.

Task Name	Task Priority	Function
MPPT	IRQ task	Running MPPT algorithm
Fuzzy	IRQ task	Running Fuzzy logic controller for load sharing process
TFT_LCD _display	osPriorityAboveNormal	Touch panel and Display data
ADC_scaling	osPriorityAboveNormal	Read and convert ADC value as frequency target

Task with low update interval such as TFT_LCD display and ADC_scaling process done by OS task normal above normal priority. But, critical time process such as MPPT and Fuzzy should be done by IRQ task.The fuzzy logic controller is predefined master controller to manageenergy sharing between PV and existing grid electricity, so that it is designed with highest IRQ task priority.

III. RESULT AND DISCUSSION

The prototype of hardware used in this paper can be shown on Figure 10. The tested RTOS task on different OS task priority and status described below.

Figure 10. Prototype of parallel boost for battery charging

The result of tested OS task priority on handling control algorithm can be seen on Table 5 below.

Table 5. Result of tested RTOS task

Task Name	Task Priority	Status
MPPT	osPriorityBelowNormal	failed
	osPriorityNormal	failed
	osPriorityAboveNormal	Run, but not very well
	IRQ task	Running well
Fuzzy	osPriorityBelowNormal	failed
	osPriorityNormal	failed
	osPriorityAboveNormal	Run, but not very well
	IRQ task	Running well
TFT_LCD _display	osPriorityBelowNormal	failed
	osPriorityNormal	Run, but not very well
	osPriorityAboveNormal	Running well

The result of field measurement test with PV 100WP, the hourly characteristic of PV power output without MPPT in the function of time with different load on the test date can be seen on Figure 11. The PV delivers maximum energy only on correct load. If load is not correct, PV only delivers energy according to the load demand. Meanwhile, PV performance on different load with MPPT controller make PV always in maximum load (Figure 12). Furthermore, from MPPT data it can be concluded that P&O MPPT is running well on RTOS system.

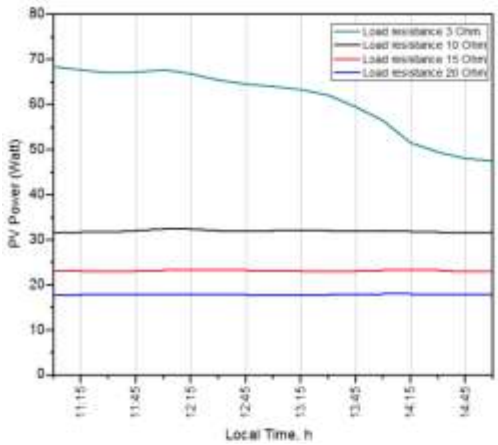

Figure 11. Hourly characteristic of PV power without MPPT.

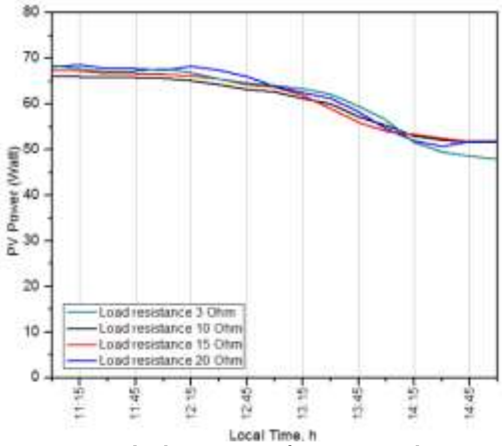

Figure 12. Hourly characteristic of PV power with MPPT.

The performance of proposed fuzzy logic controller on partial test with different set-point shown on Figure 13 below. The average error for 1.44 Ampere charging current is 0.42%, 0.38% for 1.2 Ampere and 0.17% for 1.0 Ampere. By this data, it can be concluded that fuzzy logic controller work well on RTOS system.

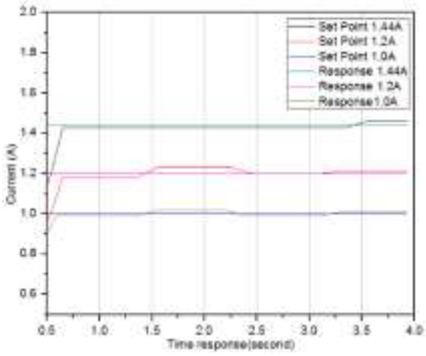

Figure 13. Performance of fuzzy logic controller with several set-point on partial test.

The result of proposed multi input parallel boost for battery charging with load sharing algorithm can be seen on Figure 14.

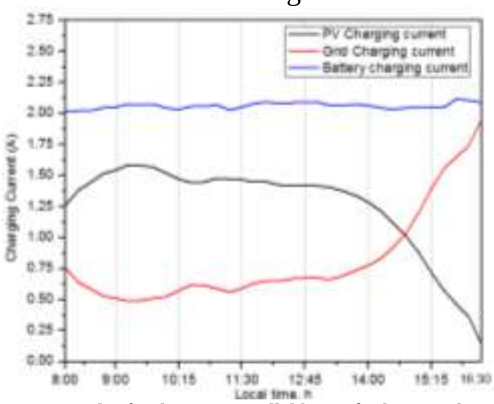

Figure 14.Result ofmulti input parallel boost for battery charging with load sharing algorithm.

In the morning and evening the PV output power is in the low power. When charging current from PV goes low, the lack current of charging to full fill set point 2A is taken from existing grid electricity. Furthermore, when PV charging current is high the lack current of charging taken from grid will be smaller. This process is repeated at each controllers until the charging current set point 2A is reached. After reaching the charging current set point, the algorithm naturally oscillates around the correct value. The controller show its ability to share energy each other with an error ±3.08% from 2 ampere charging current.

IV. CONCLUSION

Finally, The result show minimum OS task priority for MPPT and Fuzzy is osPriorityAboveNormal and for TFT_LCD_displayosPriorityNormal, but sometimes get on failure condition. The recommended OS task priority for MPPT and Fuzzy is IRQ task and for TFT_LCD_displayosPriorityAboveNormal.

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