Development of a Low Cost MPPT Circuit for Solar Panel

AN INTERNSHIP REPORT SUBMITTED TO THE DEPARTMENT OF MATHEMATICS AND NATURAL SCIENCES, BRAC UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN APPLIED PHYSICS AND ELECTRONICS

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September 2014

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Declaration

I hereby declare that the internship report titled “Development of a Low Cost MPPT circuit for Solar Panel” submitted by me had been carried out under the supervision of Mr. Mahbubul Hoq, Director, Institute of Electronics, Atomic Energy Research Establishment (AERE), Ganakbari, Dhaka and it had also been supervised from the university by Mr. Muhammad Lutfor Rahman, Lecturer, Department of Mathematics and Natural Sciences, BRAC University. It is further declared that the research work presented here is based on original work carried out by me. Any reference to work done by any other person or institution or any material obtained from other sources have been duly cited and referenced.

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Acknowledgements

I am obliged to the Mr. Mahbubul Hoq, Director of Institute of Electronics in Atomic Energy Research Establishment (AERE) for allowing me to get involved with the Solar Cell and Fabrication Division and carrying out my internship project. And I am extremely grateful to him for being our supervisor and guiding us with his ideas, advice and assistance. Without his and Mr. Firoz Pervez's continuous support the completion of internship project would not have been possible.

I am also very thankful to Ms. Salwa Shahidi for working together all along the internship and helping with the laboratory work.

I am very grateful to BRAC University for giving me the opportunity of availing its resources and enhancing my knowledge; Mathematics and Natural Sciences Department had been very supportive in all academic and official procedures. I am indeed lucky to have an affectionate Chairperson like Prof. A.A. Ziauddin Ahmad whose constant guidance and concern had encouraged me to do well in my studies. The fulfilment of the undergraduate studies would not have been possible without the supervision of my course teachers– Mr. Lutfor Rahman, Mr. Mahabobe Shobahani, Mr. Shamim Kaiser, Dr. Abu M Khan, Professor Sayeed Salam, Dr. Md. Mosaddeque Rahman, Proessor. S. Shahnewaz Ahmed, Dr. Mohammed Belal Hossain Bhuian, Dr. A.K.M Abdul Malek Azad, Ms. Amina Hasan Abedin, Mr. Iftekhar Md. Shafiqul Kalam, Ms. Sharmina Hussain, Md. Sazib Hasan, Ms. Rumama Rahman, Ms. Farzana Shabnam, Mr. S. Shakib Sharwar, Professor Quamrul Ahsan, Mr. Matin Saad Abdullah, Dr. S. M. Lutful Kabir. I am very thankful to them.

Abstract

Renewable energy source have potential of playing a vital role in electricity generation. In Bangladesh, solar panel is now a widely used renewable energy source. So extracting maximum power from solar panel is vital. In order to maximize the output from a solar panel maximum peak power tracker (MPPT) should be introduced.

This paper describes the design and development of a low cost MPPT circuit for extracting maximum power from the solar panel and charging a storage battery. The designed circuit consists of a microcontroller (PIC16F72) which generates high frequency pulse signal of different widths in accordance with the output of solar panel and electrical characteristics of the load to operate the panel at maximum power point. The generated pulse signal drives a DC-DC Buck-Boost converter which gives constant voltage of 15V to the battery ensuring optimum energy being extracted from the solar panel. The microcontroller controls the operation of the system according to the codes burned in it, which had been developed in MPLAB IDE.

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Chapter 1

Overview of Atomic Energy Research Establishment (AERE)

Atomic Energy Research Establishment (AERE) is a major research set-up of Bangladesh Atomic Energy Commission (BAEC) for peaceful application of nuclear energy in various fields of physical, biological and engineering sciences. AERE came into existence in 1975 by the acquisition of 259 acres of land at Ganakbari, Savar.

The AERE started its journey as a development project and its development at present stage has been achieved in phases. The first phase of development began with the commencement of research activities in 1981 at four of its research institutes and completed with the installation and commissioning of TRIGA MARK – II research reactor at the Institute of Nuclear Science and Technology in 1987. At present, ten research Institutes/Units are housed in AERE compound that are conducting research and development activities mainly by using peaceful application of nuclear energy and technology.

The primary aims and objectives set for AERE include fundamental and applied research in:

- Nuclear and radiation chemistry, neutron activation analysis, radiation processing of natural and synthetic polymers, stress analysis, isotope hydrology, isotope production, Reactor engineering and control, research reactor operation and maintenance, production of various radio- isotopes both for medical (diagnosis and treatment) purpose and for relevant applied researches, support of Reactor facilities for fundamental researches and training of reactor operators etc. And give academic support for students and fellows of different universities/ educational institutions.

1.1 Attached Institute (Institute of Electronics)

The peaceful applications of nuclear energy can only be ensured with the proper application of electronics. The basic purpose of this institute is to develop an infrastructure for electronics, both nuclear and non-nuclear on a national scale and at the same time to create a good impact in human resource development. IE operates as a collection of several divisions.

- GED - General Electronics Division
- MID - Medical Instrumentation Division
- NED - Nuclear Electronics Division
- PD - Production Division
- RMD - Repair and Maintenance Division
- Solar Cell Fabrication and Research Division
- Center of Excellence for VLSI Technology

The Solar Cell Fabrication and Research Division fabricates and studies the property of solar cell in association of the Center of Excellence for VLSI Technology. These along with other mentioned divisions researches on supporting device and circuit needed for the proper utilization of solar PV technology.

Chapter 2

Introduction

In this modern era of overwhelming progress of science and technology the increasing demand of power generation has become a substantial issue. Renewable energy sources have potential of playing vital role in electricity generation facilitating pollution free, less noise generating and low maintenance energy production. Solar panels have the mentioned advantages and can be widely used wherever sunlight is available. The output power from a solar panel is stored in rechargeable battery, from where it is supplied to regular household appliances. However, the output voltage as well as MPPT of the panel varies with different factors like sun irradiation, dust, temperature, etc. which result in less efficient battery charging system.

Therefore, in order to get maximum energy from solar panel we need a maximum power point tracker (MPPT) system. MPPT shifts the electrical operating point of the PV panel by coordinating the solar panel output and the input of the storage battery. The coordination is brought about by a microcontroller (PIC16F72), which monitors the PV panel and battery conditions and generate required control signals to deliver maximum power to the battery irrespective of the output voltage of solar panel.

Chapter 3

Basic Operation

Fig. 1 shows the basic block diagram of the MPPT system. To charge the storage battery at constant voltage, a DC-DC buck-boost converter is driven by the square pulse generated from the microcontroller. If output charging voltage to the battery is less than specified voltage, then duty cycle of the pulse is increased by the microcontroller to raise the output voltage and vice-versa.

The microcontroller senses output voltage of solar panel through path A. This sample is used to determine whether the MPPT system should deliver charging current to the battery or not. If the voltage generated by the solar panel is lower than the threshold then the MPPT circuit does not give any charging current or voltage for the battery. Feedback from the input of the battery received through feedback path B is used to customize the duty cycle of the pulse generated from the microcontroller such that the system get maximum possible power from PV panel to deliver the battery.

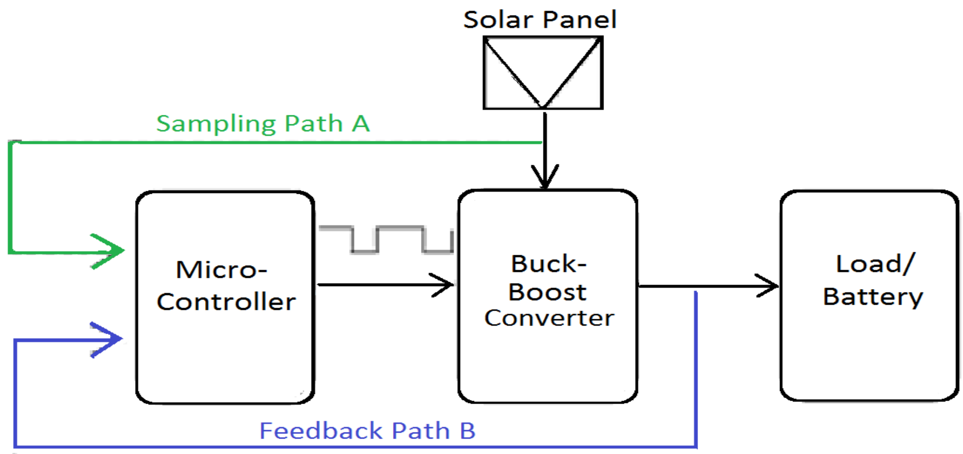

Fig. 1 Basic Block Diagram for proposed MPPT System

Our proposed system consists of the key units of sampling path, feedback path and blocks as shown in Fig. 1. The detailed schematic diagram for the proposed system is illustrated in Fig. 2. These are further discussed under the respective sub-headings.

3.1 Buck-Boost Converter

A power MOSFET and an inductor (as shown in Fig. 2) are the most significant parts of the MPPT circuit. Since the output from IO pins of the microcontroller cannot drive the MOSFETat high frequency, an n-p-n power transistor (BD437) is used in common emitter configuration to drive the input to the gate of MOSFET.

The output of Buck-Boost converter can produce output voltage either higher or lower than the input voltage. It raises the output voltage if the voltage from PV panel is lower than the specified charging voltage of the storage battery; and lowers the voltage if it is above the required level boosting the charging current. The output of Buck-Boost converter produces negative voltage as it works in inverting topology, i.e. if the input is positive the output will be negative and vice versa.

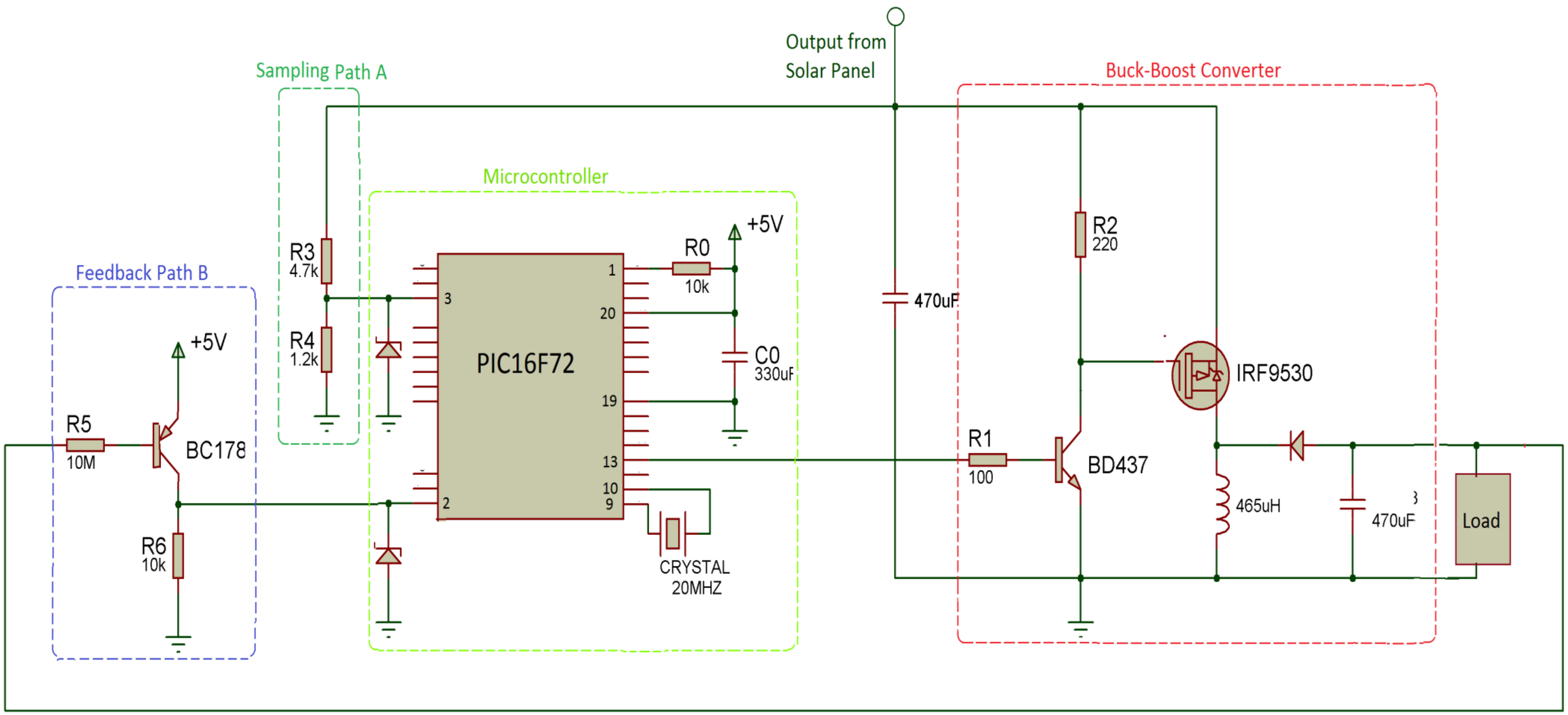

Fig. 2 Schematic Diagram for the proposed system.

The Buck-Boost converter is designed for continuous-current mode operation. The choice of switching frequency and inductance to give continuous current through the inductor is given by the following equation

$$L_{min} = (1 - D)^2 R/2f$$

Since the ferrite core inductor that was used worked best at 100kHz frequency, operating frequency (f) was set at 100kHz. Assuming the resistance (R) of the battery 22Ω, optimum charging current 800mA and voltage of 15V and minimum duty-cycle (D) to be 0.01 as allowed in this design; the minimum inductance needed was calculated to be 108uH. However, a higher inductance (465uH) was used to ensure that the circuit did not operate in discontinuous conduction mode. Other components used in this section are high power P-channel MOSFET (IRF9530), fast recovery switching diode and a 470uF capacitor.

3.2 Sampling Path A

Sampling Path A is a simple voltage divider which scales the voltage from solar panel to low level (below 5V) appropriate for using as an input to microcontroller. Since maximum output voltage from solar panel is 22V, using voltage divider the output is reduced to 20% to make sure that the maximum voltage never cross 5V, setting the resistors value R_3 and R_4 to 4.7kΩ and 1.2kΩ respectively, the microcontroller converts this sampled voltage to digital value and compares it with the reference of 1.62V (corresponding to 8V) to decide whether to keep the MPPT circuit on or off. If the sampled voltage from the solar panel is lower than the threshold (1.62V) then the MPPT circuit does not supply any charging current or voltage for the battery.

3.3 Feedback Path B

A simple voltage divider cannot be used in this feedback path as the scaling down of negative voltage would also produce negative voltage which is not suitable for using as an input to microcontroller. So, a low power p-n-p transistor (BC178) was used to invert and sample the voltage within the operating range of PIC microcontroller. The value of resistors R_5 and $R_6$was set at 10MΩ and 10kΩ respectively to make sure that the transistor was operating at linear region.

3.4 Microcontroller

The microcontroller is the key unit of the system which compares feedback values with the pre-set values to customize the duty-cycle of the pulse signal for producing the required output. The microcontroller function is governed by the codes burned in it. The flowchart in Fig. 3 shows the outline of the program which governs the operation of the microcontroller. The program has been written in assembly language using the MPLAB software and the detailed program is given in the appendices.

The sampled voltages from path A and B at the analog input pins are converted to digital value and compared with the reference values to determine the change needed in the duty-cycle of the pulse generated. These reference values and the boundary limits of duty-cycle are defined at the beginning of the program. A general register (INITIATION_CHECK) is also set at low logic at initiation, which is used for initiation check.

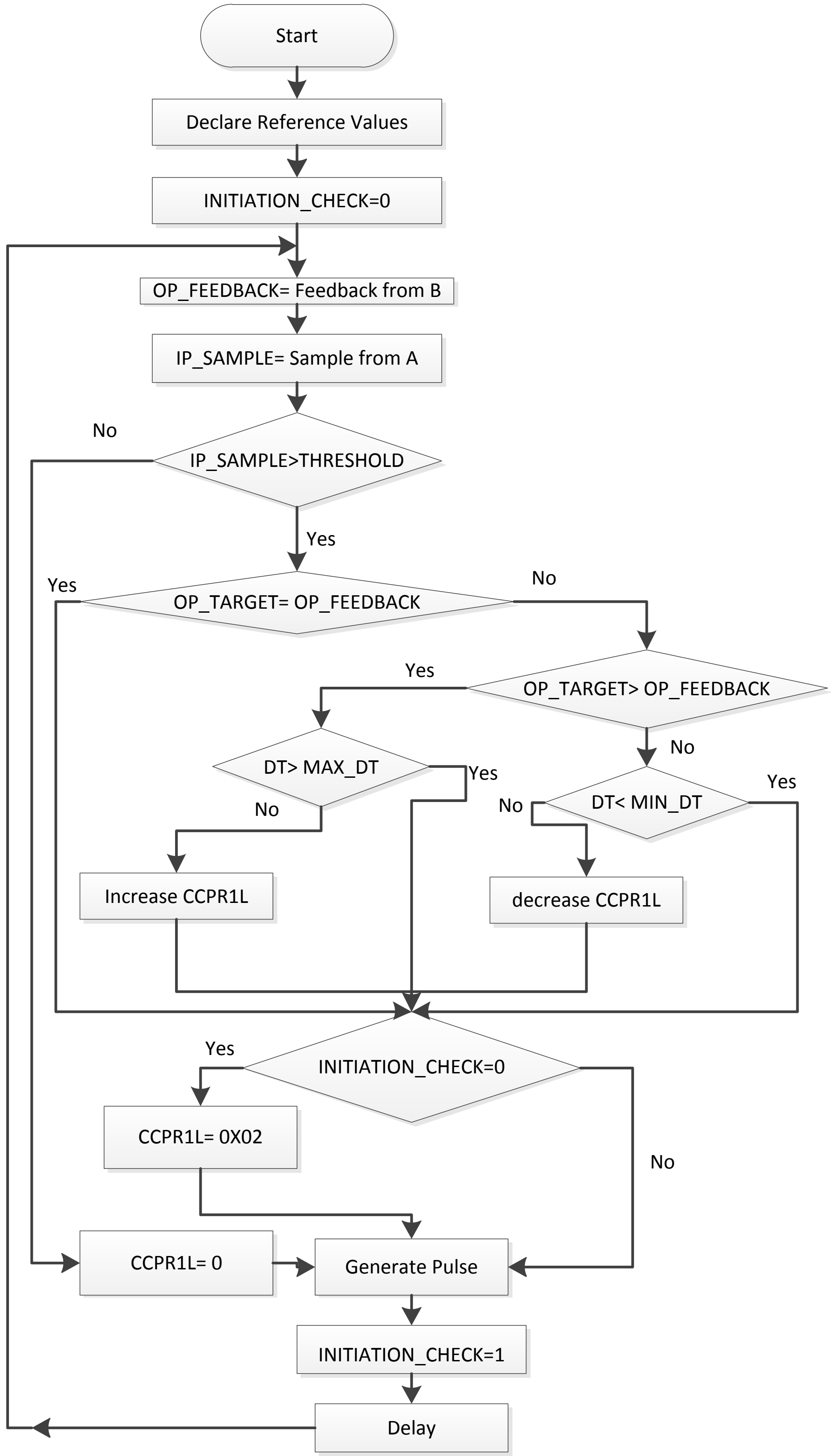

Fig. 3. Flowchart for the program developed

The conversion from analog to digital is done by the ADC module of the microcontroller and the digital result of the conversion is stored in the ADRES resister. At the beginning of each cycle digital value from feedback path B is stored in a customised register OP_FEEDBACK, followed by AD conversion from sampling path A. If this sample from A is above threshold level normal procedure for pulse generation is followed; otherwise the duty cycle is made zero (i.e. no pulse is generated).

In the normal procedure for pulse generation OP_FEEDBACK is compared with TARGET_OP, if the feedback value is less than the target, the value of CCPR1L resister which controls the duty-cycle is increased and it is decreased if feedback is more than the target. These changes in duty-cycle are made by keeping boundary conditions in check. Then an initiation check is made i.e. if INITIATION_CHECK=0 pulse with duty-cycle of 4% is generated; otherwise duty-cycle is generated according to the value of CCPR1L from prior steps. At the end of each cycle the LSB of INITIATION_CHECK is made high to signify operation in progress.

Chapter 4

Experimental Results and Discussion

The MPPT circuit was developed in the laboratory using a variable DC power supply instead of the solar panel and a dummy resistive load instead of the battery. The duty cycle was varied for various input voltages to produce a constant output of 15V. Fig. 4 shows the experimental result of the duty cycle variation against various input voltages of DC-DC converter.

Since MOSFET driver circuit consists of a power transistor, there is a delay between its input connected to microcontroller and output. Moreover, due to large gate capacitance of MOSFET, it cannot be switched off quickly. As a result, if the duty cycle of the pulse signal is more than a certain range, MOSFET never switched off completely and hence the system does not work properly. Therefore, pulse width can only be changed within a certain range.

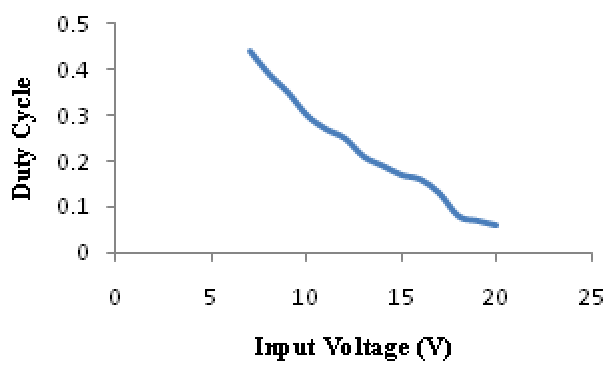

Fig.4 Relationship between input voltage and Duty cycle

The microcontroller adjusts the duty-cycle to produce 15V output. However, the Buck-Boost converter output cannot change as quickly as the change in duty-cycle in real time operation. So a suitable delay (0.63 second) is allowed at the end of each AD conversion to keep the microcontroller and DC-DC converter working in phase.

Chapter 5

Conclusions

The system developed consists of only one MOSFET reducing switching loss and component cost compared to other MPPT systems. Moreover, as the DC-DC converter was designed for high frequency; a small, low cost inductor can be used in the system, reducing the resistive loss in the inductor.

The developed system optimizes the power delivered to the battery even at low insolation level and increases the overall efficiency of solar power system extracting maximum power from the PV panel. With this effective extraction of energy solar PV can be used as a more reliable source of energy.

References

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Appendices

The following codes for the operation of microcontroller were developed in assembly language using the software MPLAB IDE, version 8.89.

```
#INCLUDE<P16F72.INC>

;--------------------NAME GENERAL REGISTERS------------------------------;

ADTARGET = 0X21                 ;Target output feedback

ADDIFF=0X23                     ;Difference between target output and current output

MAX_DT=0X24                     ; Maximum duty cycle

MIN_DT=0X22                     ; Minimum duty cycle

MIN_DTCHECK=0X27                ;Register to compare with MAX_DT

MAX_DTCHECK=0X26                ;Register to compare with MIN_DT

INITIATION_CHECK=0X40           ;Check for initiation

IP_DIFF=0x25                    ; Register to compare input from panel

MIN_IP=0x28                     ;Minimum input value

;----------------------------------------------------------------------;


;--------------------------- Set Initial values-------------------------------;

        MOVLW 0X20

        MOVWF STATUS                    ; Bank1 select


        CLRF TRISA

        COMF TRISA,1                    ; PORTA as input

        MOVLW 0X04

        MOVWF ADCON1        ; Voltage references VDD and Analog input pin select
```

```
        CLRF CCP1CON                    ; CCP Module is off
        CLRF TMR2                       ; Clear Timer2
        MOVLW 0X31 ;
        MOVWF PR2                       ;Set PWM frequency
        BCF STATUS,5                    ; Bank0 select
        MOVLW 0X3E
        MOVWF ADTARGET                  ; required output for 1.21V
        MOVLW 0X19
        MOVWF MAX_DT                    ; max dutycycle 50%
        BCF INITIATION_CHECK,0          ; Generate intial Duty cycle
        MOVLW 0X01
        MOVWF MIN_DT                    ; MIN duty cycle 2%
        MOVLW 0x7D
        MOVWF MIN_IP
;-------------------------------------------------------------------------;


;------------------------MAIN PROGRAM STARTS------------------------------;
;=================== ANALOG TO DIGITAL CONVERSION========================;
ADCONVERSION    MOVLW 0X41
                MOVWF ADCON0            ; configure AD conversion bits
                BSF ADCON0,2            ;Start AD conversion
                BACK
                BTFSC ADCON0,2          ; Check if AD conversion is complete
                GOTO BACK
```

```
;======================== PULSE GENERATION==============================;
                    BSF STATUS, RP0              ; Select Bank 0
                    CLRF INTCON                  ; Disable interrupts and clear T0IF
                    BSF STATUS, RP0              ;  Select Bank1
                    BCF TRISC, 2                 ;  Output pin select
                    CLRF PIE1                    ; Disable peripheral interrupts
                    BCF STATUS, RP0              ; Select Bank0
                    CLRF PIR1                    ; Clear peripheral interrupts Flags
                    MOVLW 0x0C
                    MOVWF CCP1CON            ; PWM mode, 2 LSbs of Duty cycle = 10
                    BSF T2CON, TMR2ON             ; Timer2 starts to increment
                    GOTO PWM_CONTROL

NO_PWM_CHANGE       MOVLW 0X02                   ;Intial value for Duty cycle
                    BTFSS INITIATION_CHECK,0     ; Check bit skip if set
                    MOVWF CCPR1L                 ;Set value for DT
                    BCF PIR1, TMR2IF             ;Clear Timer2
                    BSF INITIATION_CHECK,0
                    CALL DELAY                   ;Delay for 0.627 Sec
                    GOTO ADCONVERSION
;-----------------------MAIN PROGRAM ENDS-----------------------------;

PWM_CONTROL         GOTO INPUT_CHECK
                    BACK_FROM_IPCHECK
                    MOVF ADTARGET,0             ; Move value of ADTARGET in WREG
```

```
                MOVWF ADDIFF              ; Move ADTARGET TO ADDIFF
                MOVF ADRES,0              ; Move ADRES value to WREG
                SUBWF ADDIFF,1            ; Compare target and present value
                INCF ADDIFF
                DECFSZ ADDIFF ; Decrement & skip if target & present value are equal
                GOTO SIGN_CHECK
                GOTO NO_PWM_CHANGE

SIGN_CHECK      MOVF ADTARGET,0           ; Move ADTARGET to WREG
                MOVWF ADDIFF              ; Move WREG to ADDIFF
                MOVF ADRES,0              ; Move ADRES to WREG
                SUBWF ADDIFF,1            ;Compare target and present value
                BTFSC STATUS,0
                GOTO INC_PW
                GOTO DEC_PW

INC_PW          MOVF MAX_DT,0             ; Move maximum duty cycle to WREG
                MOVWF MAX_DTCHECK         ; Move WREG TO MAX_DTCHECK
                MOVF CCPR1L,0             ; Move CCPR1L to WREG
                SUBWF MAX_DTCHECK,1       ;Compare max DT with current DT
                BTFSS STATUS,0            ;Check carry
                GOTO NO_PWM_CHANGE
                INCF CCPR1L,1             ; Increase CCPR1L
                GOTO NO_PWM_CHANGE
```

```
DEC_PW          MOVF MIN_DT,0              ; Move minimum duty cycle to WREG
                MOVWF MIN_DTCHECK          ; Move WREG TO MIN_DTCHECK
                MOVF CCPR1L,0              ; Move CCPR1L to WREG
                SUBWF MIN_DTCHECK,1        ;Compare min DT with current DT
                BTFSC STATUS,0             ;Check carry
                GOTO NO_PWM_CHANGE
                DECF CCPR1L,1              ; Decrease CCPR1L
                GOTO NO_PWM_CHANGE

INPUT_CHECK     MOVLW 0X49
                MOVWF ADCON0               ; Configure AD conversion bits
                BSF ADCON0,2               ;Start AD conversion
                BACK1
                BTFSC ADCON0,2             ; Check if AD conversion is complete
                GOTO BACK1

                MOVF MIN_IP,0              ; Move MIN_IP to WREG
                MOVWF IP_DIFF              ; Move WREG to IP_DIFF
                MOVF ADRES,0               ; Move ADRES to WREG
                SUBWF IP_DIFF,1            ;Compare target and present value
                BTFSC STATUS,0
                GOTO NO_PULSE
                GOTO BACK_FROM_IPCHECK
```

```
NO_PULSE    BSF STATUS, RP0          ; Select Bank 0
            CLRF INTCON              ; Disable interrupts and clear T0IF
            BSF STATUS, RP0          ;  Select Bank1
            BCF TRISC, 2             ;  Output pin select
            CLRF PIE1                ; Disable peripheral interrupts
            BCF STATUS, RP0          ;  Select Bank0
            CLRF PIR1                ; Clear peripheral interrupts Flags
            MOVLW 0x0C
            MOVWF CCP1CON            ; PWM mode, 2 LSBs of Duty cycle = 10
            BSF T2CON, TMR2ON        ; Timer2 starts to increment
            MOVLW 0X00               ;Intial value for Duty cycle
            MOVWF CCPR1L             ;Set value for DT
            BCF PIR1, TMR2IF ;Clear Timer2
            CALL DELAY
            GOTO NO_PWM_CHANGE


DELAY       MOVLW     0X10
            MOVWF     0X30
    LOOP2   MOVLW     0XFF
            MOVWF     0X31
    LOOP1   MOVLW     0XFF
            MOVWF     0X32
    LOOP    DECFSZ    0X32
            GOTO LOOP
```

```
        DECFSZ    0X31
        GOTO LOOP1
        DECFSZ    0X30
        GOTO LOOP2
        RETURN
END
```