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Simulation and Digital Implementation of Fuzzy Logic Controller for Solar Maximum Power Tracker Application

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Abstract— **This paper presents the development of a maximum power point tracking algorithm using an using fuzzy logic for a solar power system.PIC16F877a microcontroller based system continuously monitored value of current and voltage from the battery. If the battery voltage less than the nominal voltage then the system moved to MPPT mode. Fuzzy logic MPPT is more effective compared to other conventional methods. In addition to the current and voltage measurement from the battery, controller also monitored value of current and voltage from the solar panel. Depends on the sensed value from the solar panel, fuzzy logic generated control signal, which control dc-dc converter output and battery charge can be done. If the battery voltage greater than the nominal voltage then the system moved to voltage control mode, in this mode controller worked either to control output of dc-dc converter or to cut off connection from converter to battery depending on the battery voltage. In addition to mode of operation, controller also control LCD and RF communication module. Simulation of the overall system was completed with the help of MATLAB / SIMULINK (version R2010a). Hardware implementation done for 21V voltage rating and 4A current rating. Control algorithm was implemented using low power low cost PIC16F877a microcontroller. Hardware implementation gives almost same result as simulation.**

Keywords— **Solar, Fuzzy Logic, Microcontroller, Communication module, battery, Embedded Systems.**

I. INTRODUCTION

Electrical energy from photovoltaic cell considered as a natural source energy that is more useful, since it is free, abundant, clean, and distributed over the Earth. Moreover, in spite of the phenomena of reflection and absorption of sunlight by the atmosphere, it is estimated that solar energy incident on the Earth's surface is on the order of ten thousand times greater than the worlds renewable energy.

Solar based application MPPT module is necessary unit for achieving maximum efficiency of solar panel. MPPT gives maximum power operation at a given time. Several algorithms are used for achieving maximum power point of a solar panel. Algorithms are differed based on the complexity, fastness and efficiency of implementation. Most common type of MPPT algorithms are Perturb and Observe (PO) Method, Incremental Conductance(IC) Method, Fuzzy logic based method .PO and IC methods is little complex, fuzzy method gives faster response and good tracking efficiency.

Output voltage regulation and charge control circuit is very important in battery charging application because batteries require specific charging methods. These charging methods are needed to improve battery life and performance. MPPT charge controller's gives better result than standard charge controller .MPPT charge controllers using microcontroller, is to compute the highest possible output at any given time.

DC- DC regulators important circuit in all MPPT applications. These circuit will increase or decrease panel voltage according to the MPPT algorithm. There are many DC-to-DC converter topologies used today, such as Buck, Boost, Buck/Boost, CUK etc. Depending on the application can select any of the type of converter. In this paper buck converters is used for controlling output voltage of system. Control signal for buck converter is generated from fuzzy logic. Fuzzy logic is implemented using low cost low power microcontroller, controller takes two input from the solar panel based on the monitored value fuzzy logic worked.

In this paper Section II includes a description of full system. Section III explains about hardware and software setups. Section IV describes about the Simulation results. Section V hardware results.

II. RELATED WORKS

There have been numerous implementations of MPPT charge controllers. These implementations differ from type of controller, type of controlling algorithms, type of MPPT, type of regulator used.

In 2013, P. Dinesh, B. Kowshik, Pankaj, Raghav. P, Ramesh, K Govindarajan studied and developed a flexible charge controller and power flow management system based on PO method. That system can easily meet load requirements by providing a charge controller for each set of PVpanel[1].In 2008 Roger Gules, Juliano De Pellegrin Pacheco, Hélio Leães Hey presented the analysis, design, and implementation of a parallel connected maximum power point tracking (MPPT) system for stand-alone photovoltaic power generation. The parallel connection of the MPPT system reduces the negative influence of power converter losses in the overall efficiency because only a part of the generated power is processed by the MPPT system. Much more controlling of the battery and monitoring modules are not included in this paper [13]. Amber Scheurer, Ersuel Ago,Juan Sebastian Hidalgo ,Steven Kobosko in 2011 developed IC(incremental conductance) based MPPT charge controller with monitoring systems. IC method little more complex than PO and fuzzy method [14]. An intelligent

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control method for the maximum power point tracking (MPPT) of a photovoltaic system under variable temperature and insolation conditions implemented M.S. Aït Cheikh*, C. Larbes†, G.F. Tchoketch Kebir and A. Zerguerras in 2007.That is fuzzy logic method is used to control a DC-DC converter. Results show that the fuzzy logic controller exhibits a much better behavior than other methods [15]. M. Estimably A. I. Alolah M. Y. Abdulghany in 2010 developed digital implementation of fuzzy logic controller for use with general purpose embedded processors.The proposed model is very flexible to be applied in various applications. The design is made to be scalable in terms of number of inputs and number of membership functions (MFs) in both inputs side and output side. The proposed model was written in C language due its popularity and efficiency in embedded and control applications [16]. In Patrick L Chapman, Trishan Esram published a paper based on comparison of different MPPT techniques, in that paper gives comparison of almost 19 techniques [5]. In 2013 Mohammad Saa Alam, M. F. Azeem, Senior Member,and Ali T. Alouani, Senior Member proposed a MPPT technique modified queen bee algorithm it is fuzzy logic based MPPT techniques with difference is that fine tuning also done from the fine it can track maximum power point as soon as possible [7].

III. Proposed System

System consists of dc-dc converter unit, microcontroller controller unit, battery system, communication system. Block diagram of proposed system shown in fig1.This system works based on two modes MPPT MODE and VOLTAGE CONTROL MODE. Controller will continuously check state of battery that is battery voltage if the voltage less than charging voltage of the battery then MPPT MODE will active and continuously charge battery else the battery voltage remain the charge voltage battery then system moves to VOLTAGE CONTROL MODE. In MPPT MODE microcontroller controller takes current and voltage from the solar panel and based on the fuzzy logic code Stored in controller generate PWM signal that will control DC-DC converter

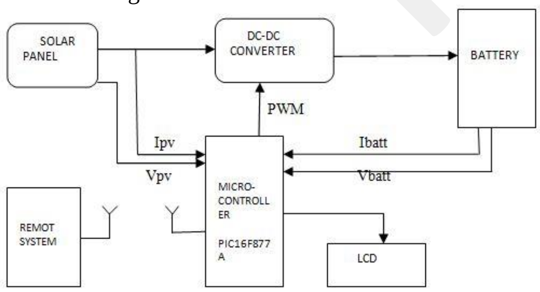

Fig1.Block diagram

In VOLTAGE CONTROL MODE microcontroller control battery voltage through PWM signal. In MPPT MODE maximum power point tracking is achieving by fuzzy logic. For fuzzy logic implementation three steps fuzzification .inference, Defuzzification requires. Microcontroller PIC16f877A is using for implementation of control strategy.

PV PANEL

The basic building blocks of solar panels are solar cells[1].A single solar cell gives an open circuit voltage of around 0.7V only and short circuit current of about 30mA/cm.[2].Because of this a single solar cell cannot be used for mass energy production. Therefore individual solar cells are connected in series and parallel so that required voltage and current can be produced. Combinations of solar cells are known as solar panel. Several solar panels connected in series to form a module. The simplified equivalent circuit of solar cell is shown in fig2.Which consists of a current source and a p-n junction diode. The PV cell output voltage is a function of the photocurrent that determines the load current .The photocurrent is a function of solar irradiation during the operation.

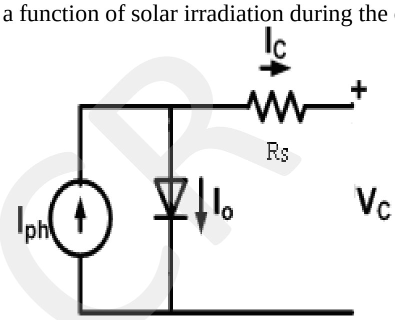

Fig 2: Equivalent circuit of a solar cell

$$V_c = \frac{AkT_{stc}}{e}\left(\frac{I_{ph}+I_o-I_c}{I_o}\right) - R_s \times I_c \dots\dots\dots\dots (1)$$

where

e : electron charge($1.602*10^{-19}$).
k : Boltzmann constant ($1.38*10^{-23}$J/K).
I_{ph} : Photocurrent.
I_o : reverse saturation current of diode.
R_s : series resistance of cell.
T_{stc} : reference cell operating temperature(25^0C).

V_c : open circuit voltage of a solar cell.

FUZZY CONTROLLER

Fuzzy logic uses fuzzy set theory is important method for controlling solar MPPT. Fuzzy controller application has been successful in many areas, particularly in the field of power electronics to regulate the dc-dc converters Pulse width modulated inverters, and lighting of PV powered system etc Advantages of FLCs over the conventional controllers are: 1) they do not need accurate mathematical model; 2) they can work with imprecise inputs; 3) they can handle nonlinearity; and 4) they are more robust than conventional nonlinear controllers. This allow as human reasoning process through computation (fuzzification) quantify imprecise information, make decision based on vague and in complete data, yet by applying a “Defuzzification” process, arrive at definite conclusions. The control inputs to the FLC are voltage error and change of errors, while the output is the change of control signal for the pulse width modulation (PWM) generator.
The FLC mainly consists of three blocks

- Fuzzification
- Inference
- Defuzzification

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In fuzzification stage each input is mapped into set of membership functions variety of shapes used for membership functions most common type is triangular shape. A triangle with one side lies on the X-axis. The process of converting Input/output variable to linguistic levels is termed as Fuzzification.

INFERENCE-A rule base must be applied to the obtained membership function according to Mamdani or sugeno. The 3D input output surface is also obtained by using MATLAB FL Inference

Defuzzification is the process of conversion of fuzzy quantity into crisp quantity. There are several methods available for Defuzzification. The most common one is centroid method,

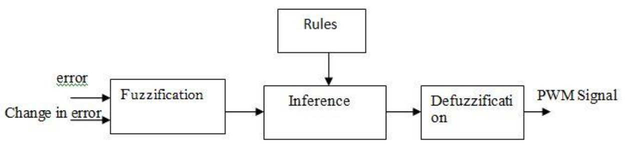

Fig3.Fuzzy output and input representation

Fig3.Shows representation of fuzzy input and output. Inputs are error and change in error and output is PWM signal. Output PWM signal can be obtained through following steps fuzzification, .inference and Defuzzification. Here input variable are represented by five triangular shaped membership functions similarly outputs. Triangular shape membership function has advantage over other membership like Gaussians, trapezoidal is can easy to handle. Following fig4, fig5,fig6, shows input and output membership functions. Inputs e(t) and de(t) are expressed in equation 2 and 3.From each five input membership functions can write 25 rules shown in fig7.

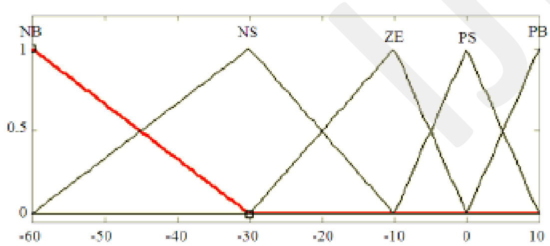

Fig4.input variable 'e'

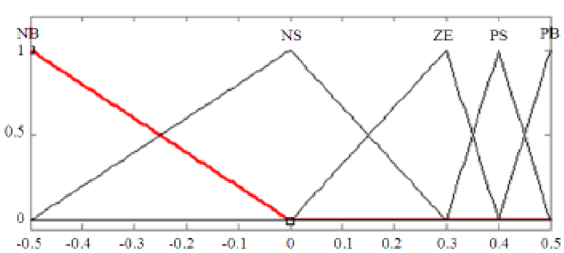

Fig5.input variable 'de'

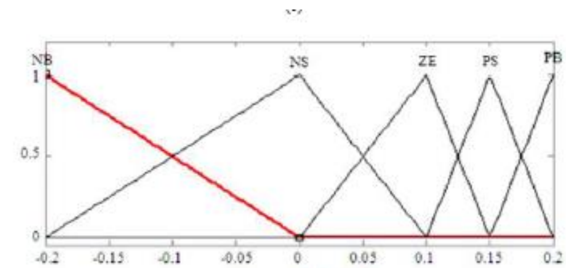

Fig6. Output variable 'D'

$$e(t) = \frac{\Delta P(t)}{\Delta V(t)} = \frac{P(t)-P(t-1)}{V(t)-V(t-1)}$$

$$\Delta e\ (t)=e(t)-e(t-1) \qquad (2)$$

DC-DC CONVERTER

There are different circuit configurations for switch mode converters. Most important classification among these configurations are step up (boost) and step down (buck) other converter topologies are combination of these two.

A buck converter or voltage regulator is also called a step down regulator since the output voltage is lower than the input voltage. In a simple example of a buck converter, a diode is connected in parallel with the input voltage source, a capacitor, and the load, which represents output voltage. A switch is connected between the input voltage source and the diode and an inductor is connected between the diode and the capacitor

Δe e	NB	NS	ZE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

Fig7.Rule base

A pulse width modulation controller controls the switch. In this project the microcontroller will serve as a pulse width modulation source

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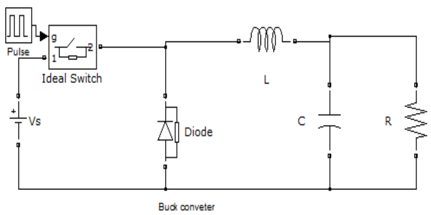

Fig8. buck converter

DESIGN

Buck converter design shown below

The required data's for designing a buck converter is as follows,

Switching frequency, f_S=20 kHz

Source voltage, V_S=21.1V-15V

Output voltage, V_o=14V

Average current, I=2A

Ripple current, ΔI=0.18A

Ripple Voltage, ΔV=0.73V

From the above specified values Duty ratio D in the range of 0.83,that is 83%.

The value of inductor is calculated the equation and the value is,

$$L = \left(\frac{V_o(1 - D)}{\Delta I \times f_S} \right)$$

L=676.00uH.

From the inductor value the corresponding capacitor value which has been calculated the equation,

$$C = \left(\frac{V_o(1 - D)}{8L\Delta V f_S^2} \right)$$

C=1.57uF

From the current rating and above calculated inductor value EE42 core 21 SWG 20 turns inductor is selected.

SIMULATION

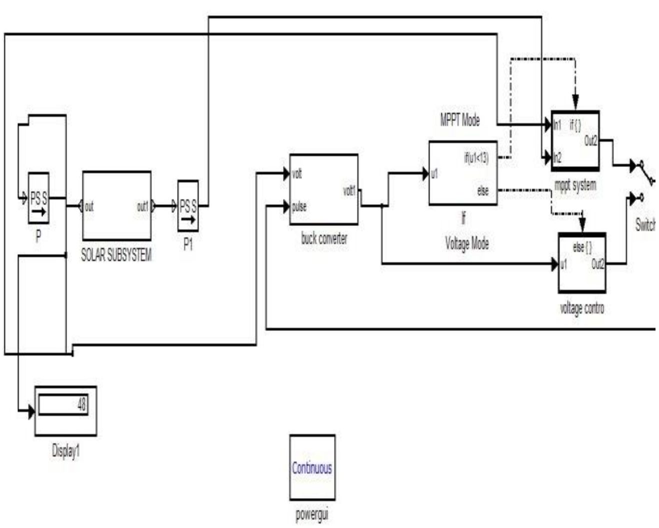

Fig8. Complete SIMULINK diagram

Above fig8.shows the simulation of entire system. System consist of solar subsystem, buck converter, MPPT mode and voltage control mode systems. Separate solar subsystem shown in fig9.in this subsystem consist of series arrangement of 40 solar cells shown in fig10, from that it can be achieved almost 24V voltage and 4A current.Fig11.shows the Simulink diagram of fuzzy system this system took two input voltage and current from the solar panel. After calculating error and change in error fuzzy system produced a defuzzified value, from that de-fuzzfied value control signal generated.Fig12 and Fig13 gives the IV characteristics and PV characteristics of solar panel from simulation.Fig14 shows pulse generation from fuzzy, using that pulse signal we can control the output of the buck converter. Buck converter output DC voltage shown in fig15.

IV. SOFTWARE IMPLEMENTATION

For fuzzy code implementation PIC 16F877A microcontroller is using.PIC is simple, low cost, low power, High-Performance RISC CPU architecture using this controller it is easy to generate fuzzy code.Fig16 shows the block diagram representation of mode selection.Fig17 shows DavC output of fuzzy code, that is according to error and change in error de-fuzzified value generated.

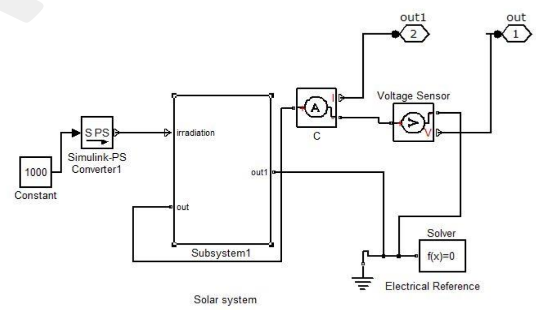

Fig9.solar subsystem

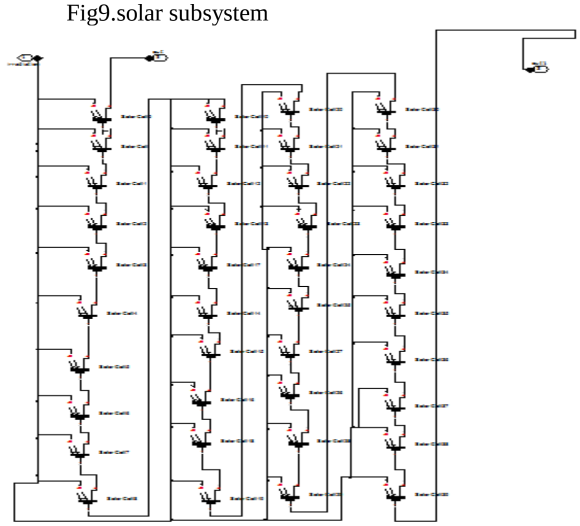

Fig 10.Series arrangement of solar cells

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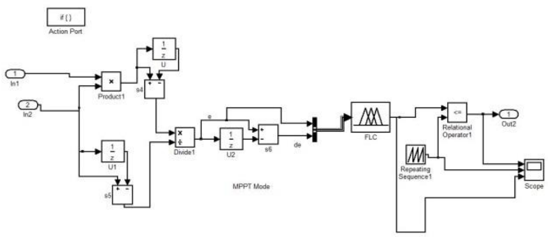

Fig11.Simulink diagram of fuzzy system

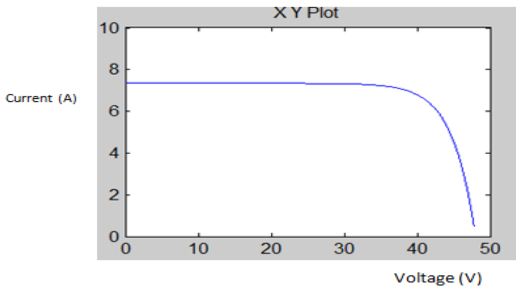

Fig12. vi characteristics of solar panel

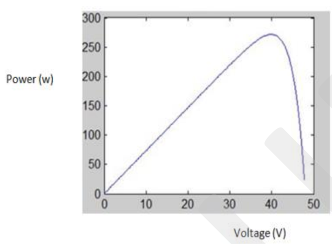

Fig13. PV characteristics of solar panel

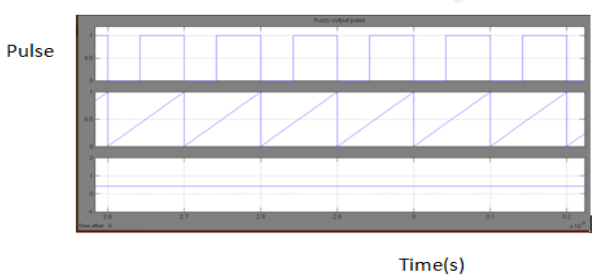

Fig14. Pulse generation from fuzzy

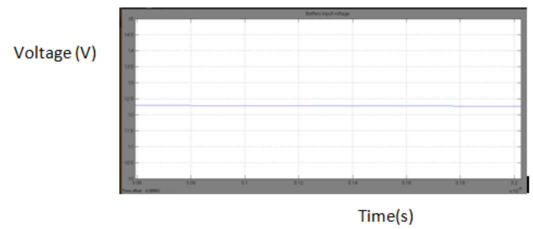

Fig15.Buck output 13V DC voltage

Steps for Fuzzy MPPT algorithm.
1. Input voltage and current from the solar panel.
2. Calculate value of current power.
3. Calculate change in power with voltage that is (error) first input to the fuzzy
4. Calculate change in error that is the difference from current value and previous.
5. Using two input error and change in error controller will finds error fuzzy and change in error fuzzy
6. Using rule base and centroid Defuzzification method defuzzified value generates.
7. Using defuzzified value can control duty ratio of output pulse.

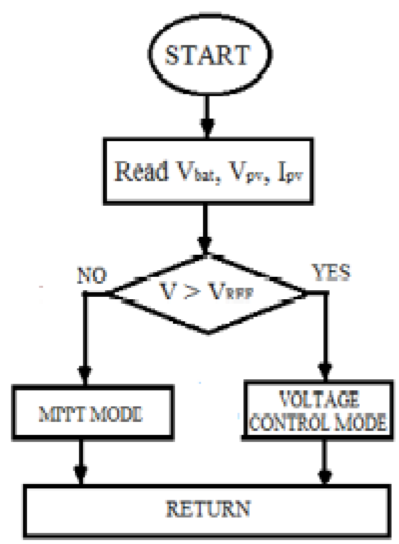

Fig16.Block diagram for selecting MODE

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HARDWARE IMPLEMENTATION AND RESULTS

Implemented hardware shown in following figures:

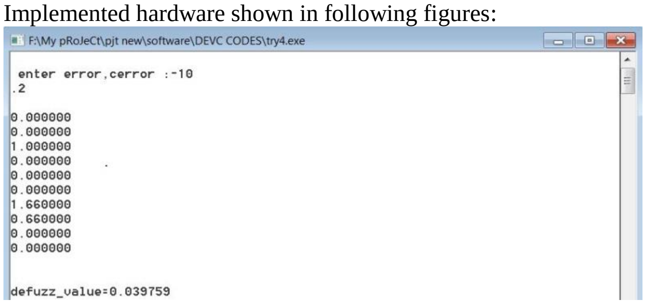

Fig 17.show fuzzy output in DavC

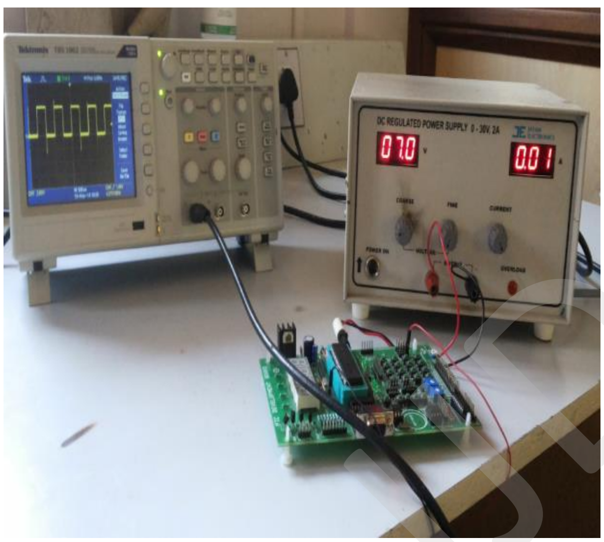

Fig18. Hardware setup and pulse generation

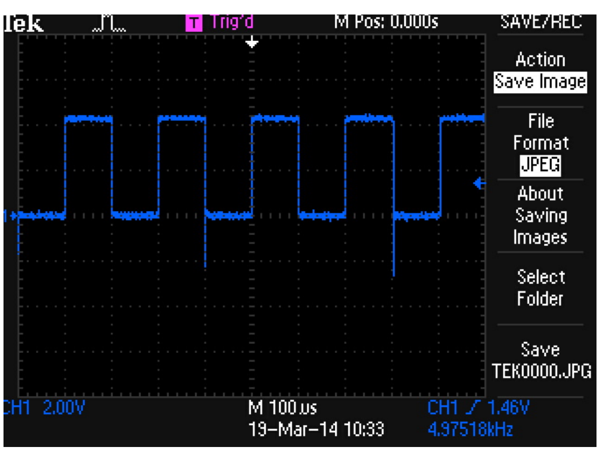

Fig19.Pulse output with 50% dutycycle

V. CONCLUSION AND FUTURE WORK

For solar maximum power point tracking MATLAB simulation, microcontroller fuzzy code implementation, buck converter hardware implementation and code implementation for voltage control mode are completed. Integration of fuzzy controller with buck converter shows designed output voltage. Hardware implementation gives almost same result as simulation.

Further work planning to do battery charging, hardware for battery control as well setup communication between controller and remote system for identifying battery details.

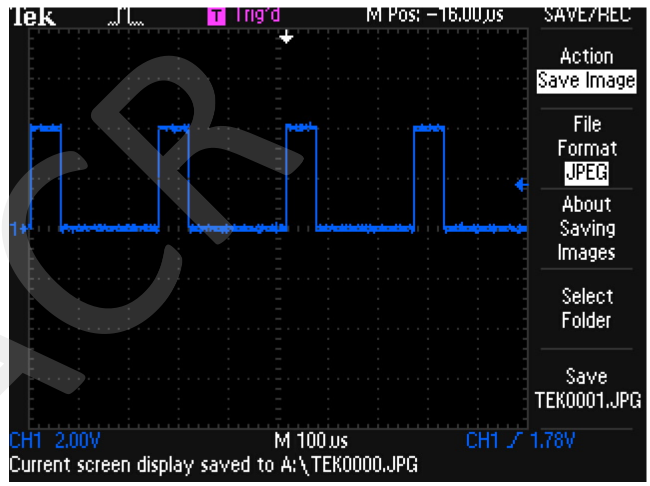

Fig 20.Pulse output with 83% duty ratio

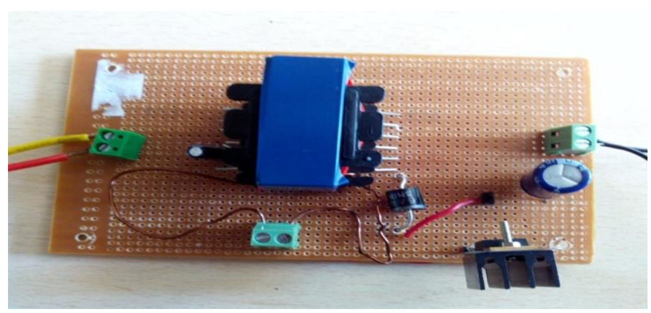

Fig 21 Implemented buck converter

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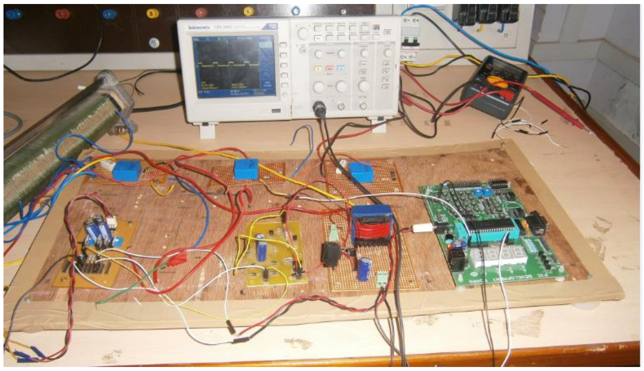

Fig 22 Hardware setup for entire system

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