Intelligent control for voltage regulation system via DC-DC Converter using Raspberry Pi 2 board

MOHAMED BOUTOUBA, ABDELGHNAI EL OUGLI, SABAH MIQOI, BELKASSEM TIDHAF
SEEER Laboratory, National School of Applied Sciences
Mohammed First University
BP 669, OUJDA 60000
MAROCCO
btba.med@gmail.com

Abstract: - In this paper, a real time simulation of a controlled voltage system for solar energy source (PV) is proposed, using Matlab Simulink as environment to develop control command algorithms as conventional PID, PI-Fuzzy logic controllers. Algorithms strategies are implemented on a low cost control board: The Raspberry Pi 2 Board in order to manage the operation of system and collecting simulation data, by controlling a DC-DC converter, a Boost converter in this paper, as an intermediary between the source and the load.
For verification purposes, several simulations were treated in order to verify the good behavior of the proposed system.

Key-Words: - Photovoltaic systems, DC DC power converters, Voltage control, PID controller, PI Fuzzy logic controller, Raspberry Pi2 Board.

1 Introduction

In many cases loads requires that the supply voltage must be as stable as possible to ensure their operation [1]. This is the main goal of the voltage regulation system also called controlled voltage system, a constant voltage in the terminals of the load even this is a change of load, change of voltage supply especially for non-regular sources, case of photovoltaic power supply which is dependent of several parameters like temperature, level of irradiation ...etc. [2].

The adaptation between source and loads is the main task of DC-DC converters. This kind of converter has many advantages like low power loss and best yield; as well its used in many industry applications [3-4].
In this paper, a real time simulation has proposed using two controls methods, a classical PID and PI-Fuzzy logic controller system, integrated on a Raspberry Pi 2 board whose purpose is to control the dc-dc converter to maintain the state of the voltage load stable, without human intervention, for a desired

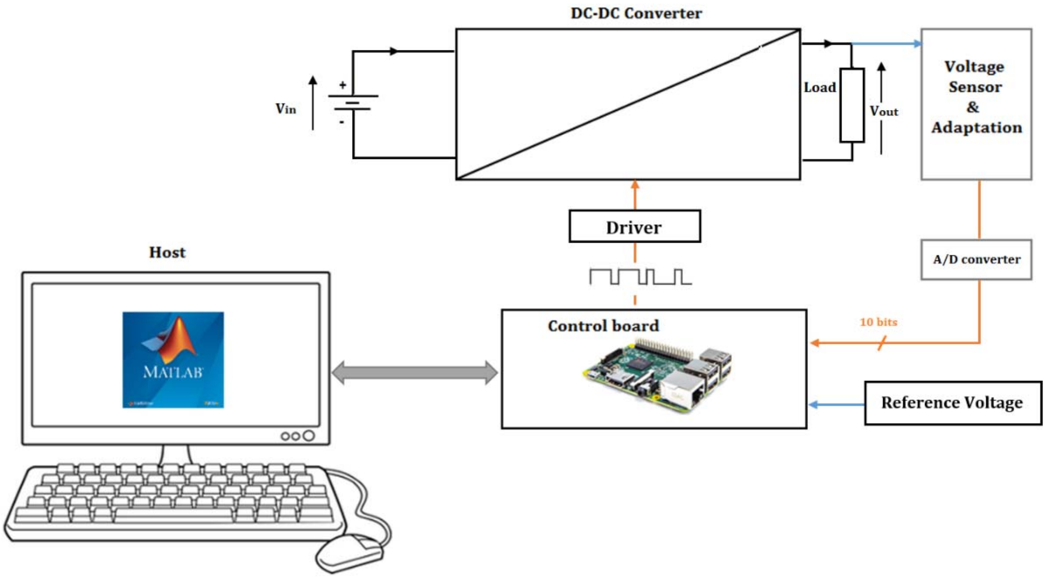

Fig.1 The proposed block diagram system.

given called the set point, per share on a manipulated variable.
Fig. 1 represents the general block diagram of the studied system, containing:

- A DC-DC converter.
- A voltage sensor and adaptation block.
- An analog/Digital converter.
- A controller board.
- The host (computer with Matlab Simulator).

2 Boost converter sizing

In this study, a boost converter has been chosen.
Fig. 2 represents the electronic circuit of a classical Boost converter [5].

The Operating principle of the converter is to control periodically the switch K with a PWM (Pulse Width Modulation) signal whose duty cycle could be variable: $\alpha = t_{ON}/T$.
Such: t_{ON} Is the time with which the switch is on, and T represents the period of the switch control signal.

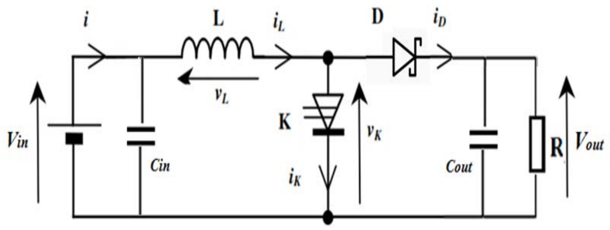

Fig.2 Topology of the Boost converter.

The choose of a schottky diode is due to it low forward voltage drop and fast switching action, in order to minimize loss power in the converter.
The equations describe the relationship between the input and output voltage as well as the dimensioning of the components are written in the form:

$$\begin{cases} V_{out} = \dfrac{V_{in}}{1-\alpha} \\ I_{out} = (1-\alpha).I_{in} \end{cases} \quad (1)$$

$$L \geq L_{\min} = \frac{V_{in}}{4 f \Delta i_L(\max)} \quad (2)$$

$$C_{out} \geq C_{\min} = \frac{V_{out(\max)}}{2Rf\Delta V_{out}} \quad (3)$$

The table 1 in the following figure shows the chosen values of the components of the power section after sizing.

Table 1. Sizing values:

Component	Value or Reference type
Entrance capacity	Cin =220µF
Inductor L	L= 4mH
Switch K	MOSFET IRFP450
Schottky Diode	STPS10M80C
Output capacity	Cout = 1000µF

3 Control system using raspberry pi 2 board

The control board used to realize the controller part of the system is a Raspberry Pi 2.
This kind of boards is chosen due to advantages of low cost, ease of use, direct communication with a multi development environment as Matlab Simulink.
A Raspberry Pi 2 model B board is used in this work, (Fig. 3) for the implementation of the Simulink controller block and data acquisition [6-9].
Raspberry is an open-source electronics platform based on easy-to-use hardware and software. The Raspberry Pi 2 model B is a microcontroller board based on the 32-bit quad-core ARM Cortex-A7 processor, with 256 KB shared L2 cache, supports all the latest ARM GNU/LINUX.
Due to its performance, the Raspberry card can integrate heavy programs easily, circulates and processes the information quickly by dint of the high operating frequency of 900MHz and the RAM size that reaches 1GB as shown in Table 2: that is why it can run real-time program without any problem.
In addition to the diversity of inputs, outputs it provides as well to the USB ports, HDMI, RJ45 ..., 40 GPIO pins for a digital communication.
All this in a miniature control board with a very reasonable price.

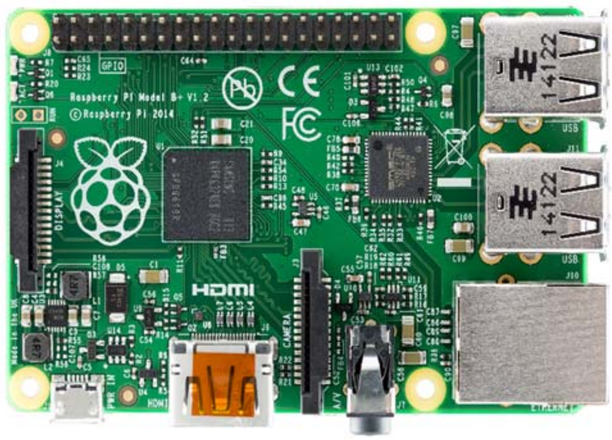

Fig.3 Raspberry Pi 2 B 32-bit microcontroller board

Table2: Characteristics map of Raspberry Pi 2.

CPU	Broadcom BCM2836 ARMv7
Clock frequency	900MHz
RAM	1GB
USB port	4
Ethernet port. RJ45	1
HDMI	1
GIPO Header	40 pin
GIPO voltage	5V
Power and current limits.	600mA (3.5W)

3.1 Output voltage adjustment

As shown in Fig. 1, a portion of the output signal V_{out} must be read via an electronic circuit and adapted to the board voltage limit.
Because of the unavailability of an analog input in the Raspberry board, it is indispensable to use an external A/D converter.
In this case, a 10 bits converter is used, with a resolution set to 4.88mV in a scale of [0-5V].

3.2 Overall system design

Fig. 4 shown the block diagram of the PID and PI-fuzzy logic controller modelized in Matlab/Simulink, and implemented on the Raspberry board.
The board receives in his GPIO pins the digital value of the output voltage, then it has to be converted to an analog value before treatment.
Thereafter, it calculates the error between the desired reference voltage and the measured one in order to generate the appropriate output response from the chosen control system technique.
Afterwards, a comparator block come to convert the generated value from the controller which is an analog signal to a PWM signal in order to control the K switch of the DC-DC converter.
The generated PWM signal is sent to the PWM output at Pin 23 of the Raspberry Board.
All data are collected and transmit to the host, which is used to acquire and plot the voltage signal in real time simulation.
The first control strategy is realized with a classical PID controller whose parameters are given in Table 4.
The second control command is based on a fuzzy logic technique, a relevant strategy offering outstanding performance and an interesting alternative approach such a raisonnement similar to that of man, and to manage complex systems intuitively. [10-12]
The fuzzy logic controller block is divided into three sub-blocks: Fuzzification, fuzzy inference engine with rules, and defuzzification.
The fuzzification is to transform the actual magnitudes linguistic variables for an inference processing.

$$\varepsilon = V_{ref} - V_{out}$$
$$\Delta\varepsilon = \varepsilon(t) - \varepsilon(t-1) \quad (4)$$

The output for the fuzzy logic bloc is the duty cycle change in order to achieve the desired duty cycle.
Seven memberships function are used for each input and output in fuzzification step, as shown in Fig. 5.
The choice of seven memberships gives to the system better representation and precision [13-14].
After that, the second step which is the fuzzy rule base comes which is a collection of rules that allows linking the fuzzy variables of input and output.
The description of the control is via these rules. It collects various combinations between the membership functions of the two inputs to generate

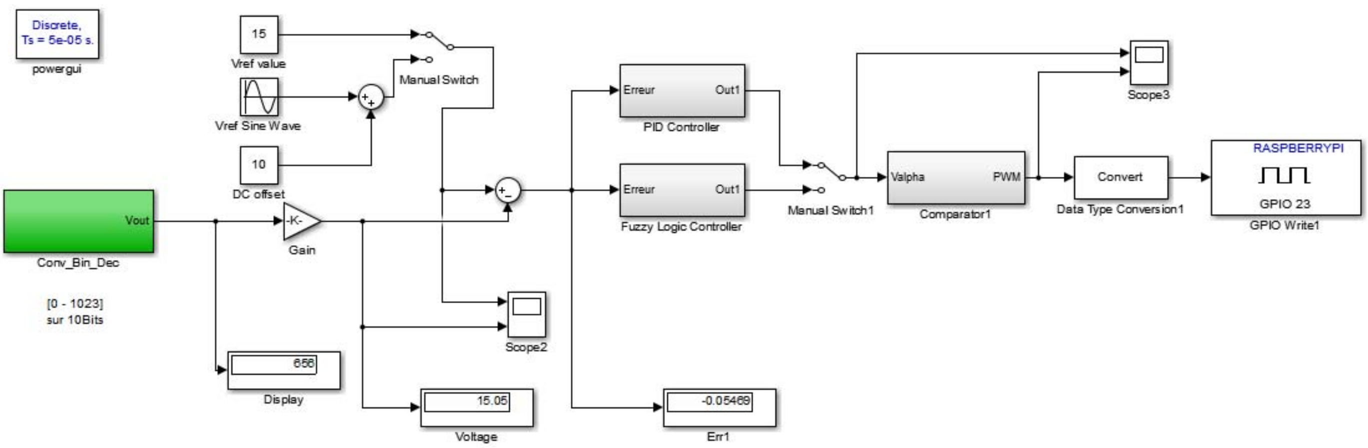

Fig.4 Block diagram of the implemented control system.

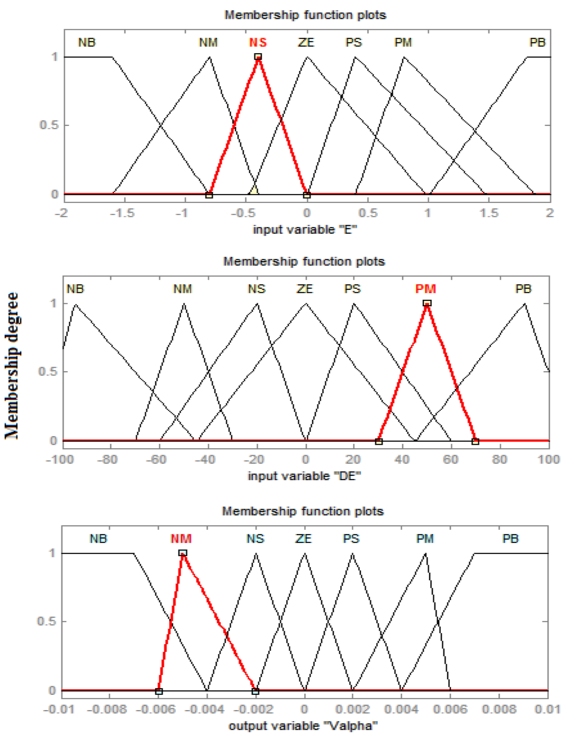

Fig. 5 Variables inputs/output linguistic

the appropriate duty cycle change value. These rules are represented in table 3.

After the inference step, the overall result is a fuzzy value. This result should be defuzzifed to obtain a final crisp or non-fuzzy output. Several defuzzification methods can be used such as center of gravity.

The values of the PID and PI-Fuzzy controller parameters are shown in table 4.

Table3. Fuzzy Rules.

DE	E						
	NB	*NM*	*NS*	*ZE*	*PS*	*PM*	*PB*
NB	*ZE*	*ZE*	*ZE*	*PS*	*PM*	*PB*	*PB*
NM	*NS*	*ZE*	*ZE*	*PS*	*PM*	*PB*	*PB*
NS	*NM*	*NS*	*NS*	*ZE*	*PS*	*PM*	*PB*
ZE	*NB*	*NM*	*NS*	*ZE*	*PS*	*PS*	*PB*
PS	*NB*	*NM*	*NS*	*NS*	*ZE*	*PS*	*PM*
PM	*NB*	*NB*	*NM*	*NS*	*PS*	*ZE*	*PM*
PB	*NB*	*NB*	*NB*	*NB*	*PS*	*ZE*	*ZE*

Table4. Controllers parameters

Control strategy	Parameters values
Conventional PID	K_p=0.09; K_I=0.01; K_d=0.001.
PI-Fuzzy logic	K_p =0.001; K_I =1/15

4 Achievement and system operation

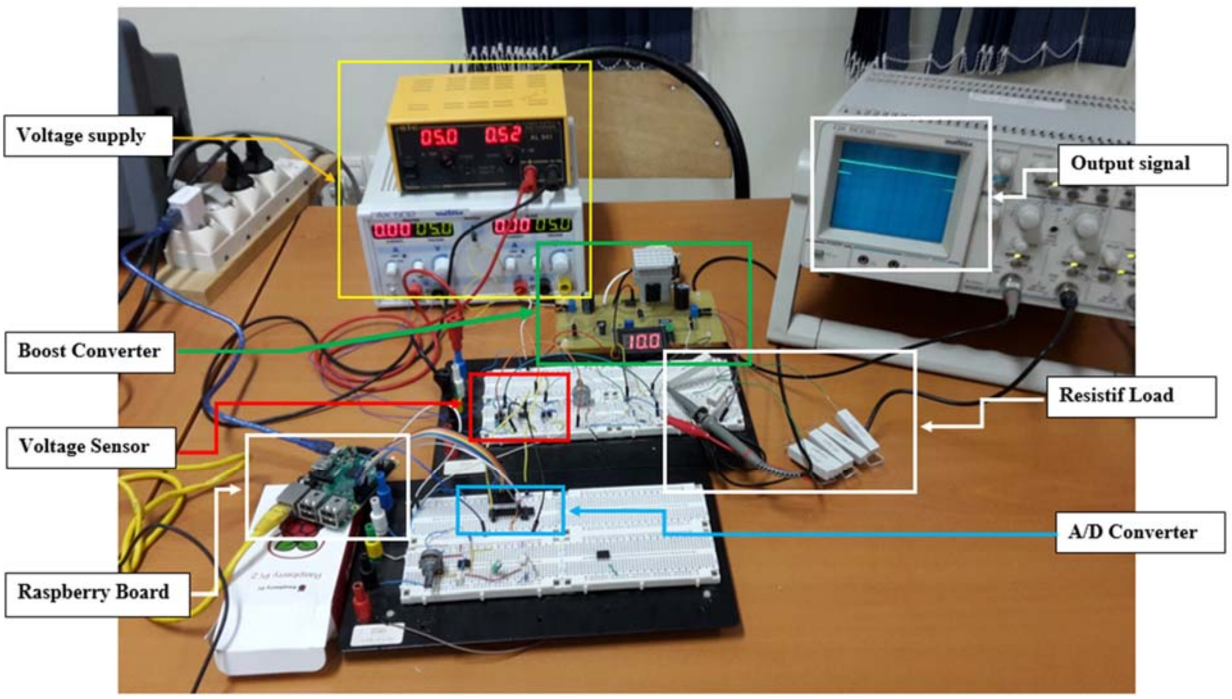

Fig.6 The experimental hardware setup.

Fig. 6 shows the assembly of different parts of the studied system.

Several real time simulations were made in order to verify the effectiveness of the proposed system, in case of input voltage, load or even in the reference voltage change using both control strategies: conventional PID and PI-Fuzzy logic [15-16].

As fixed parameters, the supply voltage input is set to $V_{in} = 5V$. The load is chosen as resistive having as initial value $R_{ch} = 245\Omega$.

4.1. Voltage input change pursuit case

In this case the voltage supply is considered as variable, it has as initial value 5V and it drops to 7V. After launching the real time simulation, the waveform in Fig. 7. shows the evolution of the output signal $\mathbf{V_{out}}$ according to the set point value using conventional PID and Fuzzy-PI control system.
As result it possible to say that the system was able to correct the voltage change then the Output voltage re-pursuit the voltage reference, with a better pursuit for the fuzzy logic controller.

4.2. Load change case

On the other hand, for a system control voltage, the output voltage should be constant even the load change.
To verify the effectiveness of the proposed system, the load value has been changed from 220Ω to 600Ω. As we can see in Fig. 8. the proposed system, for both control strategies, corrects this disturbance and the output voltage returns to the reference voltage, 12V in this case.

4.3. Variable Set point pursuit

Fig. 9. bellow shows the evolution of the output signal for the two control system.

In Fig. 9/a. the set point is chosen as a sinusoidal wave to verify the pursuit in a permanent set point change**.**

Note that the output voltage is pursuing exactly the reference voltage even in case of a change of the latter during operation of the circuit.

Comparing the output signal evolution for each control system, it is possible to say that the PI-Fuzzy logic control has better pursuit, unlike the conventional PID controller

where present a slight voltage drop, when the reference voltage changes fast as shown in Fig. 9/b.

According to Fig. 9/b, the proposed system, with both control methods, has good behavior in set point change cases and low response time to re-pursuit the set point, which does not exceed few milliseconds.

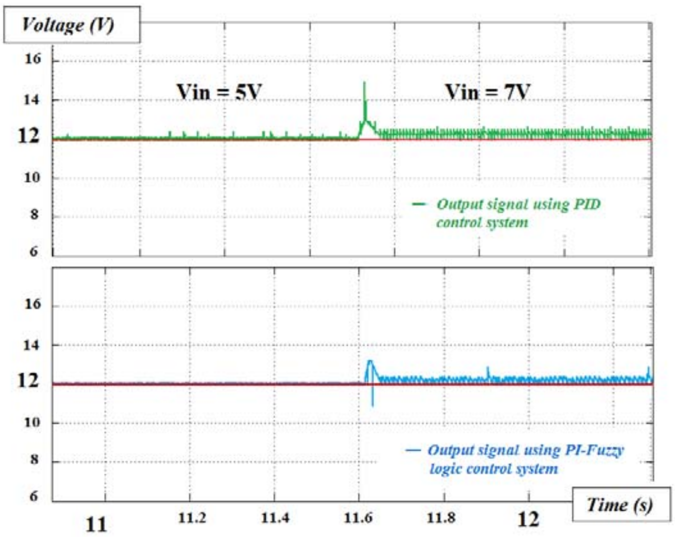

Fig.7 Simulation with irregular supply voltage.

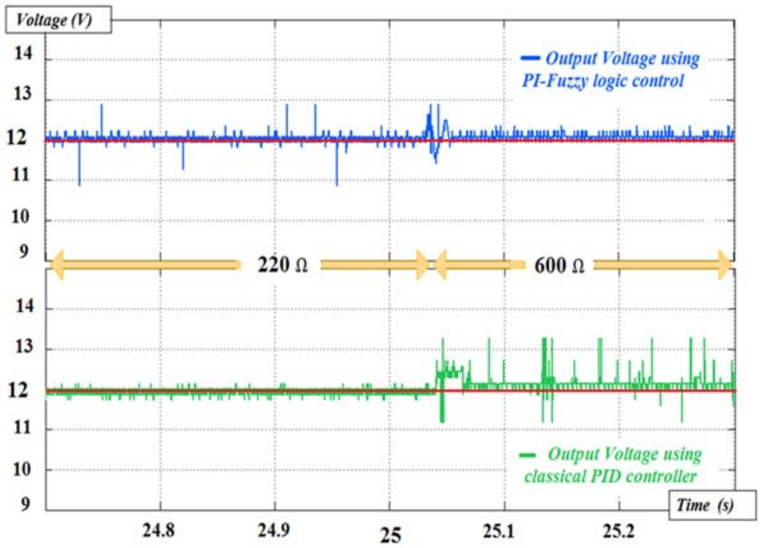

Fig.8 Output voltage for load change case.

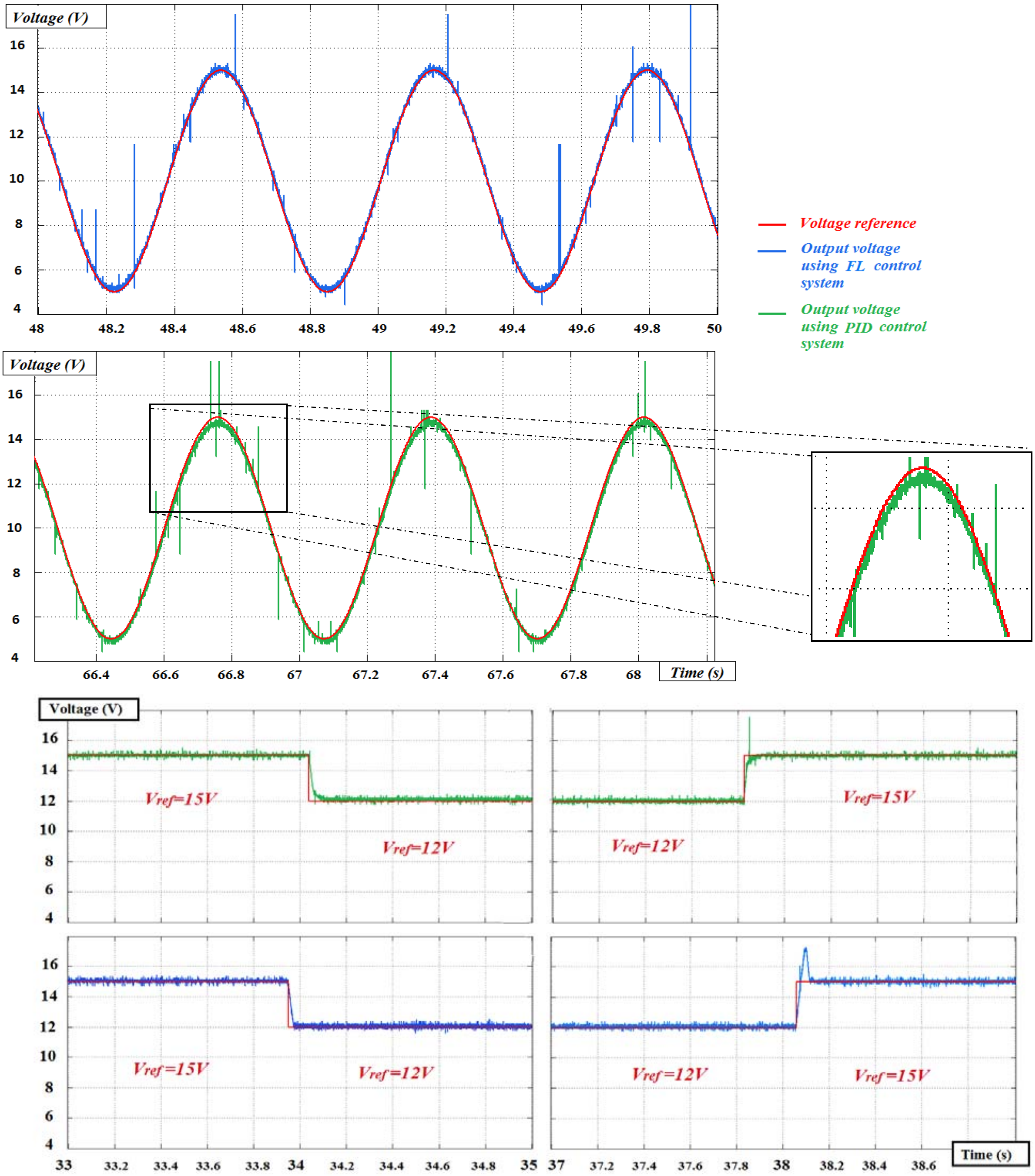

Fig.9 (a) Set point change simulation case.
(b) Output response time.

4.4. Precision

Among the most important points in a contoller voltage system that must be taken into consideration is the precision.

The system is functional only when the output stabilizes at round the set point value with the lowest ripple.

From the Fig. 10, it is possible to say that the system present good precision using both control strategies.

The output voltage ripple for an 15V voltage reference in this case is $e_r = 0.15V$.

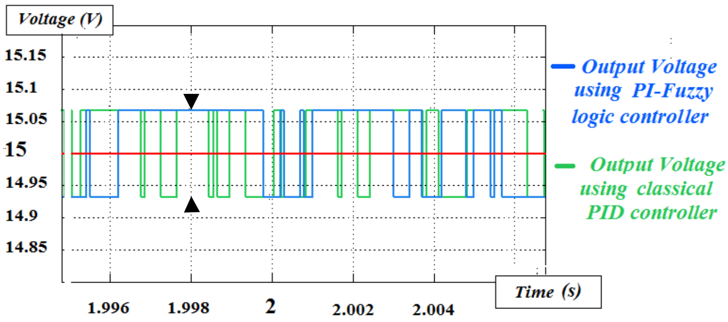

Fig.10 Output voltage ripple.

As well the ripple rate, given by the following formula, can be deduced as low:

$$\eta_{\%} = {e_r}/{Vréf} = {0.15}/{15} = 0.01 = 1\% \qquad (5)$$

5 Conclusion

In this paper, a real time simulation of a voltage controller system via a DC-DC converter was proposed, powered by an irregular source voltage case of photovoltaic panel.

The controller system was based on the use of a low cost control board: The Raspberry Pi 2, where the proposed controller system was implemented under Matlab Simulink environment.

To illustrate the work, Serval real time simulations were treated, guarantees the functionality of the proposed system.

The obtained results confirm the good behavior of the realized system especially in terms of tracking and precision.

Due to the high performances of the controlled board, the work could also be extended to others control system techniques and algorithms.

References:

[1] M. Bhunia and R. Gupta, "Voltage regulation of stand-alone photovoltaic system using boost SEPIC converter with battery storage system," Engineering and Systems (SCES), 2013 Students Conference on, Allahabad, pp. 1-6, 2013

[2] M. N. Islam, M. Z. Rahman and S. M. Mominuzzaman, "The effect of irradiation on different parameters of monocrystalline photovoltaic solar cell," Developments in Renewable Energy Technology (ICDRET), 2014 3rd International Conference on the, Dhaka, Bangladesh, pp. 1-6, 2014.

[3] H. R. Jayetileke, W. R. de Mei and H. U. W. Ratnayake, "Real-time fuzzy logic speed tracking controller for a DC motor using Arduino Due". 7th International Conference on Information and Automation for Sustainability, Colombo, 1-6. 2014.

[4] Akarsh Sinha, M. Pavithra, K.R. Sutharshan, Sarat Kumar Sahoo, School of Electrical Engineering, VIT University, Vellore, Tamil Nadu, India. "Arduino based pulse width modulated output voltage control of a dc-dc boost converter using Proportional". Integral and Derivative control strategy, pp. 104-108. Sept 2013.

[5] S. Ang. A. Oliva, "Power-switching converters", second edition, CRC press, Taylor & Francis Group, 2005.

[6] M. T. Ullah and M. H. Uddin. *Design,* "hardware implementation and performance analysis of conventional SEPIC converter for photovoltaic system applications". 4th International Conference on the Development in the in Renewable Energy Technology (ICDRET), Dhaka, pp. 1-4, 2016.

[7] D. Radianto, G. M. Dousoky and M. Shoyama. "Design and implementation of fast PWM boost converter based on low cost microcontroller for photovoltaic systems". Industrial Electronics Society, IECON 2015 - 41st Annual Conference of the IEEE, Yokohama, pp. 2324-2328,2015.

[8] Balakishan, Chouki, and Sandeep Babu. "Development of a Microcontroller Based PV Emulator With Current Controlled DC/DC Buck Converter". International Journal of Renewable Energy Research (IJRER) 4.4 2014; 1049-1055.

[9] Massimiliano Luna, Marcello Pucci*, Gianpaolo Vitale and Giuseppe Abbate. "FPGA-based Random PWM Control of a Buck DC/DC Converter". J. Electrical Systems. 2010; 6-3: 323-338.

[10] Rosli bin Abu Bakar, Craig Froome, Ilhami Fajri, Refdinal Nazir. 2nd International Conference on Sustainable Energy Engineering and Application 2014 Sustainable Energy for Green Mobility. "Fuzzy Logic-Based Voltage Controlling Mini Solar Electric Power Plant as an Electrical Energy Reserve for Notebook" , Energy Procedia, 68: pp. 97-106, 2015.

[11] P. Mattavelli, L. Rossetto, G. Spiazzi and P. Tenti. "General-purpose fuzzy controller for DC-DC converters". in IEEE Transactions on Power Electronics. Jan 1997; 12(1): 79-86,

[12] Sahin, M.E.; Dept. of Phys., Univ. of Rize, Rize, Turkey; Okumus, H.I. "Fuzzy logic controlled buck-boost DC-DC converter for solar energy battery system", Innovations in Intelligent Systems and Applications (INISTA), International Symposium on. 15-18 June 2011 IEEE, pp. 394 – 397, 2011.

[13] Boutouba M., El Ougli A., Miqoi S., & Tidhaf B. "Asymmetric Fuzzy Logic Controlled DC-DC Converter for Solar Energy system". Renewable Energy and Sustainable Development 2.1 2016; 52-59.

[14] B. Bendib, F. Krim, H. Belmili, M.F. Almi, S. Boulouma, "Advanced Fuzzy MPPT Controller for a Stand-alone PV System", Energy Procedia, Vol. 50, pp. 383-392, 2014. ISSN 1876-6102.

[15] Chandani Sharma, Anamika Jain. Department of Electronics and Communication Engineering, Graphic Era University, Dehradun, India. "Performance Comparison of PID and Fuzzy Controllers in Distributed MPPT". International Journal of Power Electronics and Drive System (IJPEDS).; Vol 6(3): pp. 625-635, Sept 2015.

[16] R. Samuel Rajesh Babu. Departement of Electronics and Instrumentation Engineering, Sathyabama University, Chennai-600 119, India. "A Comparative Analysis of Integrated Boost Flyback Converter using PID and Fuzzy Controller". International Journal of Power Electronics and Drive System (IJPEDS).; Vol 5(4), pp. 486-501, April 2015.