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A near accurate solar PV emulator using dSPACE controller for real-time control

S Mohammed Azharuddin[a]*, Vysakh M[a], Harshal Vilas Thakur[a], Nishant B[a], T Sudhakar Babu[a], Muralidhar K[a], Don Paul[a], Basil Jacob[a], Karthik Balasubramanian[a], N Rajasekar[a]

[a]*School of Engineering, VIT University, Vellore, Tamilnadu, 632014, India*

Abstract

This paper proposes a near accurate Solar PV Emulator using DC-DC Buck converter. A mathematical model serving as a reference is built using MATLAB/SIMULINK for emulating Solar PV characteristics. In the proposed Emulator by changing model parameter values it is possible to emulate any Solar PV characteristics. Hardware implementation is done using dSPACE ds1104 controller board and a closed loop control system is built using PI controller. The proposed Emulator has the following characteristics: 1. Fast and accurate Solar PV Emulator with easy interfacing and real-time control 2. Features to extend the system for other Solar PV panels 3. DC-DC Buck converter having high bandwidth. 4. Faster dynamic response and highly stable output with lower response time. 5. Lower output voltage and current ripple. Experimentations are done under different operating conditions and the results obtained are compared with the existing Emulators.

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Keywords: Solar Emulator; dSPACE ds1104; Mathematical Modeling.

1. Introduction

The Global Energy demand is increasing day by day due to Technological development, Industrial growth and rising population density. At the same time, environmental Constraints such as Global Warming, formation of Green Energy pacts; urge for a need to find an alternate source of energy. Solar Energy has caught attention worldwide as it is abundant, pollution free, noiseless and practically inexhaustible. A Solar Photovoltaic (PV) Cell is a device which converts the incident sunlight into electricity; these Cells are

* Corresponding author. Tel.: +91-9986-412-786
E-mail address: mohd786azhar@yahoo.co.in.

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grouped to form a Solar module, which when further grouped are referred as PV array. However, Solar Cell characteristics are non-linear and depend on environmental factors such as irradiation and temperature [1]. Power converters are usually employed to connect the PV array to the load in order to match the load characteristics [2]. However, these power converters before practical implementation are to be tested for all kinds of faults, grid disturbances and reliability. In practical scenario it is risky to introduce real Solar PV for testing; due to high associated cost and space requirements [3].

Therefore, a cost effective solution for experimentation without the need of a real Solar PV, atleast in first stage of experimentation is carried out with the help of Solar Emulator. Many researchers have worked on Solar Emulators [4-11]. In [4-5] authors have proposed a Solar Simulator by amplifying the photo-current and voltage of a photo-diode. With the help of digital controller power converters were employed and I-V characteristics were obtained by controlling switching state of the converter [7]. A lookup table approach for determination of Solar PV characteristics was proposed in [8]. In [9-11] a DC-DC Buck converter based Simulator with built in mathematical model has been proposed. Such approach would make the design process simpler. In result, the predicted characteristics depend on the accuracy of the mathematical model used. In general, the previously proposed Emulator has the following shortcomings: 1. No provision for real time control. 2. Larger voltage and current ripple 3. Lookup table approach for emulating I-V characteristics. 4. No easy hardware interfacing, thereby limiting its applications

Considering the above facts, in this paper, a Solar Emulator using dSPACE ds1104 controller board is proposed for emulating the Solar PV characteristics. The proposed configuration has a provision for real-time control in irradiation, temperature and parameter tuning. As a result, a Solar Emulator with better dynamics can be built for different irradiation. Further, ds1104 controller provides the flexibility of ease in hardware interfacing to MATLAB/SIMULINK.

2. System Description

Overview of the proposed system with sensor circuitry and ds1104 controller connected to the DC-DC Buck converter is shown in Fig. 1. In this work, a DC-DC Buck converter is employed for emulating Solar PV characteristics. A Solar PV model is built in MATLAB/SIMULINK with datasheet values taken from Shell S36 Solar PV panel. Further, this model serves as a reference to obtain any operating point on the Solar PV Characteristic. Solar Emulator functions as follows: 1. Irradiation, temperature corresponding to the expected I-V characteristics of Solar PV is set on the control desk of ds1104 controller 2. DC-DC Buck converter is operated with an initial duty cycle and the sensed current, voltage feedback signals are sent as input to the mathematical model. 3. The model generates a voltage reference signal corresponding to the set irradiation, temperature, load connected and this reference value is compared with sensed feedback signal to generate an error voltage 4. Finally, the error value is fed to the PI controller and the required gate pulse is sent out through the PWM port of dSPACE. One of the major advantage of the proposed system is its flexibility to derive any operating point on the I-V Plane of a Solar PV panel.

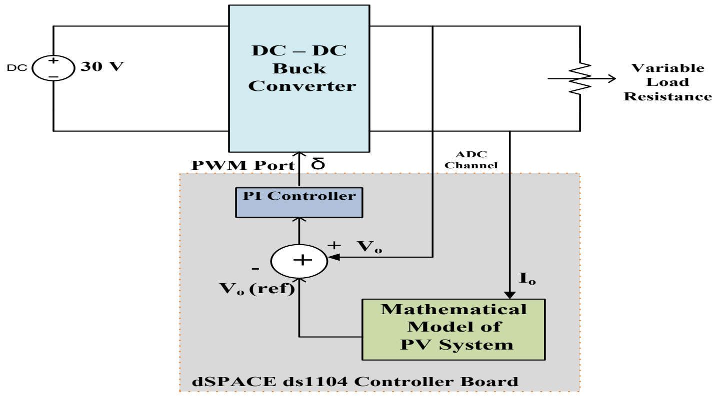


Fig. 1 Overview of the proposed system

2.1 Modelling of Solar PV characteristics

Most important part of the Solar PV Emulator is its mathematical modelling. There were many approaches followed in the literature for modelling the I-V characteristics of the Solar PV. However, single diode model [12] is popular because of its simplicity and easy implementation. The authors, in their previous work, have applied Bacterial Foraging Algorithm (BFA) for Solar PV parameter extraction [13]. It is important to mention that, while developing the mathematical model for the Solar PV system, one must consider the effect of R_s and R_p; since R_s decides the slope of constant voltage region and R_p decides the slope of constant current region. The solar cell parameters are extracted via BFA procedure and subsequently substituted in to the MATLAB model. The computed I-V curves of Shell S36 Solar PV panel for different irradiation and temperature along with datasheet values are plotted in Fig. 2. To evaluate the accuracy of the simulated characteristics, comparison is made between the datasheet values and simulated values. From the comparison, it is evident that there exists a good agreement between the predicted I-V characteristics and actual one.

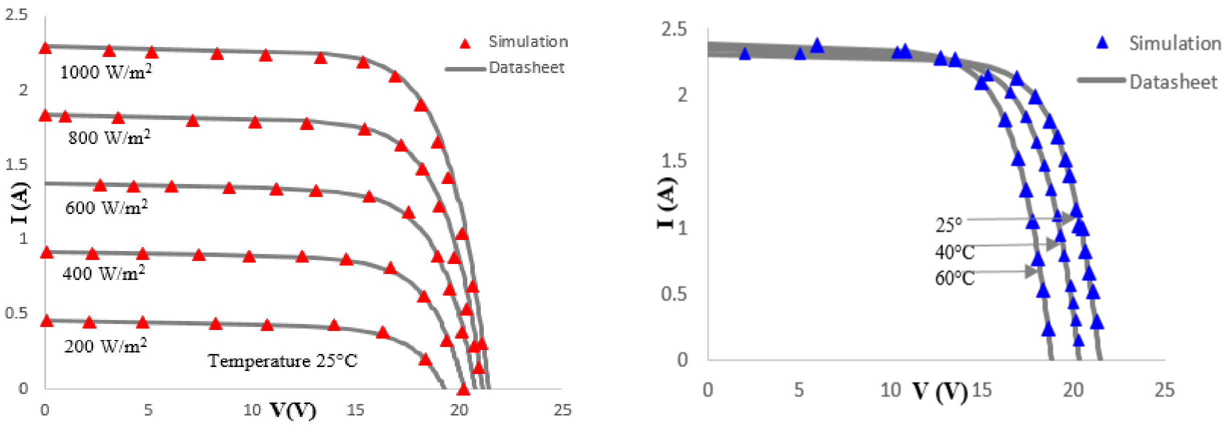


Fig.2. Comparison of simulated I-V curves with datasheet values of Shell S36 Solar PV Panel under different irradiation and temperature

2.2 DC-DC Buck Converter

DC-DC Buck converter is used for in current work due to the preference of step down operation. A DC-DC Buck converter is designed to operate under continuous current mode operation. Since, the designed converter must possess the ability to replicate the characteristics of Solar PV panel selected. The values of L and C are designed with the help of the following equations.

$$\partial = \frac{V_o}{V_{in}} = \frac{I_{in}}{I_o} \tag{1}$$

$$L_{\min} = \frac{(1-D)R}{2f} \tag{2}$$

$$C_{\min} = \frac{(1-D)}{8L(\Delta V_o / V_o)f^2} \tag{3}$$

Further, equation (1) helps to know the range of duty cycle; various factors like voltage ripple, current ripple and also safety factor are taken into consideration in the design process. The DC-DC Buck converter is operated at switching frequency of 10 kHz with V_{in}=30V, voltage and current ripple are set to 1% and <2% respectively. The computed values of L and C are 1.5mH and 100 μF respectively. Switching frequency is selected by following procedure given in [14] to reduce interaction between the Solar Emulator and the interfacing converter.

2.3 dSPACE ds1104 controller

The dSPACE ds1104 controller board is an ideal hardware prototyping development system especially for cost-sensitive, rapid control prototyping and dedicated for high speed multivariable digital controllers and real-time simulations in various fields. These controllers make use of the real time interfacing toolbox available in MATLAB to interface the SIMULINK model with the real hardware models. The ds1104 controller demonstrates high-end control development from block diagram design to online controller optimization. Solar Emulators using dSPACE real time hardware is very simple since the developed Simulink model can be extended for any Solar PV and also possible to observe the effects of parameter changes on system's behaviour via online tuning. This feature is important in case of Solar Emulator where behaviour of system performance with change in environmental conditions is to be studied. The block diagram of ds1104 controller board along with two processors is as shown in Fig. 3.

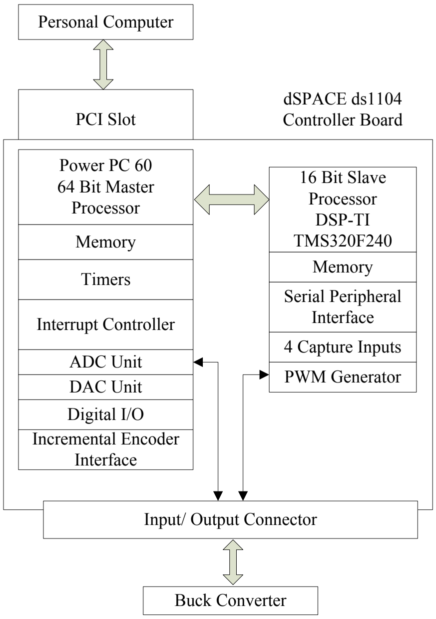


Fig. 3 Block Diagram of ds1104 Processor Board

The ds1104 board consists of 8 ADCs and 8 DACs for interfacing. A dSPACE connector panel ports provides easy access to all input and output signals of the ds1104 board [15]. Using animation mode, user can monitor and control the hardware model. The captured view of the control desk corresponding to voltage, current parameter and controller constants are shown in Fig. 4. The control desk has provisions to not only display the measured value but also provide an interface to change the values instantaneously. The control knob provided for K_p , K_i irradiation and temperature can be varied in real time; simplifying the task of creating change in atmospheric condition. Every single event can be monitored and corrected spontaneously. However, this feature is absent in the earlier proposed Solar Emulators [4, 5, 6, 10 and 11].

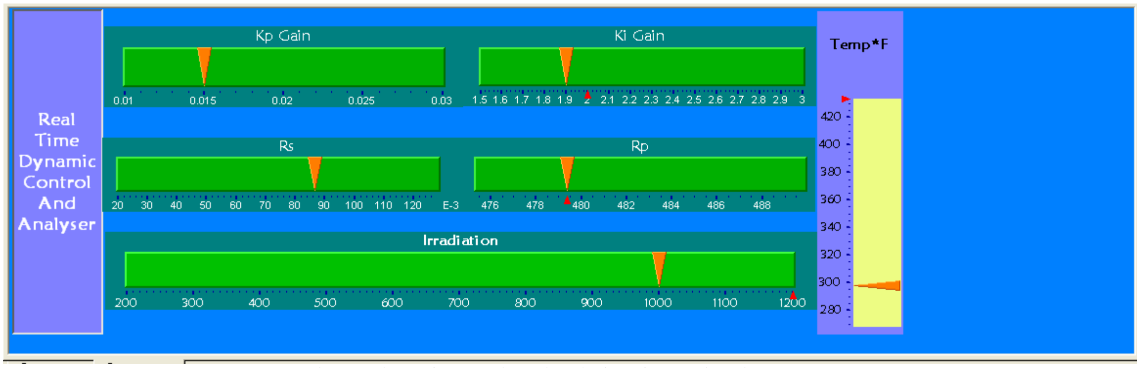


Fig. 4. View of Control Desk Window for Tuning the Parameters

2.4 Closed Loop Control

The converter transfer function $G_p(s)$ and the compensator transfer function $G_c(s)$ are as shown in equation (4) and (5). The closed loop control strategy for the DC-DC Buck converter is shown in Fig. 5. A

PI controller acting as compensator is implemented for output voltage regulation of the DC-DC Buck converter, minimization of steady state error and good stability under sudden load changes. The PI controller is so designed to have the following characteristics: (i) High gain at low frequencies to minimize the steady-state error at the output of the converter (ii) Selected crossover frequency which is high enough to provide good dynamic regulation and low enough to avoid sub-harmonic instability and noise amplification, typically $f_{c\max} < \frac{1}{5} f_s$ (iii) Large phase margin p_m to yield well damped transient load responses to ensure good stability for sudden changes in the load and the output voltage. The designed values of k_p and k_i are 0.01 and 3 respectively. The designed controller provides better stability, zero steady state error and faster response.

$$G_p(s) = \frac{V_{dc}}{s^2 LC + s\left(\frac{L}{R} + Cr_L\right) + 1} \tag{4}$$

$$G_c(s) = \frac{K_p s + K_i}{s} \tag{5}$$

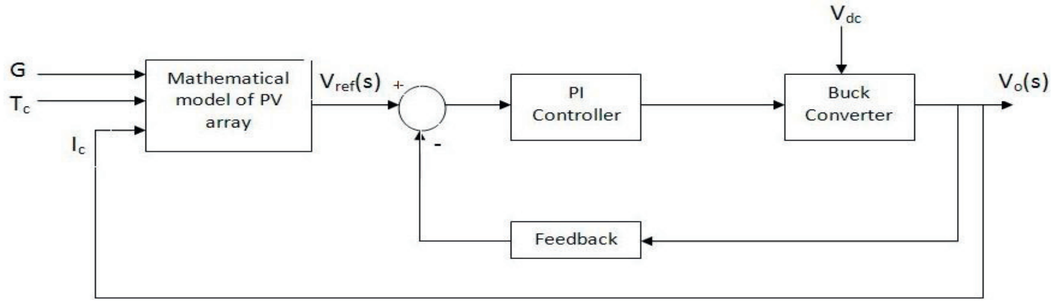


Fig. 5 Feedback Control system of DC-DC Buck converter

3. Hardware Test setup

The complete experimental setup for implementation of proposed Solar PV Emulator is shown in Fig. 6. A DC-DC Buck converter was built using IRFP450 MOSFET with previously designed **L** and **C** values. Sensors LA55P and LV25P were used for voltage and current measurement. Sensed current and voltage feedback signals are subsequently fed to the inbuilt ADC ports of the ds1104 controller. Through these ports the measured values are interfaced to built-in MATLAB mathematical model. The generated PWM pulses are sent out using PWM port 7. The gate pulses are isolated from the power circuit with the help of TLP250 opto-coupler before being applied at the gate terminal of the MOSFET. The major advantage of this hardware setup is its flexibility to implement any required changes, online parameter tuning and easy implementation.

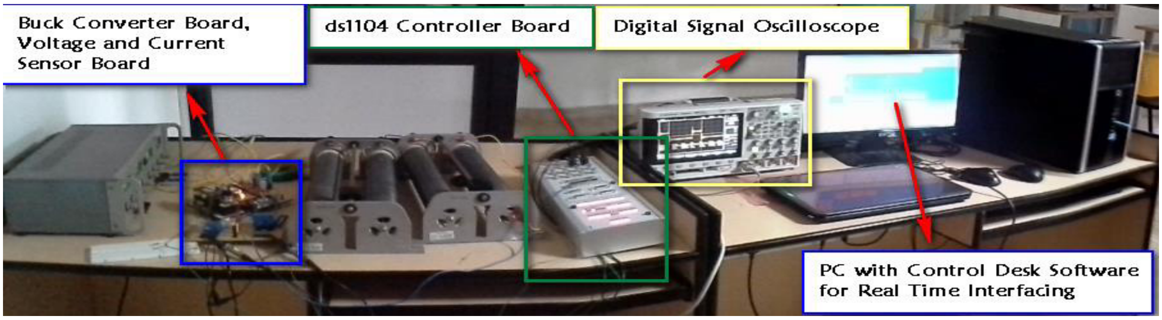


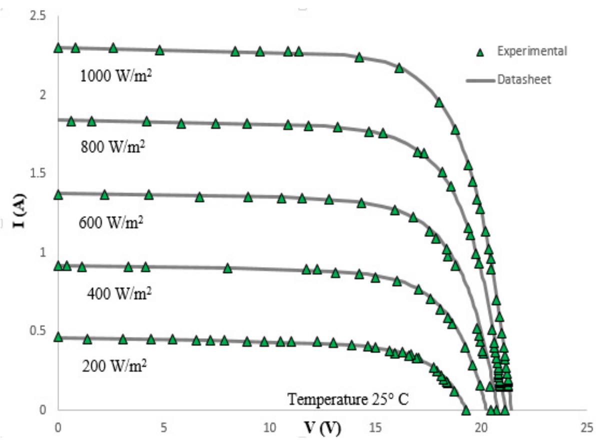
Fig. 6 Hardware setup

4. Results and Discussion

To estimate the effectiveness & flexibility of the proposed system, experiments are carried out on real time control. The steady state I-V characteristics with changes in load condition for difference of irradiation and temperature is presented in Fig. 7 a. Absolute error between the experimental results and datasheet values are computed and it is shown in Fig. 7 b. The absolute error value is found to be very small and it is less than 0.08. Comparison with Emulator proposed in [9], the proposed Emulator exhibits negligible voltage and current ripple at all operating points.

4.1 Performance analysis with step change in load, irradiation and temperature

To estimate the transient response of the system; step change in load, irradiation, and temperature are applied and its effect on system performance is analysed. Change in weather conditions changes with irradiation temperature and it is quite common. The Solar Emulator must have the capacity to mimic this behaviour without any delay. Hence to verify this condition change in irradiation is introduced from 1000 W/m^2 to 200 W/m^2 and vice versa. The dynamic change in output voltage corresponding to above step change is shown in Fig. 8. From the result one can observe that, when sudden change in irradiation occurs, the Emulator responds immediately by changing its output. Further the response time of the Emulator under various irradiation change is found to be less than 15 μs compared to 50 – 150 μs in [11].



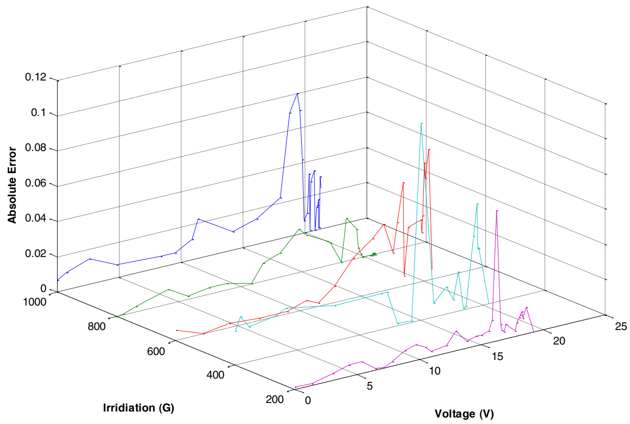


Fig. 7 a. Comparison of Experimental values with datasheet values at different irradiation
Fig. 7 b. Absolute error graph for different irradiation

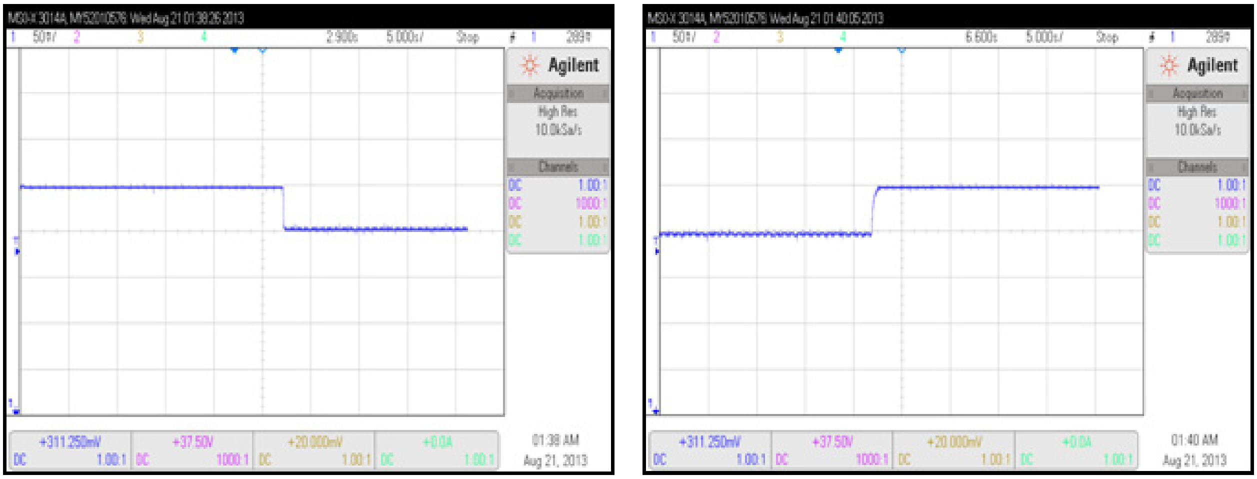


Fig. 8 a. and b. Dynamic response for sudden change in irradiation from 1000 to 200W/m^2 and 200 to 1000 W/m^2 with constant temperature respectively.

5. Conclusion

In this paper a Solar PV Emulator using DC-DC Buck converter is presented and it is controlled via dSPACE ds1104 controller. The Emulator allows to characterize any Solar PV panel by changing the Solar Cell parameters. Based on experimentation and in comparison with current Emulators, the proposed Emulator has the following characteristics: 1. Fast and accurate Solar PV Emulator with easy interfacing and simple real-time control 2. Features to extend the system for other Solar PV Panels 3.Faster dynamic response and highly stable output with response time less than 15 μs .

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