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Global Scientific JOURNALS

Design and Analysis of Fractional Order Control System (FOCS) for Buck Converter PV Emultor

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KeyWords

ABSTRACT

To generate electric power, the community uses atmospheric friendly ways to lessen the threat to the environment. Almost everyone knows that energy acquired from sun light (solar energy) and creative research's demand is on its peak. Whereas live experiments on PV solar systems cost too much Containing industrial, environmental changes, and also need vast area. Hence based on particular simulations for practical verification and analysis, an alternative PV system is needed. This patent will recognize a "PV Emulator system grounded on buck converter". Main purpose is to imitate the characteristics curves (Power—Voltage, Current—Voltage) of the solar system. A strong control of buck convertor to get load variations to achieve the same exact curves will be needed. This patent includes designing and analysis of Fractional Order Proportional Integral Control (FOPI). Results will proved that Compared to old techniques, performance of FOPI are more precise. PV Emulator and FOPI will be executed in Design using MATLAB.

The first page should be used only for Title/ Keyword/ Abstract section. The main paper will start from second page.

1. INTRODUCTION

In present days, many renewable sources of different power and nature levels are being created by PE (Power Electronics) engineers. These engineers perform their job in research-based facilities using different and expensive energy sources and data collecting tools. Which makes it difficult to calibrate and also need a huge amount of space. Slight difference in the environmental condition also have a huge impact on energy collection using these tools, which makes it very difficult to collect readings at stable conditions [1]. Therefore, interest is developed for programmable energy sources which can also copy the characteristics of the energy collecting tools with the aim that PE (Power Electronics) engineers can go around producing and evaluating the performance of their context [2]. Avoiding the use of multifunctional nature of tools, Power source is one of them which can do the job but are not manageable and their emulator's readings are of inhibited range. Main goal of this paper is to create a programmable energy sources which can fulfill this important and basic need [3, 4]. To deal with this we have proposed two steps. In the first step we combine the load independent power provisions by arranging the main control circuit. Who's aim is to get the resultant impedance approaches to '0' for voltage source, Therefore the effect of the output impedance is negligible. The above statements set the energy sources for the 2nd step which contains the working of consumer adjustable computer-generated Z_{out} or the affirmation of sustainable energy which is imitated. Power supplies which were produced in previous two Steps will frame the main unit over high power frame work which will be analyzed by relating different module either in parallel or series combinations [5, 6].

Our target in this research work is to understand the conversion technique of power with the help of converters which will be useful to support all these requirements of modern technology. This project will differentiate the control processes that will improve the vigorous response of power convertors to a level where theatomicity of the close load is achieved, which will set the resultant impedance of output voltage source or the involvement of the power supplies for the input current source and set them up for the succeeding steps.

We will propose a control plan to present the adjustable Zout or free admission of load to sources of energy which were developed in the previous step. Main aim is to associate the sources of energy which establish the qualities of Zout. To look at the problems in power applications, this patent will move from, the suggested investigation, from examining of single drive contexts to contexts with diverse interlocked convertors. The major complications challenging the researchers are the problem of reliability and delivery of the energy got from the planning of few power supplies, also to guard the wanted impedance or the stimulation of resultant and improvement of convertor from simple to several alteration schemes. Answers to these problems will be measured and shaped in this patent.Some of the objectives of the proposed work are given as follows

- To investigate the procedures for manufacturing close impeccable power sources, as well as fortitude of new models and control tactics.
- To manufacture sources of control with operator programmable resultant impedance or consent in difficult border.
- To replicate the control profile of output of unlike upgradable sources and capability devices by resources of encoding the Zout or Yout of force sources.

2. RELATED WORK

Many scientists and engineers from across the globe participate in the field of PV based emulator. This patent will show an emulator which is a nonlinear method which have the same current-voltage characteristics to PV module [7-11]. The steady periodic settings are hard to duplicate the controlled domain to examine PV hardware. These days, the more emerging thing for applications of RES, with all the linked problems of their ultimate manipulation, has prolonged the need of investigational hardware to do approximations and tests, without the straight consumption of the PV panels [12, 13]. To test the huge power rating PV based system, widespread power rating boards are essential which are very expensive and needs extra space. A PV emulator will simulate the I-V characteristics of a photovoltaic board under these fluctuating circumstances. Partaking dependable electrical characteristics re-formed, which allows less challenging investigation and system improvement in this emulator. Original PV panels are too much expensive [14, 15].

1) A huge amount of space is required to set up real PV panels. A time consuming and a hard job is to acquire the knowledge of features for different panel's setup we need to recombine the PV modules in an unanticipated way.
2) The hard job is to copy a PV panel by voltage source or by current source.
3) Even at night or under cloudy weather you can complete your investigation under the unavailability of sun.
4) As the climate does not remain the same so it is very tough to replicate and keep up the comparable qualities.
5) These types of emulators can replicate the different required properties, without using any extra time and further money, by just developing several slight developments in the controller's deviousness.

From the above cited literature, it is obvious that fractional order controllers are rarely used in solar PV emulators systems [16]. So In this work, a FOPI control scheme based solar PV emulator is implemented using a buck converter. Arduino is used for the Implementation of fractional order control scheme using MATLAB/Simulink and real time workshop [17-23].A few papers on sun-based PV emulator have been published thinking about different issues identified with sun-based PV plants like infiltration, stability of grid, impact of climate what's more, geological area of PV plant on grid security and soundness, control quality, voltage and frequency ride through ability of sun powered PV plants and so on. PV plant demonstrate advancement began with detailed demonstrating including, PV cell models, DC-to-DC arrange, DC-to-AC stages, DC-connect capacitor, Phase-bolted circle, and matrix show spoken by a solitary stage or a three-stage source in view of particular examinations [24-27].

3. PROPOSED PV MODEL

The purpose of the PV emulator is that its output current and output voltage is to follow the diode equivalent model very nearly as possible. From Figure1 few models can be made with expanding complexity to show a PV module. The PV emulator will utilize the improved model to simulate a PV panel [28, 29]. The practical model won't be utilized since shunt resistance is insignificant in modules and calculation turn out to be harder to calculate the output current and output voltage.
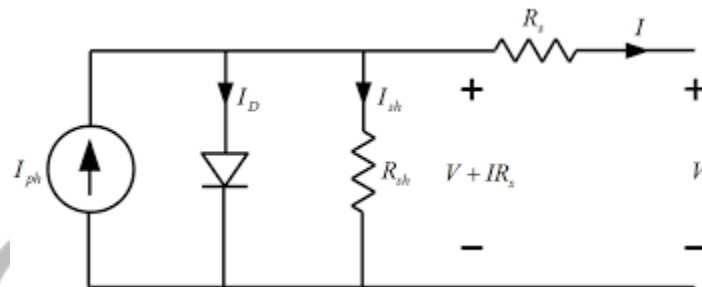

Figure 1.Network of PV cell

PV generators are neither steady voltage sources nor current sources yet can be approximated as current generators with subordinate voltage sources. Figure 1 demonstrates an equivalent circuit of a PV cell [30, 31]. We can get a single PV cell along with a current source, a diode, a shunt resistor, and a series resistor. The diode condition is given as I_{out}

$$I_D = I_0 (e^{Vd}/_{nVt} - 1) \qquad (1)$$

$$V_t = \frac{AKT}{q} \qquad (2)$$

PV module is the combination of many PV cells connected in series with each other; so to calculate the total output voltage of the PV module we should get the voltage across each cell and divide it by the total number of cell connected in series [32]. We can derive the output equation for the output voltage and the output current of PV module as

$$I_{out} = I_{ph} - I_0 (e^{\frac{V_{out} + I_{out} R_S}{NV_t}} - 1) - \frac{V_{out} + I_{out} R_S}{R_{sh}} (3)$$

A PV module IV curve can be affected by insolation level, temperature, which shows the short circuit current, shunt resistance and series resistance. To model different kinds of PV module we can vary the parameters in equation (3) under different suitable condition.

Where
I_D Is the current in diode
V_D Is the voltage in diode
I_0 Is the reverse saturation current
A   Is the ideality factor
K   Is the Boltzmann's constant
T   Is the absolute temperature

Q   Is the elementary charge
R_s Is the series resistance
R_{sh} Is the shunt resistance
V_t Is the thermal voltage
T_{stc} Is the cell temperature at standard test condition
N_s Is the number of series cells in the module
A   Is the ideality factor of the diode Iph: is the photo generated current (A)

Table 1. PV module and circuit parameters

Switching frequency (f_{sw})	
Inductor (L_1)	
Capacitor(C_1)	1005μF
Capacitor(C_2)	1005μF
Capacitor(C_3)	1005μF
Short circuit current (I_{sc})	4 A
Open circuit voltage (V_{OC})	9 V
Internal series resistance (R_s)	
Internal shunt resistance (R_{sh})	

3.1 OVERVIEW OF BUCK CONVERTER.

The power converters are also the fundamentalcircuitsinpower electronic used to change over voltage to different levels by exchanging its activities. This is a result of their significant part in numerous applications like apparatuses control, DC engine drives, flying machine, and media transmission equipment's [33]. The buck chopper is utilized in interfacing the photovoltaic based boards or wind-based turbines to the small-scale DC networks. High productivity can be achieved using step down converters by operating at full load conditions. The buck converter can be modified in such a manner that it provides compensation to the varying conditions imposed by stack, variations in input voltage and vulnerabilities related to different parameters. Wise choice of the converter and appropriate design of the control systemutilizedfor converter play an important role in obtainingscale matrix which can provide the possible DC miniaturization [34, 35].

3.2 DEVELOPMENT OF BUCK CONVERTER

The buck converter is a chopper which is used for conversion of dc voltage to dc voltage in such a way that it steps down the voltage applied to it. The step-down converter consists of a switch, diode, capacitor and inductor. The switch is brought into on and off with high frequency switching. To step down the voltage inductor plays important role. The inductor stores energy in magnetic field. Subsequently, the output voltage will be less compared to the input. The capacitor is used to decrease voltage stress. The diode is used as freewheeling device [36]. This circuit can be additionally altered by including the input part which is essential for a SMPS on the grounds that in view of the criticism it balances out the yield. Now to get a steady DC voltage, PWM controller output to be added to the buck converter converters switch. The PWM controller provides corrective action to settle DC output voltage.

3.3 OPERATING STATES

The buck device works essentially in 2 distinctive states. These 2 numerous operating states are on and off states. The average state model is derived based on the individual on off states.

3.3.1   ON State
The power convertor operation in on mode is shown in Figure 2. The inductance over its terminals produces contradicting voltage in response to evolving current. The diode works as freewheeling device. The stream of current to the heap at first gets confined in light of the vitality putting away in inductor. The current over the heap and charge upon capacitor begin bit by bit to develop amid the on period. At the point when yield voltage achieves want esteem, turn kills, and diode begin to work in forward predisposition.
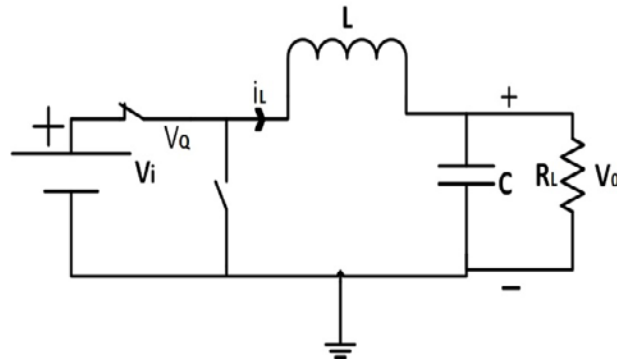
Figure3.2. ON state of Buck converter

OFF State

During the off-mode operation, the electronic switch used acts like an open circuit. The diode is in conduction state being forward biased and gives a way to the stored inductor current. The inductor begins to release energy through the freewheeling diode. The capacitor part is to decrease the swells in the output voltage off mode state of the converter.
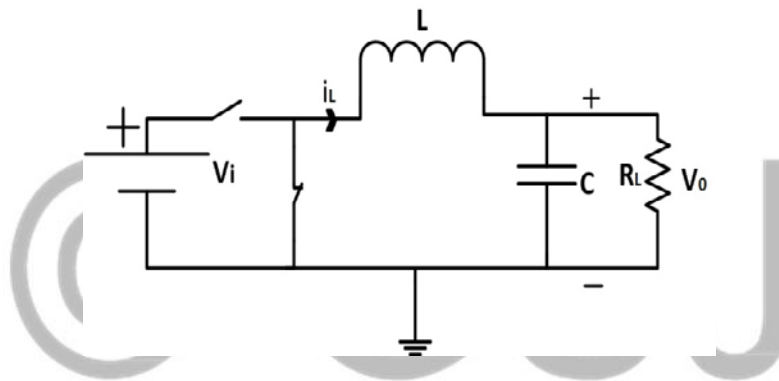

Figure3.OFF state of Buck Converter

3.4 WAYS OF ACTION

Operation of buck converter can be classified into two categories based on the conduction status. These two categories are Continuous Conduction mode (CCM) and Discontinuous Conduction mode (DCM).

3.4.1   CCM

In continuous conduction mode, the inductor current value never approaches zero. The working principal of the continuous conduction mode is shown in Figure 4. In continuous conduction mode the inductor current is always positive and greater than zero. Since the inductor current is always greater than zero hence it is called the continuous conduction mode.
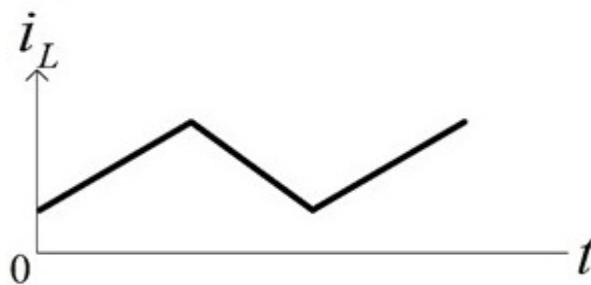

Figure 4: Buck converter in CCM

3.4.2   DCM

In discontinuous mode the inductor current reaches zero. The working principal of discontinuous conduction mode is shown in Figure 5. In discontinuous conduction mode the inductor current is sometimes zero. Since the inductor current is sometimes equal to zero so it is called discontinuous conduction mode.
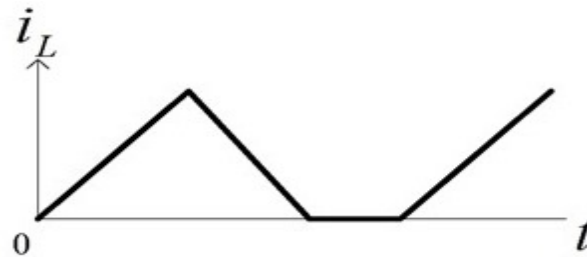

Figure 5: Buck converter in DCM

3.5 CONTROLLER DESIGN

In modern world applications, control system theory has gained wide attention of the readers and researchers. For designing a controller, prior information about the system parameters are required. The closed loop system consists of sensors for measurement and then feeding the signal back to the controller to generate error signal. The output state to be controlled is the voltage across the capacitor in our experiment [37]. Linear control system has several disadvantages such as lack of robustness to the parameters uncertainty in the system. Moreover, fractional order control offers superior performance as compared to the fractional order control.
In closed loop the system output is used as feedback and in open loop vice versa. The Figure 6 demonstrates the closed loop control system for a plant to be controlled [38].
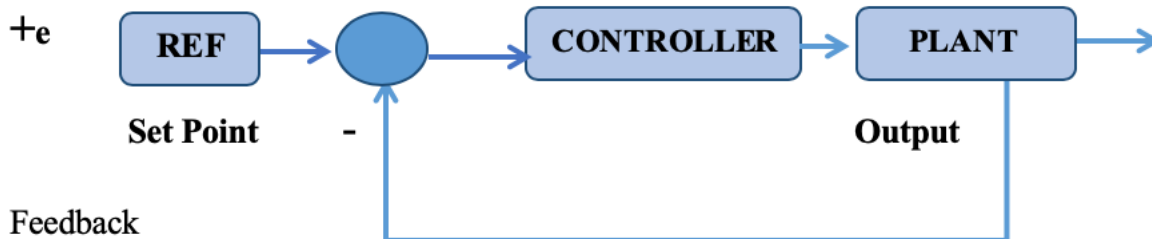

Figure 6. Block Diagram of Closed Loop System

4.1 PID CONTROLLER

The widely used linear control system is called the Proportional Integral Derivative (PID) controller The PID controller is a linear control method which is very easy to program and implement over a processor [39, 40]. It has wide applications in different industries such as automotive, aerospace and medical industry. The PID controller can be used to control different process such as motor speed control, air flow, temperature and pressure control. The PID controller is robust to some extent however it shows poor performance in case if there is discrepancy in the system parameters [41, 42]. The PID controller depends on three fundamental coefficients namely proportional, integral and derivate coefficient. The proportional term improves transient response of the system, however larger proportional gain generates overshoots and the system can become unstable. The integral gain is used to improve the transient response however the settling time is degraded with larger integral gains. The integral gain eliminates steady state error. The derivative gain adds damping to the system, in other words it slows down the response of the system [43, 44]. The effect of different gains on the system performance is showninTable 2.

Table 2: PID controller performance description

Coefficient	Rise time	Over shoot	Settling time	Steady State error
Kp	Decrease	Increase	Small change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kid	Small change	Decrease	Decrease	Small Change

The PID controller can be composed by following below steps:

i.   System open loop response is measured.
ii.   Adjust proportional gain to set the limit of the overshoot.
iii.   After step ii, adjust derivative gain to adjust the damping
iv.   In order to eliminate the steady state error, add integral gain.
v.   Finallytune the gain values ofKP, Ki and KDfor the desired response.

The output in time domain from PID controller as is given beneath:

$$U = Kpe(t) + Ki \int_0^t e(t)d(t) + Kd\frac{d}{dt}e(t) \qquad (4)$$

4.2 FRACTIONAL ORDER PID CONTROLLER

The fractional order PID still an intriguing field for researchers as of late. A huge gap still exists in determining a robust and effective FOPID. It's because of no tuning rules existence for these controllers. Fractional order PID additionally expands the features of sample PID controller. FOPID is an emerging area of interest on control side that integratebothfractional integrals and derivatives in desire controllers. The fractional order integrals and differentialsbasic concept is well explained in [45, 46]. While in general degree of freedom is compatibly greater in fractional order controllers compare to integer order [47]. Henceforth fractional controllers can be tuned for ideal response with robustness and can be further discussed in [48].

From most recent quite a few years, PID controller is ceaselessly utilized in many enterprises for control applications [49]. The reason for this lied in its simple design and superiorperformedparametersincorporateslow overshoot and little settling time. A FOPID is an advancement of PID. The FOPID is small delicate for the fluctuating parameters of control system and furthermore to the controller [50]. The FOPID can assure an isof damping feature effortlessly. Tuning is an important task for the vast majority of the controllers. In FOPID, five different parametersare tuned. Because of five different parametersof tuning, it's little bit difficult task to tune these sorts of controller. The FOPID generalized form in form of transfer function is as below [51-52].

$$C(s) = \frac{U(s)}{E(s)} = Kp + \frac{Ki}{S\lambda} + KdS^{\mu}, (\lambda, \mu \geq 0) \quad [\text{Eq. 4.2}]$$

In above-mentioned equation, $C(s)$ is control output, E(s) shows error signal &U(s) represent control signal, and. The Ki is integral gain constant; Kp is Proportional gain constant and Kdrepresent derivative gain constant. The other two parameters are μand λ . The μ and λ shows order of integration & difference.

4. RESULTS AND ANALYSIS

The hardware implementation of fractional order controller for PVemulator is implemented using Matlab software. We will connect a PV emulator to MATLAB by using Arduino due. We will perform simulation in closed loop. We will apply different methods for the verification of robust performance of the PV emulator.

5. SIMULINK BASED CODE GENERATION

It is a simulation technique based on the top of matlab. It's a model-based software designing technique for dynamic system in matlab. Simulink can be used to simulate, analyzed and modeled multi domain dynamic. In Simulink u can use libraries to model any system. For integration of different algorithms from matlab to the model u can use Simulink. The important feature of Simulink is to export results from Simulink to matlab for the analyzation of further results. Different features include:

Design system model.

Simulation will be performed;

We can generate code;

Testing and analyzation of embedded system;

It is an enlargement of MATLAB for showing, reproducing, and exploring quick, hard, linear and nonlinear control system. Graphical User Interface and visual depiction by utilizing Simulink squares are two key segments.

5.1 EMPLOYMENT OF PV EMULATOR IN SIMULINK

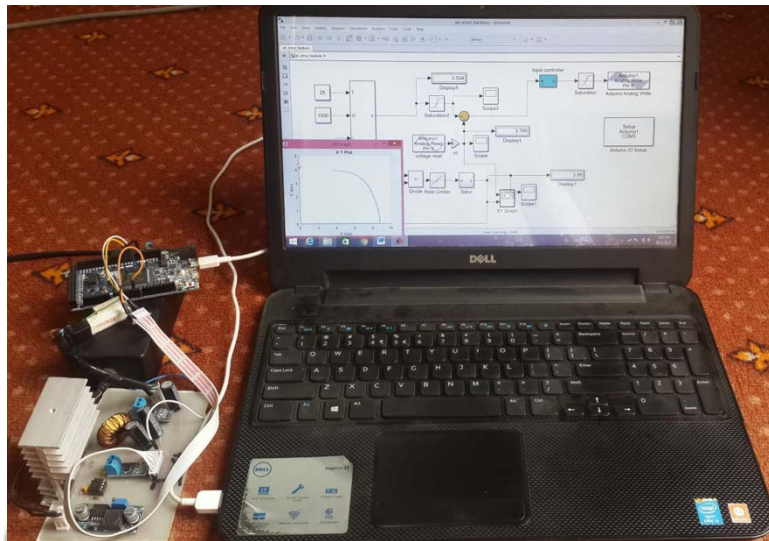Figure 7 shows the experimental plate form that was used as a PV emulator system

Figure 7. Implementation of proposed model in Simulink

5.2 PV EMULATOR SIMULINK MODEL
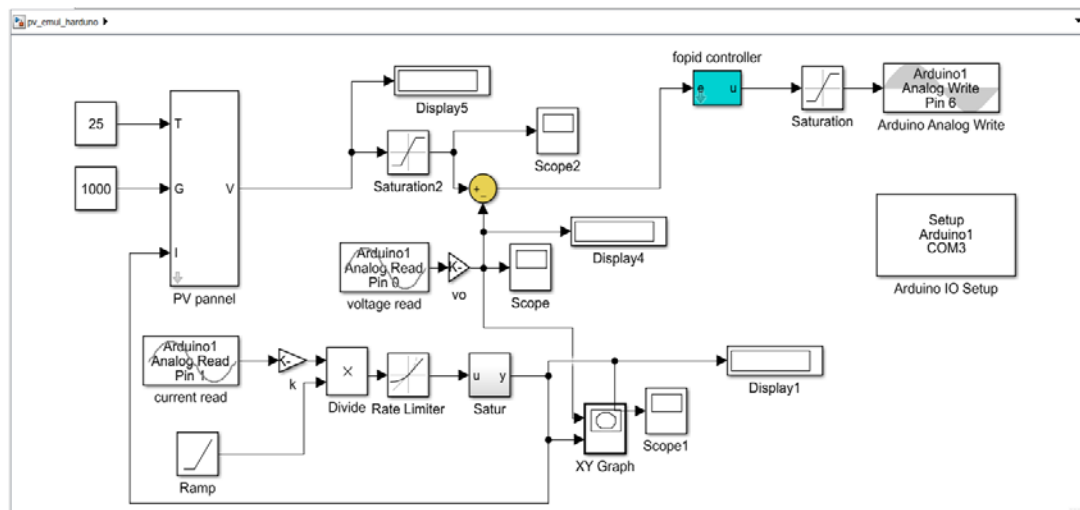
Figure 8 Block diagram of PV emulator based on FOPID

Figure 8 shows the Simulink model of buck converter-based PV emulator. In this model we use fractional order controller (FOPID) and Arduino due. When PV module generates less current so we use buck converter as reference to produce greater voltage in output we need. Buck converter maintains the IV and PV curve generates by PV module. As shown in Figure 8 we can check our PV emulator by increasing and decreasing its temperature and irradiance. We will get the ideal result as produce by PV module as discuss below in this chapter in detail.

5.3 PV EMULATOR SIMULATION RESULTS

Voltage response for PV emulator
Figure 9 shows output voltage response of the buck converter-based PV emulation system for temperature of 25 degree Celsius and irradiance magnitude five hundred. From the presented experimental results, it is clear that the output voltage of the buck converter varies with time and with reference to the current characteristics.
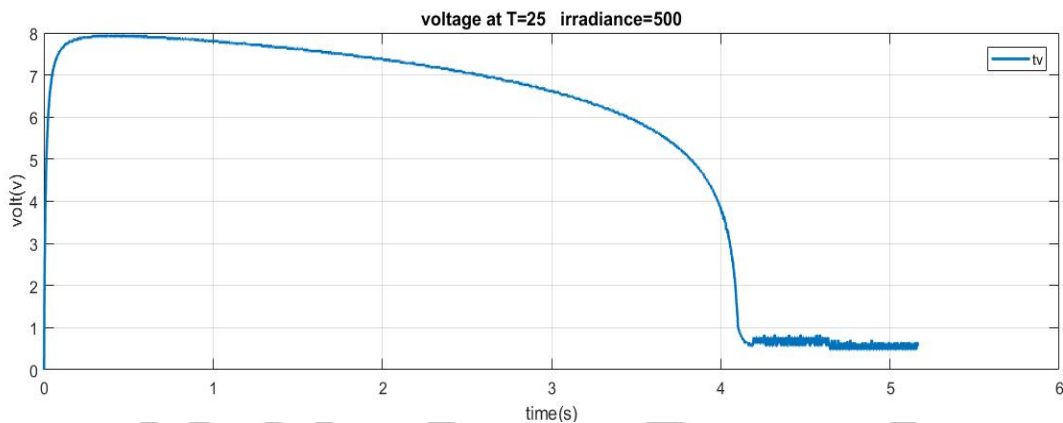
Figure 9. voltage resultant curve for PV emulator

From figure 5.3 initially the voltage of the buck converter is zero at time t =0 then in the steady state the voltage decreases from a peak value gradually as the time passes and finally from t=4.25 to 5.2 second the output voltage of the buck converter is almost constant round one volt.

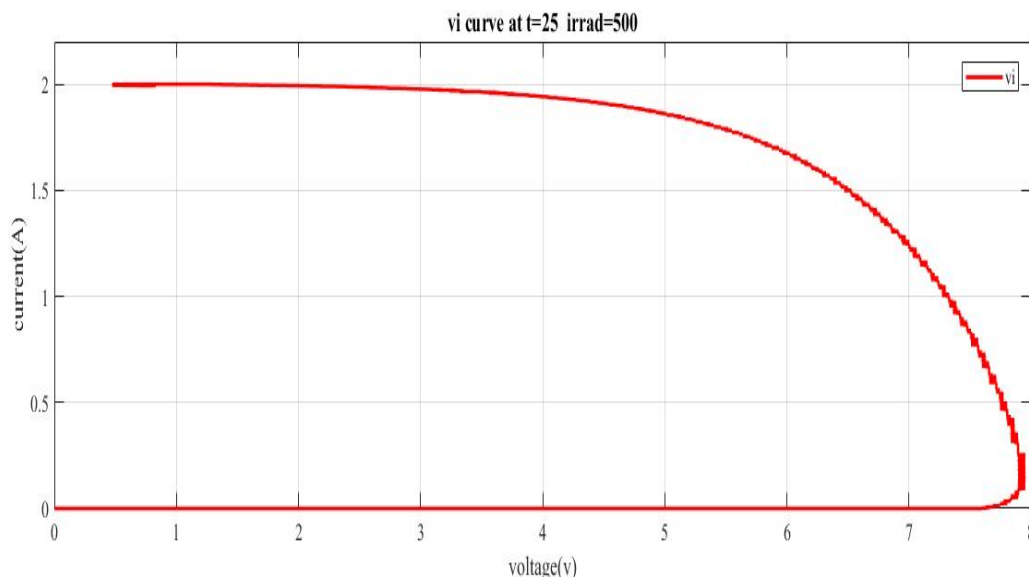**I-V response of PV emulator at T =25c^o and irradiance =502**

Figure 10. Typical IV curve of the PV emulator

The above Figure 10 shows the closed loop IV characteristics of the proposed buck converter-based PV emulator system. From the presented experimental results, it is obvious that the emulator behaves like a constant current source and the same can be verified from t=0.55 to t=5.5sec. after 5.5 sec the emulator shows similar IV trend as observed in many practical solar or photovoltaic cells.
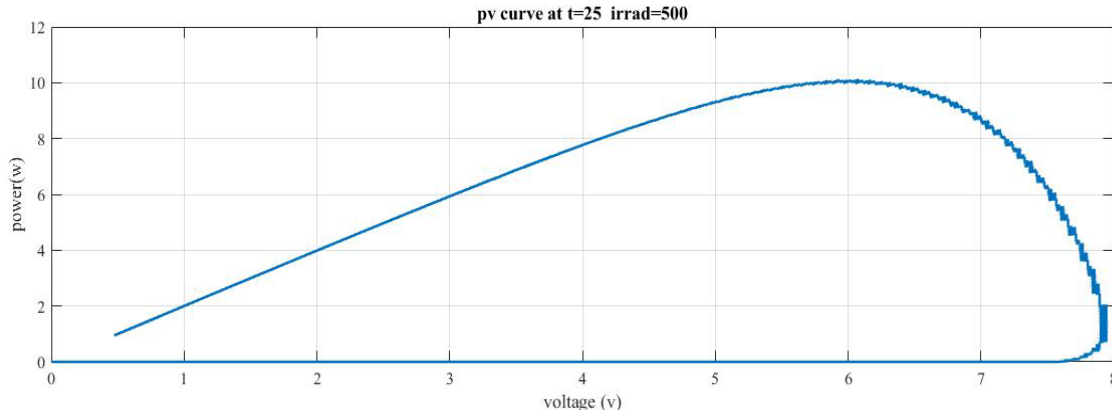
P-V response for PV emulator for T=25c^o and irrad=502

Figure 11. Typical IV curve of the PV emulator

Figure 11 shows P-V characteristics of the proposed solar PV emulator. It can be seen from the given results that the emulator behaves like an ideal solar cell. More ever from the PV characteristics curve the maximum power point for our proposed emulator is around 9 watts and it can be verified from the PV characteristics curve given in Figure 11.

Buck converter voltage tracking response
Since in our case buck converter is used as solar PV emulator so the reference voltage generated by the MPPT algorithm is feed as a reference signal to the voltage loop. Figure 12 shows the experimental results of the buck converter's voltage tracking response. From the given results it is seen that the steady state voltage error is very small. Due to the good tracking performance of the voltage loop, the emulator perfectly replicates the P-V curve of the solar/PV cell shown in the previous Figure 12.
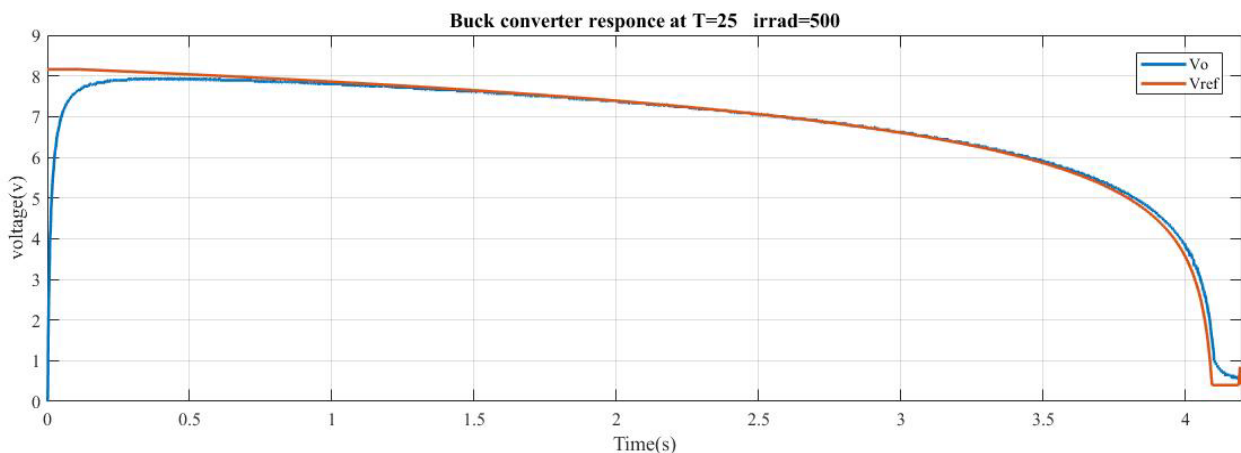

Figure 12. Voltage VS Time curve of Buck Converter

Voltage response for PV emulator at T =25c^o and irrad=1005
Figure 13 shows output voltage response of the buck converter-based PV emulation system for temperature of 25 degree Celsius and irradiance magnitude 1005. From the presented experimental results, it is clear that the output voltage of the buck converter varies with time and with reference to the current characteristics
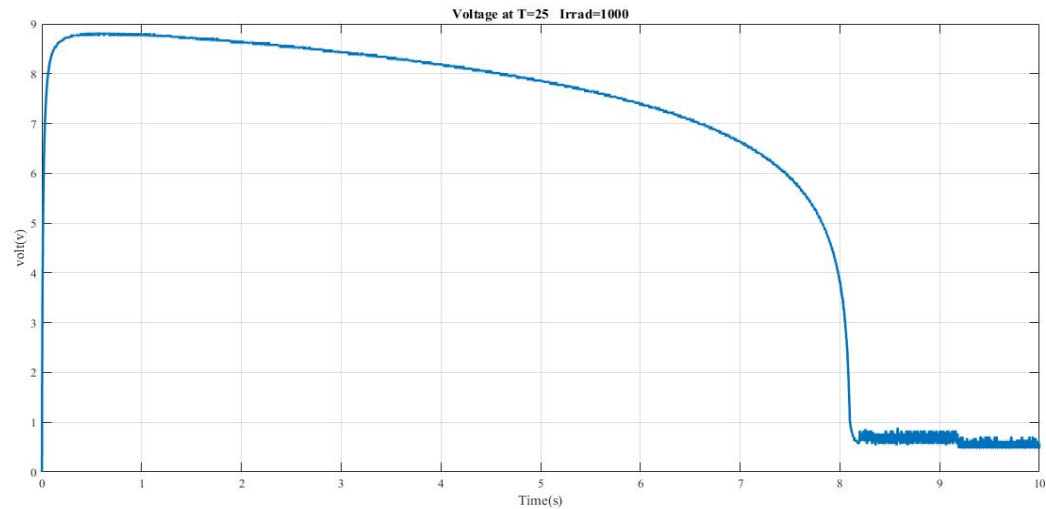
Figure 13 voltage resultant curve.

From Figure 13 initially the voltage of the buck converter is zero at time t =0 then in the steady state the voltage decreases from a peak value gradually as the time passes and finally from t=8.25 to 9.8 second the output voltage of the buck converter is almost constant round two volt. Change occurs just off because of the value of irradiance increases.
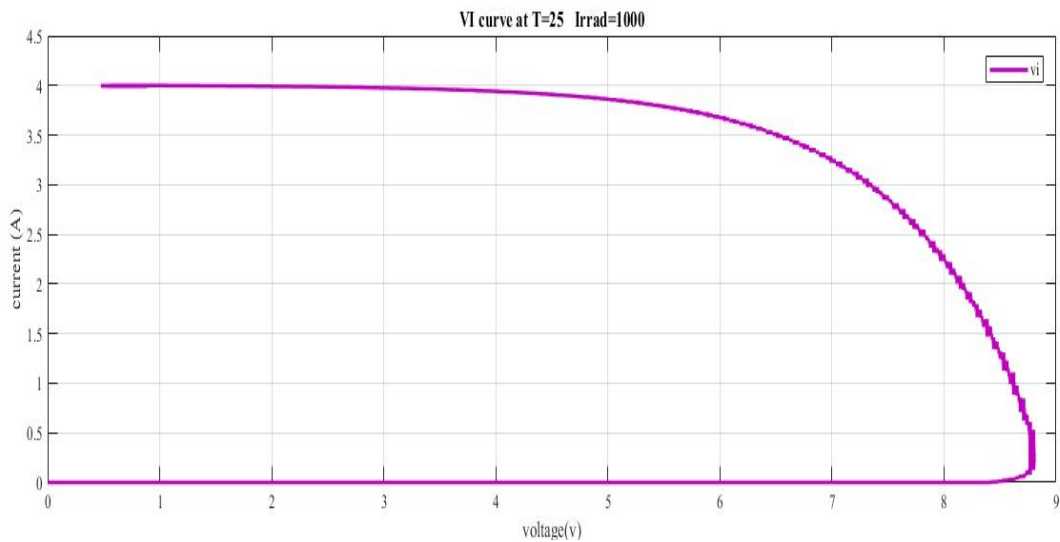
I-V response of PV emulator at T =25c⁰ and irrad=1005

Figure 14. I-V resultant curve.

The above Figure 14 shows the closed loop iv characteristics of the proposed buck converter-based PV emulator system at T=25degree and irradiance of 1005. From the presented experimental results, it is obvious that the emulator behaves like a constant current source and the same can be verified from t=1 to t=5.5sec. after 5.5 sec the emulator shows similar IV trend as observed in many practical solar or photovoltaic cells. If we compare both figure 6.4 and 6.8 small change occur with respect to increasing value of irradiance.

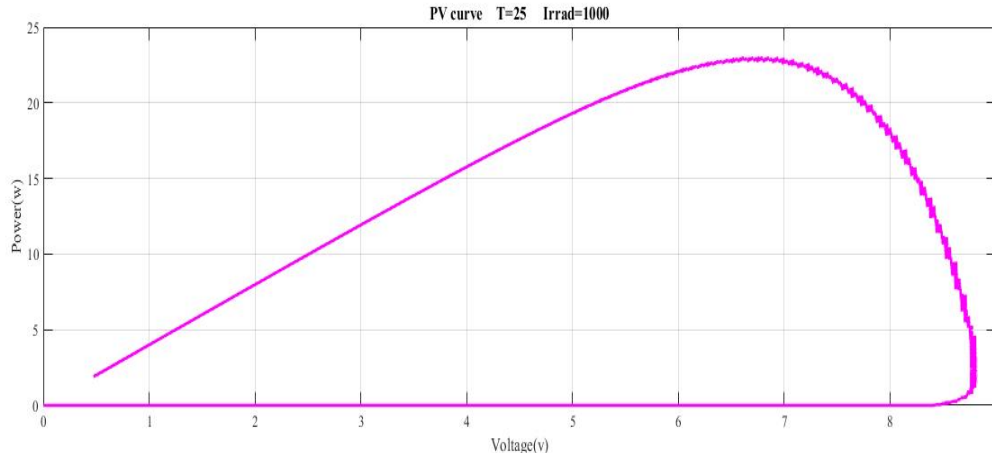**P-V response for PV emulator at T=25c° and Irrad=1005**

Figure 15   P-V resultant curve

Figure 15 shows P-V characteristics of the proposed solar PV emulator. It can be seen from the given results that the emulator be-haves like an ideal solar cell. More ever from the PV characteristics curve the maximum power point for our proposed emulator is around 23 watts and it can be verified from the PV characteristics curve given in Figure 15. If we compare Figure 15 and Figure 11 when we doubled the value of irradiance the power become doubled.

Buck converter voltage tracking response at T=25c° and irrad=1005
Since in our case buck converter is used as solar PV emulator so the reference voltage generated by the MPPT algorithm is feed as a reference signal to the voltage loop. Figure 16 shows the experimental results of the buck converter's voltage tracking response. From the given results it is seen that the steady state voltage error is very small. Due to the good tracking performance of the voltage loop, the emulator perfectly replicates the P-V curve of the solar/PV cell shown in the previous Figure 16. We can clearly see the dif-ference between Figure 16 and Figure 12.
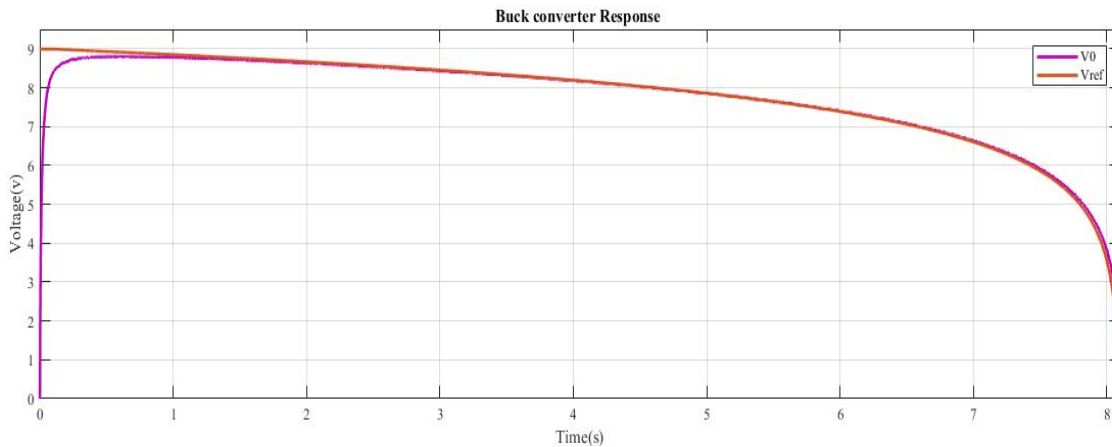

Figure 16.Voltage following resultant curve

Voltage response for PV emulator at T =50c° and irrad=505
Figure 17 shows output voltage response of the buck converter-based PV emulation system for temperature of 50 degree Celsius and irradiance magnitude 505. From the presented experimental results, it is clear that the output voltage of the buck converter varies with time and with reference to the current characteristics
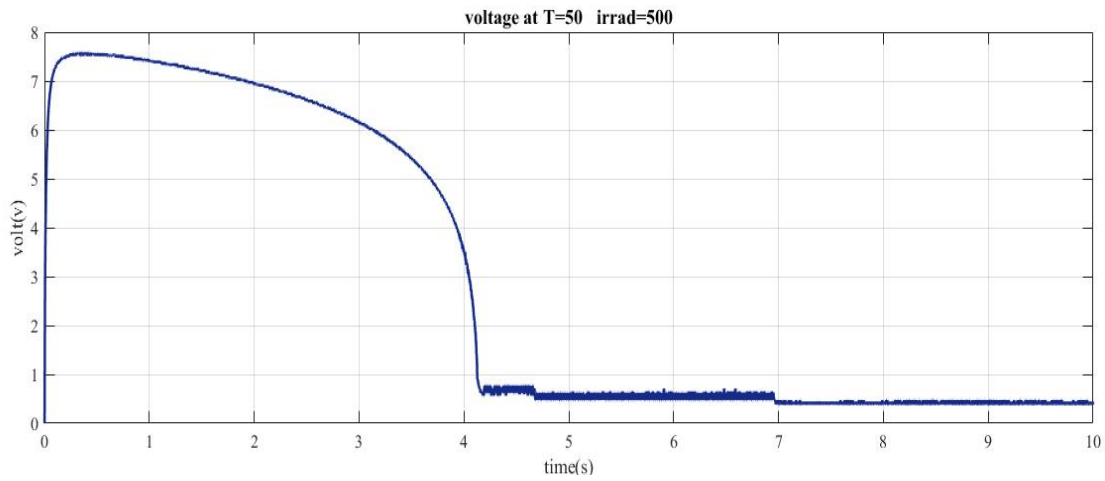
Figure 18. voltage resultant curve

From Figure 18 initially the voltage of the buck converter is zero at time t =0 then in the steady state the voltage decreases from a peak value gradually as the time passes and finally from t=4.22 to 10 second the output voltage of the buck converter is almost constant round two volt. Change occurs just off because of the value of irradiance increases.

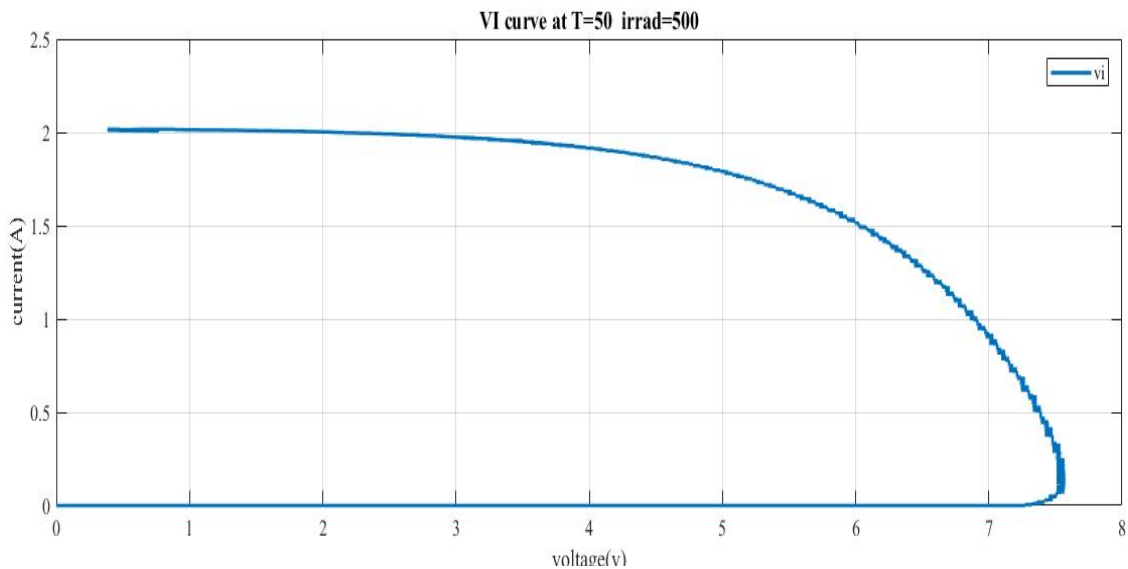**I-V response of PV emulator at T =50c⁰ and irrad=505**

Figure 19. I-V resultant curve

The above Figure 19 shows the closed loop IV characteristics of the proposed buck converter-based PV emulator system. From the presented experimental results, it is obvious that the emulator behaves like a constant current source and the same can be verified from t=1 to t=6sec. after 5 sec the emulator shows similar IV trend as observed in many practical solar or photovoltaic cells. If we compare both Figure 19 and Figure 12 small change occur with respect to increasing value of temperature.

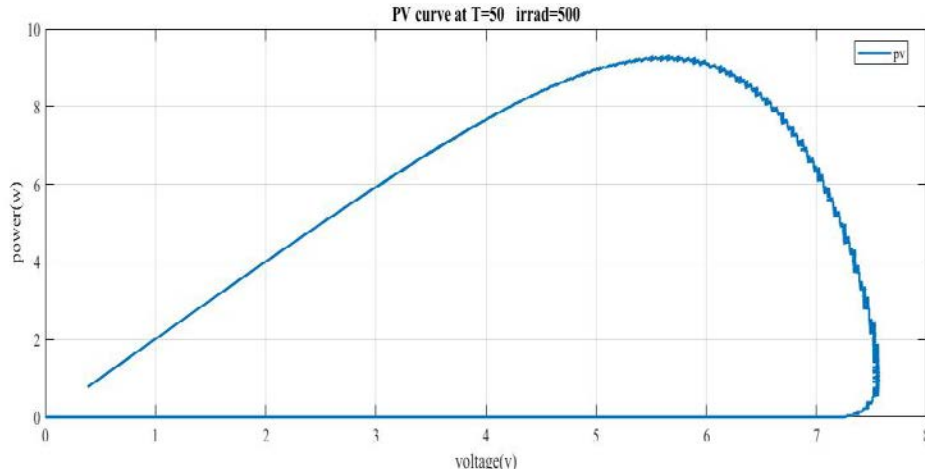**P-V response for PV emulator at T=50c° and Irrad=505c°**

Figure 20. P-V resultant curve

Figure 20 shows P-V characteristics of the proposed solar PV emulator. It can be seen from the given results that the emulator behaves like an ideal solar cell. More ever from the PV characteristics curve the maximum power point for our proposed emulator is around 10 watts and it can be verified from the PV characteristics curve given in Figure 20.

Buck converter voltage tracking response at T=50c° and irrad=505

Since in our case buck converter is used as solar PV emulator so the reference voltage generated by the MPPT algorithm is feed as a reference signal to the voltage loop. Figure 21 shows the experimental results of the buck converter's voltage tracking response. From the given results it is seen that the steady state voltage error is very small. Due to the good tracking performance of the voltage loop, the emulator perfectly replicates the P-V curve of the solar/PV cell shown in the previous Figure 21.
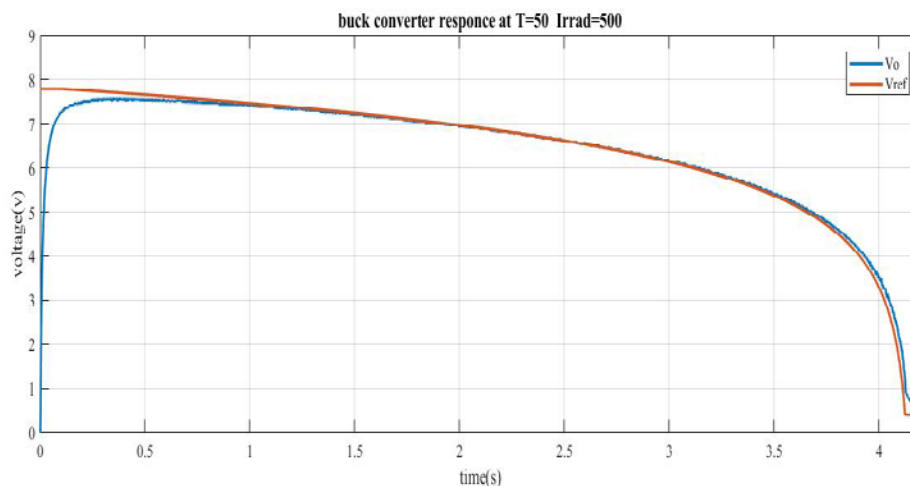

Figure 21. Voltage resultant curve of Buck Converter

Buck converter voltage tracking response at T=50c° and irrad=1005

Figure 22 shows output voltage response of the buck converter-based PV emulation system for temperature of 50 degree Celsius and irradiance magnitude 1005. From the presented experimental results, it is clear that the output voltage of the buck converter varies with time and with reference to the current characteristics
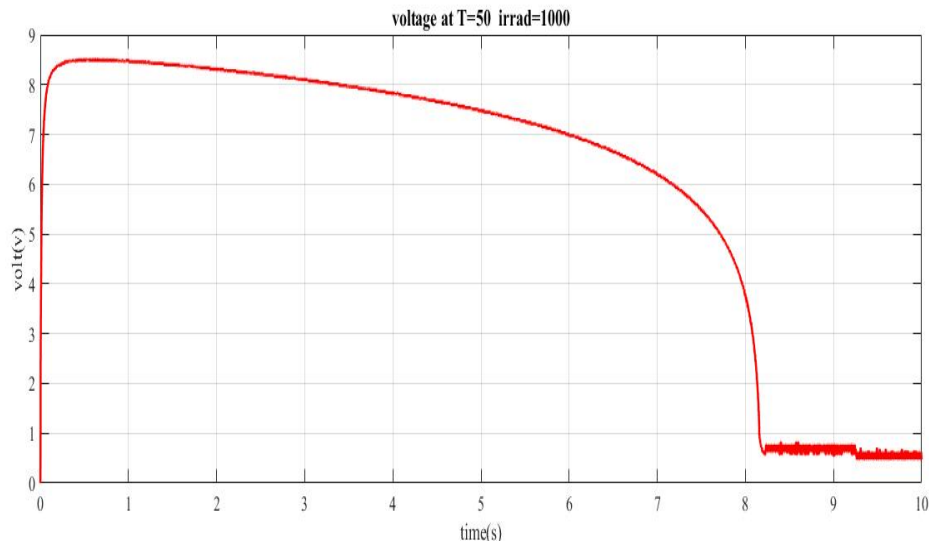
Figure 22. Voltage following resurtant curve of Buck Convert

From Figure 22 initially the voltage of the buck converter is zero at time t =0 then in the steady state the voltage decreases from a peak value gradually as the time passes and finally from t=8.22 to 10 second the output voltage of the buck converter is almost constant round two volt.

I-V response of PV emulator at T =50c⁰ and irrad=1005
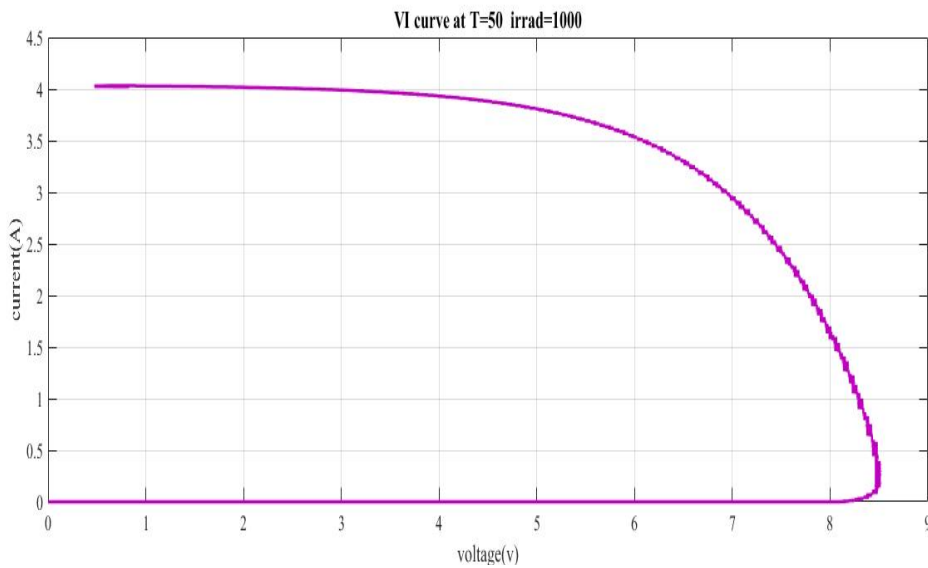

Figure 23. PV emulator's I-V resultant curve

The above Figure 23 shows the closed loop IV characteristics of the proposed buck converter-based PV emulator system. From the presented experimental results, it is obvious that the emulator behaves like a constant current source and the same can be verified from t=1 to t=5sec. after 5 sec the emulator shows similar IV trend as observed in many practical solar or photovoltaic cells.

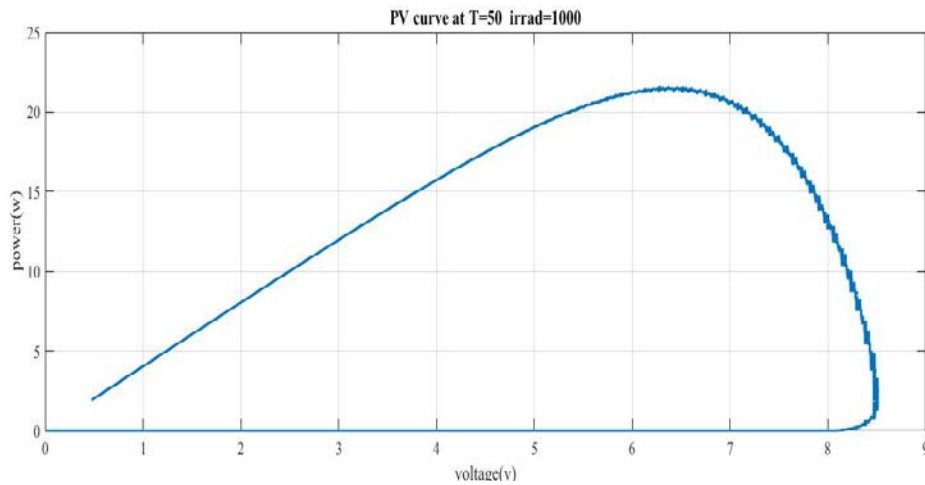**P-V response for PV emulator at T=50c⁰ and Irrad=1005**

Figure 24. PV emulator's P-V resultant curve

Figure 24 shows P-V characteristics of the proposed solar PV emulator. It can be seen from the given results that the emulator be-haves like an ideal solar cell. More ever from the PV characteristics curve the maximum power point for our proposed emulator is around 23 watts and it can be verified from the PV characteristics curve given in Figure 24.

Buck converter voltage tracking response at T=50c⁰and irrad=1005

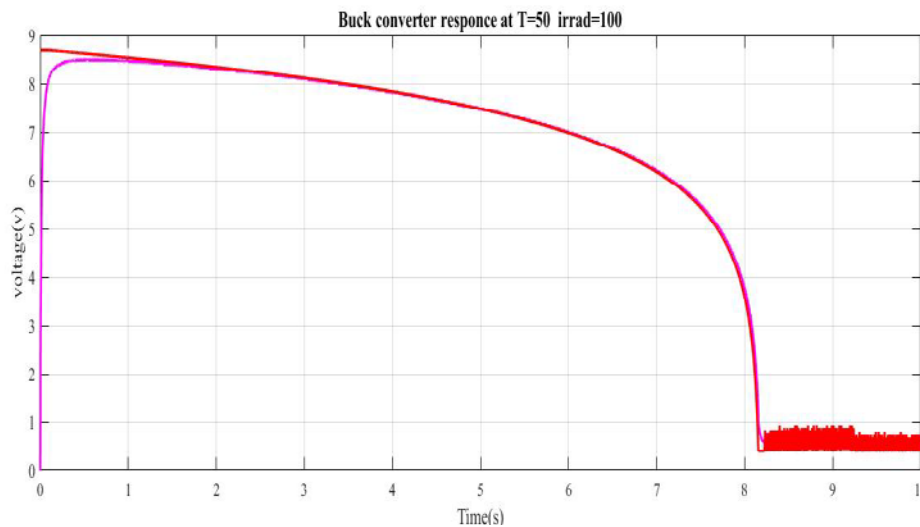
Figure 25. Voltage following curve of Buck Converter

Since in our case buck converter is used as solar PV emulator so the reference voltage generated by the MPPT algorithm is feed as a reference signal to the voltage loop. Figure 25 shows the experimental results of the buck converter's voltage tracking response. From the given results it is seen that the steady state voltage error is very small. Due to the good tracking performance of the voltage loop, the emulator perfectly replicates the P-V curve of the solar/PV cell shown in the previous Figure 25. We can clearly see the dif-ference between Figure 25 and Figure 16.

5.4 Examination of all IV curves as for various temperature and irradiance.
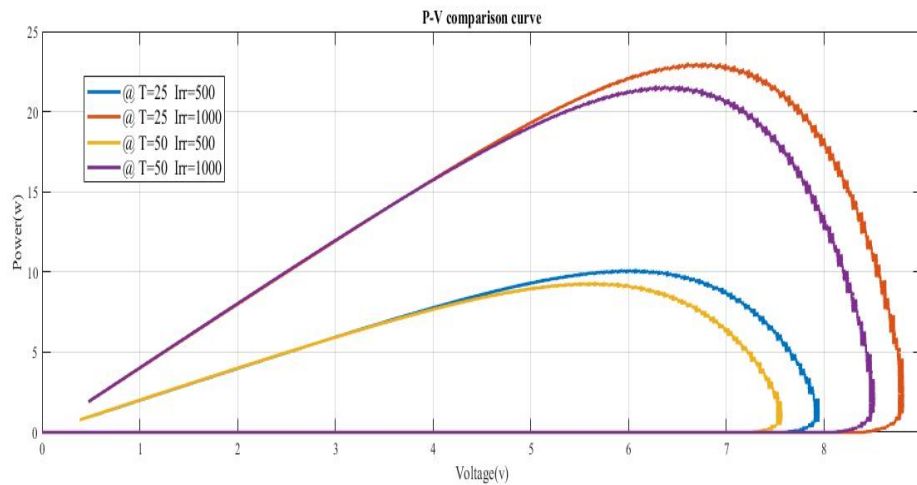

Figure 26 Difference of PV curves

In Figure 26 we can clearly see the difference of all PV curves we get from the Simulink. At T=25 if we change the irradiance the MPPT increases and voltage changes from 7.8 to 8.8 approximately and also if we change the temperature with respect to irradiance the small change occur in the voltage and MPPT.

Figure 27 shows the comparison of all IV curves we get from the Simulink. Figure 27 shows that if we change the irradiance to different values from 505 t0 1005 the current value increase to the maximum value at 505 irradiance current values is 2Amp and at 1005 irrad current value goes doubled to 4Ampere. With respect to temperature and irradiance change occur in the value of voltage. Value of voltage gradually increase when we increased the value of irrad and temperature.
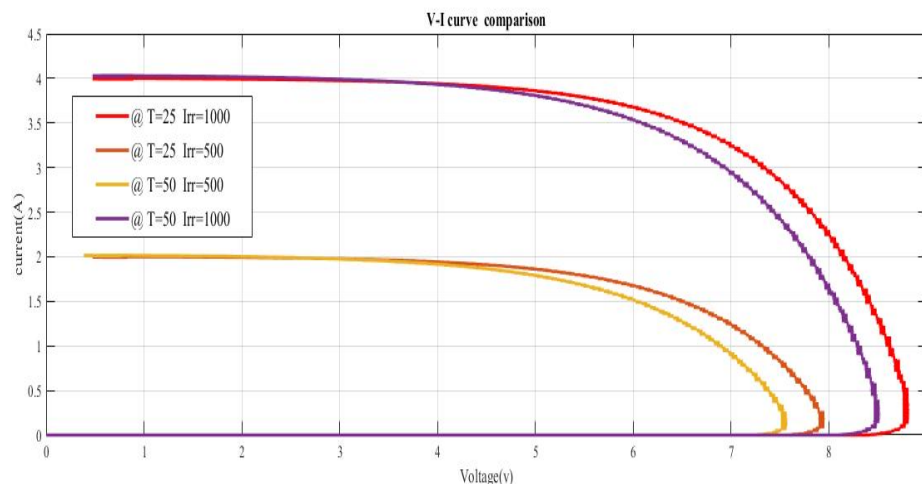

Figure 27 displays difference of IV curves at altered temperature and irrad

Conclusion

In this research, a buck converter based solar PV emulator has been implemented using Arduino based closed loop control system. A fractional order proportional integral (FOPI) control scheme was implemented and the I-V and P-V curves of the emulator were recorded under resistive load. I-V curve of the PV emulator was plotted for open circuit voltage Voc =9   and short circuit current Isc= 4 the emulator was tested under variable resistive load and the control scheme were robust enough for ensuring the emulators operation independent of load. The FOPI controller and the emulation scheme were implemented in Simulink environment. MATLAB real time workshop was used to auto generate the C code from the Simulink model, and the output hex file was programmed to the Ar-

duino microcontroller. I-V and P—V curves of the proposed emulator were recorded and the maximum power point was recorded as Pmax= 23watts. Maximum voltage recorded as Vmp=6.8v and maximum current recorded as Imp= 3.36amp at irradiance= 1005 and temp= 25c.

In the current work, a FOPI based solar PV emulator was proposed and tested practically. The emulator showed good performance under system's nominal parameters. Especially the power stage parameters of the buck converter may vary depending upon the operating conditions. With parameters variation, the conventional FOPI controller may show poor performance and the characteristics curve of the emulator may show variation over time. To rectify this problem, and in future the idea will be extended to a PV emulator system based on robust control techniques such as sliding mode, back stepping and high infinity methods.

Acknowledgment

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