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Comparison of Different Control with Sliding Mode Control for Solar PV Boost Converter

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ABSTRACT: In this paper, Non-linear controller like sliding mode controller (SM) is applied for the DC-DC boost converter due to its non-linear properties. This controller is used for the photo-voltaic application. The results and performance of sliding mode controller shows that the sliding mode control scheme provides good voltage regulation and is suitable for boost DC-to- DC conversion process and these results are compared with the results of proportional integral (PI) controller and proportional integral derivative (PID) controller. The results for sliding mode controller are found much satisfactory compared to PI and PID results.

KEYWORDS: DC-DC boost converter, pulse width modulation (PWM), PI controller, PID controller, Photo-Voltaic modeling.

I. INTRODUCTION

Due to the continuous depletion of fossil fuels, we are more concerning about the renewable sources of energy like hydro power, wind energy, photo-voltaic. Among all the renewable energy such as, wind energy, fuel cells, bio-energy, ocean energy etc., solar energy seems to be a promising source of energy. The advantages of utilizing solar energy by using PV devices are the short time for designing and installing of a new system, output power matching with peak load demands, static structure, no moving parts, longer lifetime, noise free, and non-polluting clean source of energy [2]. A PV system directly converts sunlight into electricity, and the basic device of a PV system is the PV cell [3]. Cells may be assembled to form modules or arrays. The power available at the terminal of a PV system can provide electricity to either small loads such as calculator, or utility scale PV system in the range of 10 MW and more. The principle for generation of photo-current is shown in below fig.

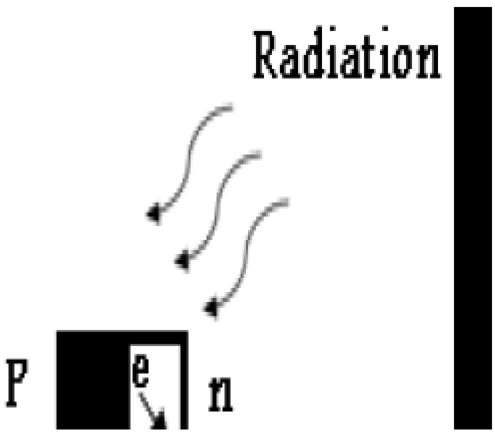

Fig. 1 photocurrent generation

The above figure shows the principle for photocurrent generation. This application is used for DC-DC boost converter. DC-DC boost converter (step-up converter) is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched-mode power supply (SMPS) containing at least two semiconductor switches (a diode

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and a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. Since DC-DC boost converters are non-linear systems, they represents a big challenge for control design. Classical control methods are not able to respond satisfactory, since these control methods are designed at one nominal operating point, due to this they often fail at large variations and load. Most industries make use of PID or PI type controllers for the control of DC-DC Converters due to their simplicity and low cost. However it is found that these controllers may lose stability when system uncertainties exist. They are not suitable for parametric variations, arising out of lumped uncertainties, or when large load variations are suddenly subject to the system. Sliding mode[SM] controllers are known for their robustness and stability. Variable structure control with sliding mode is found to be effective as it provides system dynamics with invariance properties to lumped uncertainties. However many problems such as chattering phenomena, variable switching frequency etc. arise when implemented in power converters. Ideally, sliding mode controllers operate at infinite, varying switching frequency. This makes the application of sliding mode control to power converters challenging. For sliding mode controllers to be effective with power converters, their switching frequencies must be confined within desirable limits. Otherwise, it may lead to problems such as inductor saturation, frequency exceeding beyond switch ratings etc. Sliding mode control has been successfully applied to robot manipulators, underwater vehicles, automotive transmissions and engines, high-performance electric motors and power systems. SMC provides a systematic approach to the problem of maintaining stability and consistent performance in the face of modeling imprecision.

II. CONTROL TECHNIQUES USED IN DC-DC BOOST CONVERTER

A. *Proportional Integral (PI) Controller:*

The integral term in a PI controller causes the steady-state error to reduce to zero, which is not the case for proportional only control in general. The lack of derivative action may make the system steadier in the steady state in the case of noisy data. This is because derivative action is more sensitive to higher frequency terms in the inputs. Without derivative action, a PI controlled system is less responsive to real (non-noise) and relatively fast alterations in state and so the system will be slower to reach set-point and slower to respond to perturbations than a well-tuned PID system may be.

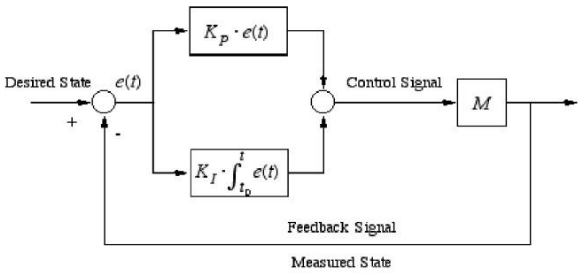

Fig. 2 Generic PI Controller

B. *Proportional, Integral & Derivative (PID) controller:*

For control over steady state and transient errors all the three control strategies discussed so far should be combined to get proportional-integral derivative (PID) control. Hence the control signal is a linear combination of the error, the integral of the error, and the time rate of change of the error. All three gain constants are adjustable. The PID controller contains all the control components (proportional, derivative, and integral). In order to get acceptable performance the constants KP, KD and Ki can be adjusted. This adjustment process is called tuning the controller. Increasing KP and KI tend to reduce errors but may not be capable of producing adequate stability. The PID controller provides both an acceptable degree of error reduction and an acceptable stability and damping.

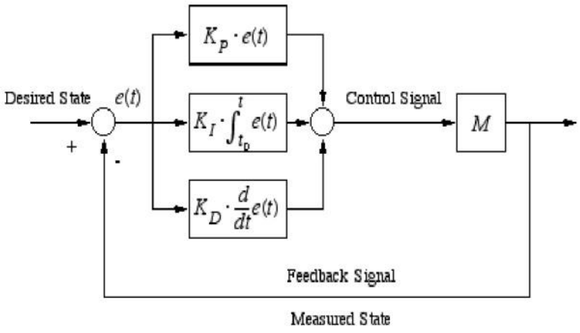

Fig.3 Generic PID controller

C. Sliding mode controller:

Sliding mode controller provides a systematic approach to the problem maintaining stability and consistence performance in the face of modelling imprecision [3]-[4]. For example, the gains in each feedback path switch between two values according to a rule that depends on the value of the state at each instant. The purpose of the switching control law is to drive the nonlinear plant's state trajectory onto a pre-specified (user chosen) surface in the state space and to maintain the plant's state trajectory for the subsequent time. This surface is called the switching surface [6]. When the plant trajectory is above the surface a feedback path has one gain and a different gain if the trajectory drops below the surface. This surface defines the rule for proper switching. This surface is also called a sliding surface (sliding manifold). Ideally, once intercepted, the switched control maintains the plants state trajectory on the surface for all subsequent time and the plants state trajectory slides along this surface. By proper design of the sliding surface, VSC attains conventional goals of control such as stabilization, tracking, regulation etc.

Sliding mode control law for DC-DC boost converter:

Its mathematical model can be derived as

$$\begin{cases} i_l = \frac{1}{L}\int (v_i u - v_o)dt \\ v_o = \frac{1}{c}\int (i_L - i_R)dt \end{cases}$$

where u represents the state of the switch Q_l and $\overline{u}$ is the inverse logic of u. A PID based SM controller is adopted. The control variable used is of the form:

$$x = \begin{bmatrix} x1 \\ x2 \\ x3 \end{bmatrix} = \begin{bmatrix} vref - \beta vo \\ \frac{d}{dt}(vref - \beta vo) \\ \int (vref - \beta vo) \end{bmatrix}$$

where, x_1, x_2 and x_3 are the voltage error, the voltage error dynamics and integral of the voltage error resp. and v_{ref} is the reference voltage.:

By substituting the behavioral models of the converters as derived in (1) and (2) in (3), the control variables for boost and bi-directional buck converters are found to be:

$$X_{boost} = \begin{bmatrix} vref - \beta vo \\ \frac{\beta vo}{RLC} + \frac{\beta}{LC}\int (vo - vi)\bar{u}dt \\ \int (vref - \beta vo) \end{bmatrix}$$

$$X_{\text{bi-buck}} = \begin{bmatrix} vref - \beta vo \\ \frac{\beta vo}{RLC} + \frac{\beta}{LC}\int(vo - viu)dt \\ \int(vref - \beta vo) \end{bmatrix}$$

Since the control variables makes use of three parameters, the instantaneous state of the system can be represented by:

$$S = \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3$$

An appropriate sliding mode control law is chosen that makes use of a switching function given by:

$$U = \begin{cases} 1 \text{ When } s > 0 \\ 0 \text{ When } s < 0 \end{cases}$$

Derivation of existence conditions

For SM controller to work, i.e. :

$$\lim_{S \to 0} S\dot{S} < 0$$

(A) Boost Converter Existence Condition:

For the boost converter:

$$\dot{S} = \alpha_1 \frac{d}{dt}(v_{ref} - \beta \frac{1}{c}\int i_c \, dt) + \alpha_2 \frac{d}{dt}(\frac{\beta vo}{RLC}) + \frac{\beta}{LC}\int(v_o - v_i)\bar{u}\, dt) + \alpha_3 \frac{d}{dt}\int(v_{ref} - \beta v_o)dt$$

Two cases arise as shown:

Case 1: $S \rightarrow 0^{+,} \dot{S} < 0$:

Substituting (7) in (8)

$$\dot{S} = -\alpha_1 \frac{\beta ic}{c} + \alpha_2 \left(\frac{\beta ic}{RLC2}\right) + \alpha_3 (v_{ref} - \beta v_0) < 0$$

Case 2: $S \rightarrow 0^{+,} \dot{S} > 0$:

Substituting (7) in (10)

$$\dot{S} = -\alpha_1 \frac{\beta ic}{c} + \alpha_2 \left(\frac{\beta ic}{RLC2} + \frac{\beta vo}{LC} + \frac{\beta vi}{LC}\right) + \alpha_3 (v_{ref} - \beta v_0) > 0$$

From (9) & (10) the existence condition for boost converter is found to be:

$$0 < \beta L\left(\frac{\alpha 1}{\alpha 2} - \frac{1}{RLC}\right) i_c - LC\frac{\alpha 3}{\alpha 2}(v_{ref} - \beta v_o) < \beta(v_o - vi)$$

The existence condition is used to arrive at the expression for ramp voltage and control voltage. This is done by applying the duty cycle constraint to (11) , yielding the expression:

$$0 < \frac{\beta(vo - vi) - \beta L\left(\frac{\alpha 1}{\alpha 2} - \frac{1}{RLC}\right)ic + LC\frac{\alpha 3}{\alpha 2}(vref - \beta v0)}{\beta\,(vo - vi)} < 1$$

Using (12) , the expression for control and ramp voltages are chosen as:

$$V_{control} = -K_{p1} i_c + K_{p2}(v_{ref} - \beta v_o) + \beta\,(v_o - v_i) \quad (13)$$

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$$V_{ramp} = \beta (v_o - v_i)$$

Where, $K_{p1} = \beta L \left(\frac{\alpha 1}{\alpha 2} - \frac{1}{RLC}\right)$, $K_{p2} = LC \left(\frac{\alpha 3}{\alpha 2}\right)$ and β = feedback factor.

Using control voltage equation, the sliding mode controller for boost converter can be modelled as shown in fig.

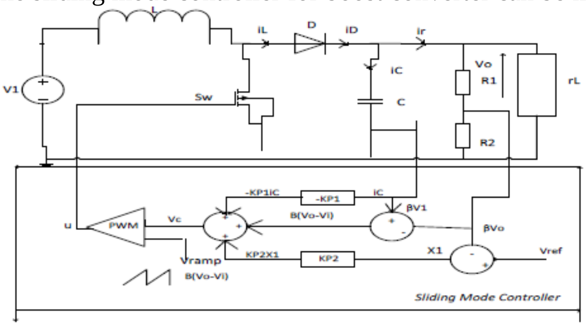

Fig 4 System modeling of sliding mode controller

TABLE NO 1.
ELECTRICAL SPECIFICATION FOR THE PV MODULE

S.NO	DESCRIPTION	PARAMETER	NOMINAL VALUE
1.	Maximum power	Pmax	71 W
2.	Voltage at Pmax	Vm	26.5 V
3.	Current at Pmax	Im	2.65 A
4.	Open circuit voltage	Voc	30 V
5.	Short circuit current	Isc	4.75 A
6.	Series resistance	Rs	5.1e-3 Ω
7.	Parallel resistance	Rp	Inf
8.	No. of cells	Ns	48
9.	Diode saturation current	Is	1 A

TABLE NO 2.
LIST OF PARAMETERS FOR CONTROLLER

S.NO	DESCRIPTION	PARAMETER	NOMINAL VALUE
1.	Input Voltage	Vin	26.5 V
2.	Capacitance	C	3000 µF
3.	Inductance	L	300 µH
4.	Switching frequency	F	100 kHz
5.	Load resistance	Rl	250 Ω
6.	Sliding mode controller gain	Kp1	1.25
		Kp2	0.121

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7.	PID controller gain, proportional constant	Kp	25
	Integral constant	Ki	12
	Derivative gain	Kd	0.5
8.	PI controller gain proportional constant	Kp	0.17
		Ki	15
9.	Expected voltage	Vo	48

III. SYSTEM MODELLING

3.1 Basic model for photovoltaic generation:

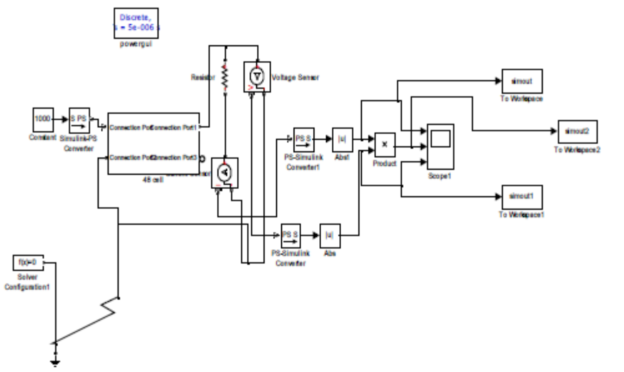


Fig 5 Simulated block diagram for photovoltaic Generation

3.2 Basic model of boost converter:

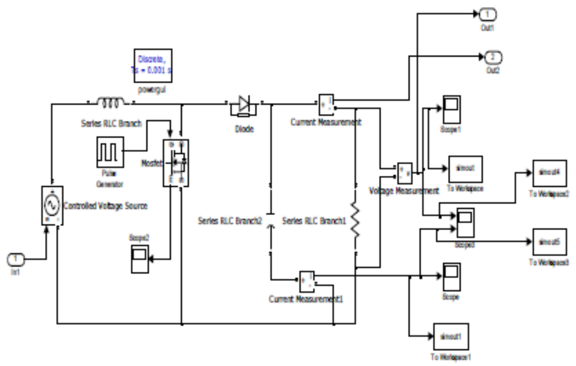


Fig 6 Simulated block diagram of boost converter

Result: For input voltage of Vin=26.5v, output voltage,

Vo=30V, and output current, Io=0.12 amp with nonlinearity up to 0.7 sec.

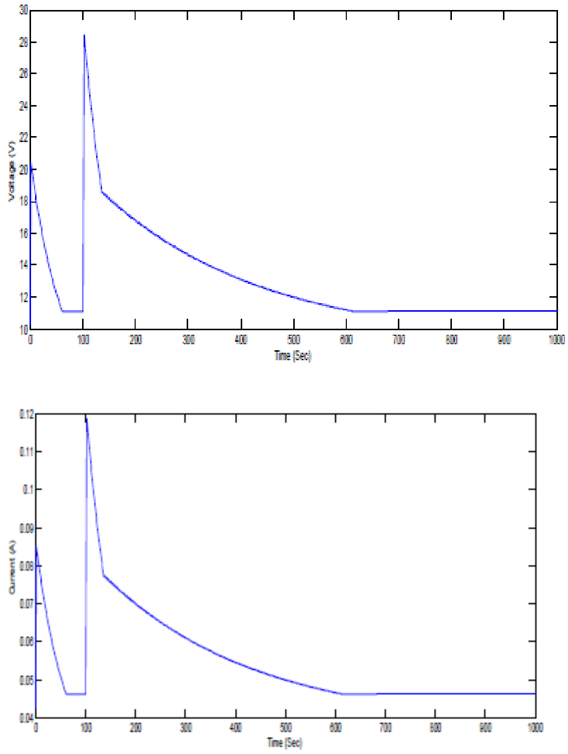


Fig 7 Simulation result for voltage and current of basic boost converter

3.3 Simulated block diagram of boost converter using PI controller:

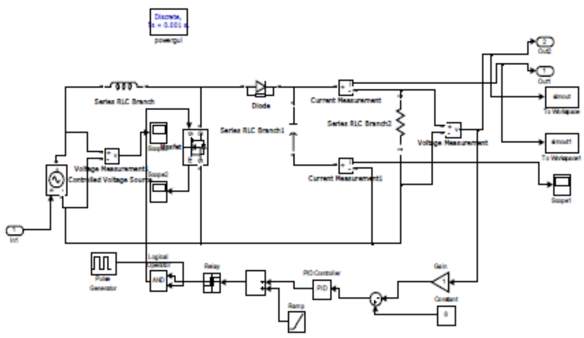


Fig 8 Simulated block diagram of boost converter using PI controller

Result: For input voltage of Vin=26.5v, output voltage,

Vo=48V, and output current, Io=0.2 amp with maximum drop of voltage from 24v to 25v at 0.4 Sec.

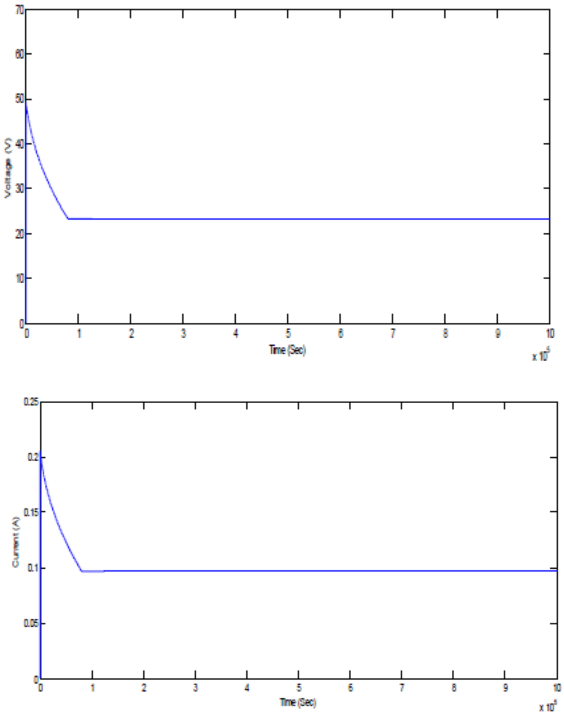


Fig 9 Simulation result for voltage and current of boost converter using PI controller

3.4 Simulated block diagram of boost converter using PID controller:

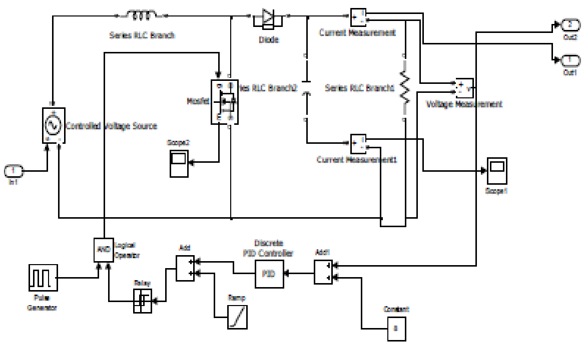
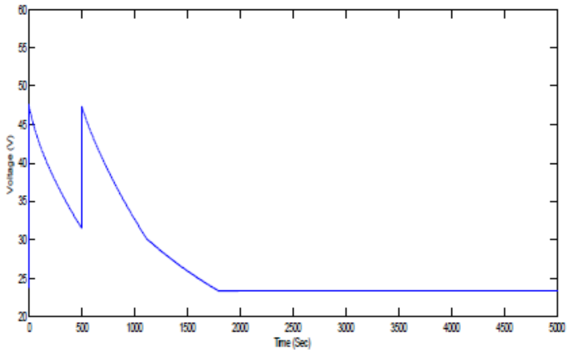


Fig 10 Simulated block diagram of boost converter using PID controller

Result: For input voltage of Vin=26.5v, output voltage,
Vo=48V, and output current, Io=0.16 amp with on linearity up to 0.8 sec.



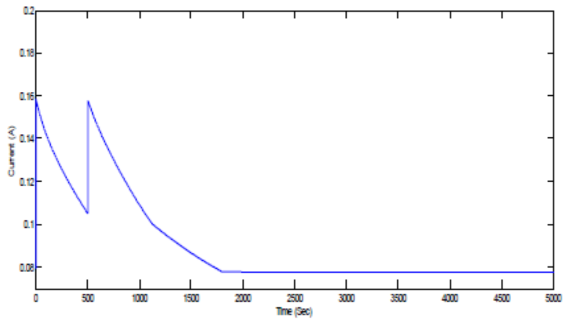


Fig 11 Simulation result for voltage and current of boost converter using PID controller

3.4 Simulated block diagram of boost converter using sliding mode controller:

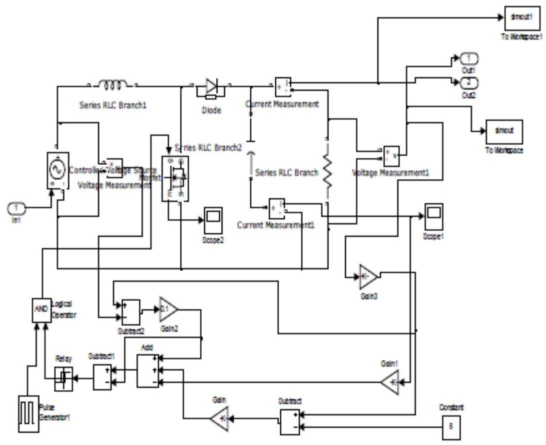
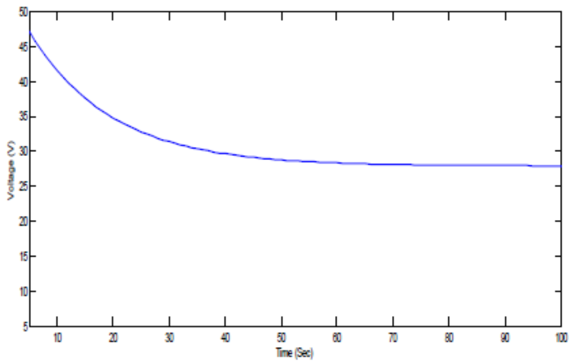


Fig 12 Simulation result for voltage and current of boost converter using sliding mode controller

Result: For input voltage of Vin=26.5v, output voltage,
Vo=48V, with linear curve.



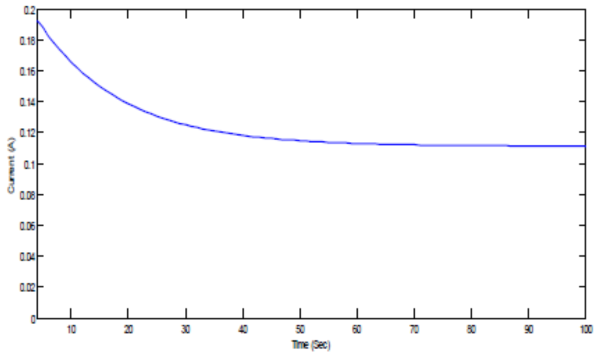


Fig 13 Simulation result for voltage and current of boost converter using sliding mode controller

TABLE NO. 3
RESULT COMPARISON FOR PI, PID AND SLIDING MODE CONTROLLER

Controller	Voltage profile	Settling time	Current profile
Without controller	30 volt with nonlinearity	0.8 Sec	0.11 amp
PI controller	48 volt to 26.5 volt linearity	0.4 Sec	0.2 amp
PID controller	48 volt to 26.5 volt with nonlinearity	0.8 Sec	0.2 amp
Sliding mode controller	48 volt with linearity	0.01	0.2 amp

IV. CONCLUSION

A comparison between the PWM based sliding mode controller, PID and PI controllers for dc-dc boost converter are highlighted. Performance analysis for controlling of dc-dc boost converter is evaluated in simulation under the internal losses and input voltage variation. Sliding mode controller and PI controller have the same overshoot voltage but voltage drop is more using PI controller.PID controller has maximum settling time as compared to sliding mode controller and PI controller. In order to test the robustness of the sliding mode control scheme, the input voltage is changed from 24v to 20v. This variation took place, at t =2.3sec, while the system was already stabilized to the desired voltage value. Due to the internal losses, the variation took place at 0.05 sec. PWM based sliding mode controller shows acceptable performance than PID and PI controller having lowest deviation from reference voltage under internal losses and input voltages changes. Using the sliding mode controller, the non-linearity and un-stability of power converters can be improved which is applicable in many engineering applications.

REFERENCES

[1] Marion, B., 2002, "A Method for Modeling the Current- Voltage Curve of a PV Module for Outdoor Conditions," Prog. Photovoltaics 10, pp. 205–214.
[2] Firor, K., 1985, "Rating PV Systems," Proc. 18th IEEE Photovoltaic Specialist Conference, Las Vegas, NV, October, pp. 1443–1448.
[3] D. Amomdechaphon, S. Premrudeepreechacham, and K. Higuchi, "Small grid-connected PV-system with lossless passive soft-switching technique, " ICCAS-SICE, 2009, vol., no., pp.424-429, 18-21 Aug. 2009.

[4] A. Durgadevi, S. Arulselvi, and S.P. Natarajan, "Photovoltaic modelling and its characteristics," International Conference on Emerging Trends in Electrical and Computer Technology (ICETECT), 2011, vol., no., pp.469-475, 23-24 March 2011.
[5] M.G Villalva, 1.R. Gazoli, and E.R. Filho, "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays, " IEEE Transactions on Power Electronics, , vo1.24, no.5, pp.1198-1208, May 2009.
[6] X. Weidong, W.G. Dunford, and A. Capel, "A novel modeling method for photovoltaic cells, " Power Electronics Specialists Coriference, 2004. PESC 04. 2004 IEEE 35th Annual , voi.3, no., pp. 1950- 1956 Vo1.3, 20-25 June 2004.
[7] E. Saloux, M. Sorinand and A. Teyssedou, "Explicit Model of Photovoltaic Panels to Determine Voltages and Currents at the Maximum Power Point, " CanmetENERG Y, Ottawa, Canada, Rep. CETC Number 2010-156, 2010.
[8] T. Esram, and P.L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques, " IEEE Transactions on Energy Conversion, vo1.22, no.2, pp.439-449, June 2007.
[9] H. S. Rauschenbach, Solar Cell Array Design Handbook. New York:Van Nostrand Reinhold, 1980.
[10] J. A. Gow and C. D. Manning, "Development of a photovoltaic array model for use in power-electronics simulation studies, " lEE Proc. Elect. Power Appl., vol. 146, no. 2, pp. 193-200, 1999.
[11] F.A. Himmelstoss, J.W. Kolar and F.C. Zach, “Analysis of a Smithpredictor-based-control concept eliminating the right-half plane zero of continuous mode boost and buck-boost DC/DC converters,” in Proceedings, International Conference on Industrial Electronics, Control and Instrumentation IECON, pp. 423–428, Nov. 1991.
[12] R. Venkataramanan, A. Sabanoivc, and S. ´Cuk, “Sliding mode control of DC-to-DC converters,” in Proceedings, IEEE Conference on Industrial Electronics, Control and Instrumentations (IECON), pp. 251–258, 1985.
[13] P. Mattavelli, L. Rossetto, G. Spiazzi, and P. Tenti, “General-purpose sliding-mode controller for dc/dc converter applications,” in IEEE Power Electronics Specialists Conference Record (PESC), pp. 609–615, June 1993.
[14] J. Mahdavi, A. Emadi, and H.A. Toliyat, “Application of state space averaging method to sliding mode control of PWM DC/DC converters,” in Proceedings, IEEE Conference on Industry Applications (IAS), vol. 2, pp. 820–827, Oct. 1997.
[15] S.C. Tan, Y.M. Lai, and Chi K. Tse, “A unified approach to the design of PWM based sliding mode voltage controller for basic DC–DC converters in continuous conduction mode”, IEEE Transactions on Circuits and Systems I, to appear.
[16] Sumita Dhali, P. Nageshwara Rao, Praveen Mande, K.Venkateswara Rao “PWM-Based Sliding Mode Controller for DC-DC Boost Converter”, International Journal of Engineering Research and Applications (IJERA) ISSN: 2248- 9622, Vol. 2, Issue 1, Jan-Feb 2012, pp.618-623.
[17] Syed Ali Akbar Hussainy, Revant Ganguli Tandon, Saurav Kumar, “PWM Based Sliding Mode Control of DC- DC Converters”, Manuscript received May 16, 2012; accepted May 26.2012.
[18] Anjum W, Husain AR, Abdul Aziz J, Abbasi MA, Alqaraghuli H (2020) Continuous dynamic sliding mode control strategy of PWM based voltage source inverter under load variations. PLoS ONE 15(2): e0228636. https://doi.org/10.1371/journal.pone.0228636
[19] Souvik Das, Mohd Salim Qureshi, Pankaj Swarnkar, “Design of integral sliding mode control for DC-DC converters”, Materials Today: Proceedings 5 (2018) 4290–4298.
[20] Y. Chaibi , M. Salhi, and A. El-jouni, **“**Sliding Mode Controllers for Standalone PV Systems: Modeling and Approach of Control”, Hindawi International Journal of Photoenergy Volume 2019, Article ID 5092078.
[21] M. E. Şahın, H. İ. Okumuş and H. Kahvecı, "Sliding mode control of PV powered DC/DC Buck-Boost converter with digital signal processor," 2015 17th European Conference on Power Electronics and Applications, 2015, pp. 1-8, doi: 10.1109/EPE.2015.7309361.