International Journal of Electrical Engineering & Emerging Technology, Vol. 03, No. 02, DEC 2020, pp 59-63

Nonlinear Controller for Buck Boost Converter for Photovoltaic System

A. R. GHANGHRO *[1], A. A. SAHITO [1], M. MEMON [1], A. M.SOOMRO [1]
[1] Department of Electrical Engineering, Mehran University Engineering and Technology Jamshoro,Pakistan
Corresponding author e-mail: (raqeeb001@gmail.com)
[**Received on:** 22-11-2020 **Accepted on**: 30-11-2020 **Published on:** 08-12-2020]

***Abstract*: This paper proposes the advancement and perfection design of nonlinear controller for buck boost converter to maintain output voltage of the PV generation to be used in DC micro grid by implementing SMC for Buck-Boost converter and will perform simulation based analysis of buck-boost converter connected with PV generation and controlled by proposed control scheme. There are two parts in the proposed controller scheme namely linear and non-linear portion. PI controller comprise of linear part hysteresis control implements nonlinear part. The PI controller and hysteresis control are used to control output voltage loop and inductor current ripple respectively. The selection of the ON/OFF points of hysteresis control are based on ripple produced in inductor current. The simulation of the proposed controller for buck-boost converter performed in MATLAB®/SIMULINK® software.**

Keywords: Buck-Boost converter; sliding mode controller; current and voltage. Introduction

I. INTRODUCTION

DC Micro grids with renewable energy generation as major source of energy are increasing rapidly around the world. Photovoltaic (PV) generation has great potential in Pakistan for small scale and large power generation. DC micro grid is an efficient power generation and distribution system for institutions in general and educational institutions in particular. Keeping in consideration the generation availability constraints and varying load demands, energy storage devices are becoming essential for micro grid applications (Sofla & Wang, (2011). Batteries are conventionally used for energy storage. With research on super capacitors, storage have become even more significant. DC-DC converters working on Pulse Width Modulation (PWM) based switching are highly efficient and popular (Rana & Banerjee, 2019). Buck-Boost converter is one the topology that can be used to increase or decrease the output voltage by varying duty cycle (Kaouane, Boukhelifa & Cheriti, 2016). Special topology of Buck Boost converter is Non-inverting Bi-directional Buck Boost converter for energy storage elements (Jia, 2019). Additionally these converters can be effectively used with solar power generation (Banaei & Bonab, 2019)

Buck-boost converter which either buck (i.e. step down) the input voltage level or boost (i.e. step up) the input voltage level (Memon et. al. 2018). But due to disturbances output voltage does not remain constant which means it changes according to disturbance, which is not permissible as most constant output voltage is required (Sahito et. al, 2014). Apart from disturbance changes in input voltage (i.e line variation) as present in converter connected to solar system, or load variation can be occurs which engender or cause variable output voltage (Mohapatra et. al. 2019) .To eliminate these problems many types of controller have been used such as Proportional integral and derivative (PID) controller, fuzzy logic controller and more recent sliding mode controller (SMC). The controller basically provides constant voltage even when subjected to internal or externally disturbance which occur in the system (Al-Baidhani, Kazimierczuk & Ordóñez, 2018). Although many controller have been used since many decade .there is no controller, which has all aforementioned properties. Due to advancement in technology PID controller has been used for many systems but it is a linear controller, which is one drawback of this controller and its performance is also affected due non-linear disturbances. SMC has been one of the advanced controller is a nonlinear controller (Chrifi-Alaoui. 2016). It is applicable for both linear and non-linear devices (Xie et. al. 2019).Lu, Tse & Dranga, (2005) thoroughly discussed the non-linear controller, Simulation results of SMC were compared with the results of other linear controller for Buck-Boost converter and better results were observed for SMC. Vasanthakumar & Srikanth, (2014), discussed the various types of controllers for DC-DC-converters and their advantages and disadvantage to set guidelines for selection of suitable controller. Barrado et. al. (2004) compared performance of Boost converter with PI, PID and SMC controller by performing simulations using MATLAB. Results of SMC controller were superior as compared to other two controllers. Komurcugil (2012) derived the state space equation for DC-DC converters and applied SMC for particular application to show its effectiveness. Chonsatidjamroen, Areerak, & Areerak, (2012) compared, through simulation performance of Buck converter using SMC with PID. Thus showed the advantages of SMC over PID linear controllers. Aharon, Kuperman, & Shmilovitz, (2014) designed and analyzed PID controller based modulator for Bidirectional Buck-Boost converter for energy storage devices in DC micro grid applications. Effectiveness of converter for such application was properly highlighted but use of PID controller had shown high settling time and overshoot. Callegaro et. al. (2016) developed cascaded control scheme for Buck-Boost converter for PV cell applications. Both loops were implemented by PID controllers. Developed controller performed well for steady state operation but high overshoot and settling time was observed for load variations. Cucuzzella, et. al. (2018) used SMC for DC Micro grid application focusing on load converters. Improved performance was observed for load variations. For PV generation and energy storage elements conventional converters were employed. He et.al. (2019) developed SMC based controller for DC-DC Buck-Boost converter to be used as constant power load. Performance of the controller is found suitable for modelling of the constant power loads in DC Micro grids.

II. DYNAMICS OF BUCK-BOOST CONVERTER

Among the DC-DC converter topologies, the buck-boost converter is most widely used. The buck-boost converter circuit which comprises of inductor, diode, capacitor and load as is shown in figure. It can be described in two states, first one is on state and second is off state. When the switch is closed current will start to flow as diode block the current so all the current will pass through the inductor which gets charged is known as On State .Off state: When switch is opened then power is supplied by the inductor to the load which was charged during on-state The main difference is the placement of inductor. So by changing the time on and time off of switch we can change the voltage level of the supply off of switch we can change the voltage level of the supply.

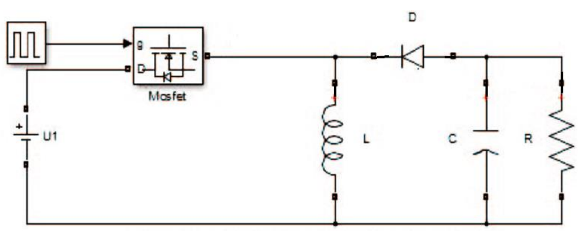

Fig. 1: Buck-Boost converter circuit diagram.

Selection of inductor

$L = \frac{V_1 D}{(I_{L1)(PP)} F_{(SW)}}$ Where

v_1= Input voltage, D= Duty cycle

$I_{L1=}$ Inductor current

$F_{(SW)}$= Switching frequency

Output voltage ripple

$V_{O(PP)} = \frac{I_O D}{f_{(sw)} C_O} + (\frac{I_O}{1-D} + \frac{I_{L1)(PP)}}{2}) ESRC_o$

Where;

$v_{o(pp)}$= Output voltage ripple D= Duty cycle

$f_{(sw)}$= Switching frequency

I_o = output current

$I_{L1=}$ Inductor current

Selection of capacitor

$C_{0MIN} = \frac{I_O \times D}{F_{SW}[V_{O(PP)} - \left(\frac{I_O}{1-D} + \frac{I_{L1)(PP)}}{2}\right) ESRC_O}$ Where;

$F_{(SW)}$= switching frequency

I_O = output current

$I_{L1=}$ Inductor current

D= Duty cycle

Duty cycle

$d = \frac{T_{ON}}{T}$ Where;

T_{ON}= Turning on time

T= Total time period

DC conversion ratio

$\frac{V_o}{V_1} = \frac{-D}{1-D}$

Where;

$V_{0=}$Voltage across load

V_1= supply voltage

D= Duty cycle

III. SLIDING MODE CONTROLLER

One of the main advantage of sliding mode controller is the stability under load, line and parameter variation. Compared to other nonlinear controllers, it is relatively easier to implement. There are many application of SMC, some of which include motor drives, generation units and plant operating on chemical conversion. (Khandekar and Patre, 2015). Sliding mode refers to the motion of the system when it slides along preset boundaries known as sliding surface. SMC is considered as hybrid dynamical system as system flows through a continuous state as well as different discrete control states. SMC can developed by two sections. Firstly designing a plane for switching that can describe the stated specification. Secondly a control law that sets switching function. To set the path of system to slide along the sliding surface, practically infinite gain is forced by SMC (Zhao, et. al. 2014). Switching function for SMC is defined as:

$$s(x, \dot{x}) = kx + \dot{x} \quad (5)$$

Where k is positive design scalar.

Eq. 5 decides which control action to use at any point on the sliding surface. Switching control for SMC is given as

$$u(t) = \begin{cases} -1 & \text{if } s(x,\dot{x}) > 0 \\ +1 & \text{if } s(x,\dot{x}) < 0 \end{cases} \quad (6)$$

Or it is also written as

$$u(t) = -\mathrm{sgn}(s(t)) \quad (7)$$

Where sgn(.) is a sign function.

ON or OFF control is done by switching between two states. There is no need to model any precise methodical modelling for controller. Very small portion of time is needed for discrete control law that is way better than nonindicating behavior. The selection of control law makes sure that when the sliding mode is achieved, it maintains the path for control. Control law transfer old state to new state depending on the sign of the state displacement describing sliding surface. Sliding mode is maintained by control system. Therefore switching function is viewed like plane where a varying path is maintained in a specified path. (Larik, et.al. 2009).

IV. Research Methodology

- Simulation model development for buck boost converter
- Implementation of SMC for buck boost converter connected with PV generation
- Simulation based analysis of SMC controller for buck boost converter with PV generation

V. Result discussion

The parameters of the Buck-Boost converter used in this work for the analysis are shown in Table 01. It is designed to maintain output voltage at 48 volts with varying input i. e. 10-60 volts. The proposed SMC contains two control portions i.e. voltage control loop based on PI controller and current loop based on hysteresis., The values of proportional and integral gains utilized by PI controller are calculated as Kp=1 and Ki=14.36 For voltage control loop while the switching point is selected as 0.25 and -0.25 as half of the inductor ripple current (0.5A) for hysteresis control. The complete simulation diagram of the buck-boost converter with proposed SMC shown in figure 03.

Table 1. Buck-Boost Converter Parameters

Parameter	Value
Output Voltage	48V
Supply Voltage	10 – 60 V
Capacitor (C)	220 µF
Inductor (L)	2 mH
Load Resistance (R)	3-8 Ω

The proposed control scheme of SMC for buck-boost converter connected with PV generation shown in Fig 2. It is evident from the figure that output voltage of buck-boost converter with proposed SMC contains no initial overshoot in voltage and it settles down in 0.15 sec Fig 3. Transient response for inductor current show no overshoot and settling time of 0.1 sec Fig: 4. Response for different Input voltage (Vs) Line variation are also observed through proposed scheme. The output voltage or response of Buck-Boost converter with proposed SMC when Input Voltage is 10 V, It is shown in figure that there is no overshoot and the settling time is 0.2 Sec Fig 5. When Input Voltage is 20 V, It is shown in figure that there is no overshoot and the settling time is 0.08 Sec Fig 6. When Input Voltage is 30 V. It is shown in figure that there is no overshoot and the settling time is 0.08 Sec Fig .7. When Input Voltage is 40 V. It is shown in figure that there is no overshoot and the settling time is 0.04 Sec Fig .8. When Input Voltage is 50 V. It is shown in figure that an Overshoot of 0.4V is observed with settling time of is 0.025 Sec Fig .9. When Input Voltage is 60 V. It is shown in figure that an Overshoot of 0.9V is observed with settling time of is 0.025 Sec Fig. 10. A step/Variable change in Input voltage is applied to check response against supply variation. Input Voltage is varied from 10 to 60 V. It is Shown in figure that an Overshoot of 3.25V is observed with settling time of is 0.5 Sec. It is evident that output voltage is unaffected by line variation Fig. 11(a) and 11(b). The performance of proposed controller is observed in terms of voltage response of buck-boost converter during load variations. When RL changes from 5Ω to 3Ω, voltage dip of 4 V is observed with a settling time of 0.1 sec as shown in Fig 12. When load resistance changes from 5 Ω to 8 Ω an overshoot of 3.5 V is observed with a settling time of 0.5 sec as shown in Fig 13.

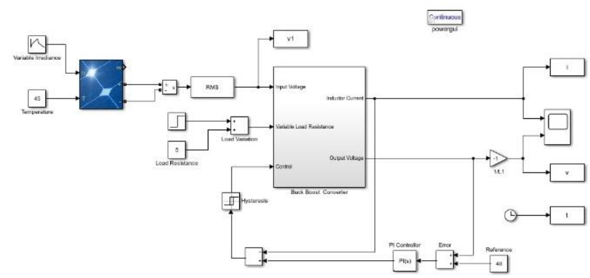

Fig. 2: Simulink model for sliding mode controller for buck-boost converter connected with PV generation

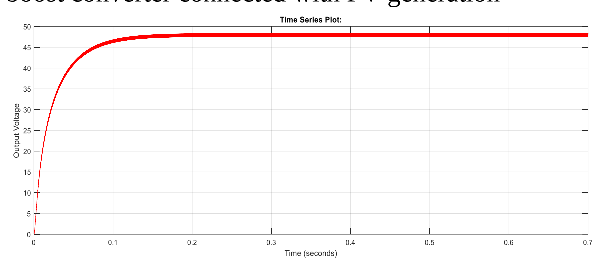

Fig. 3: Voltage response of buck-boost converter with proposed controller

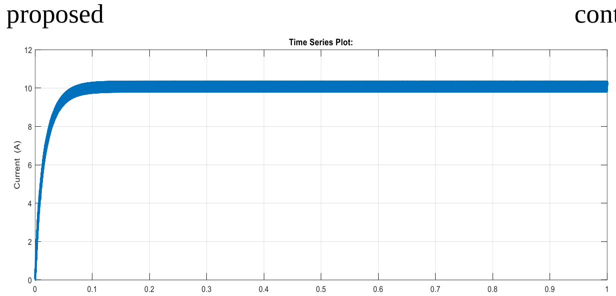

Fig. 4: Transient response for inductor current

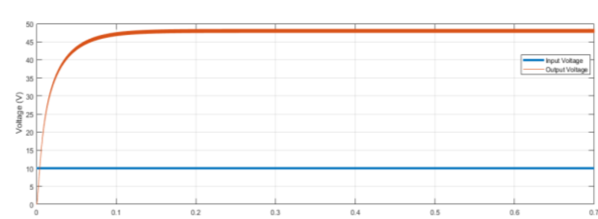

Fig. 5: Voltage response of buck-boost converter proposed controller at Vin= 10 V

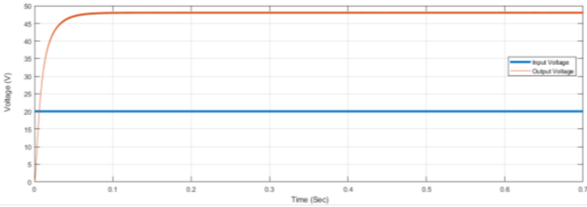

Fig. 6: Voltage response of buck-boost converter proposed controller at Vin=20V

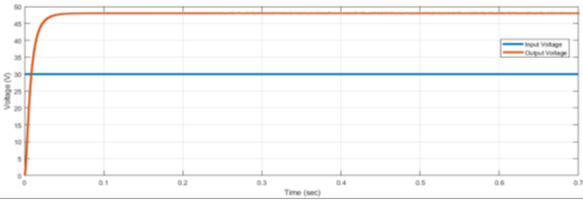

Fig. 7: Voltage response of buck-boost converter with proposed controller at Vin=30 V

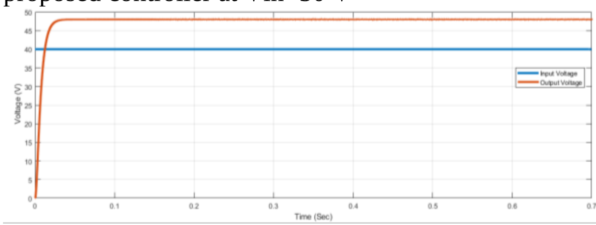

Fig. 8: Voltage response of buck-boost converter with proposed controller at Vin=40 V

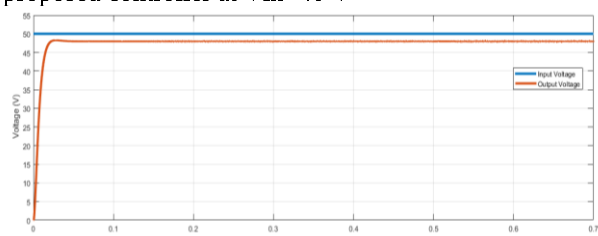

Fig. 9: Voltage response of buck-boost converter with proposed controller at Vin=50 V

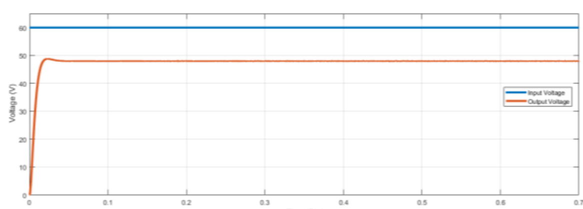

Fig. 10: Voltage response of buck-boost converter with proposed controller at Vin=50 V

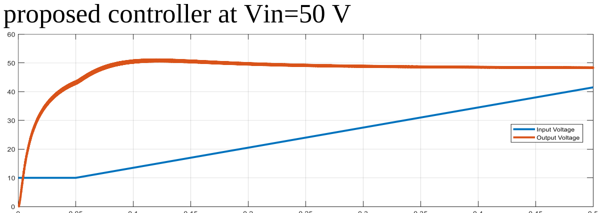

Fig. 11(a): Step change in Vin is changed from 10 to 60 V

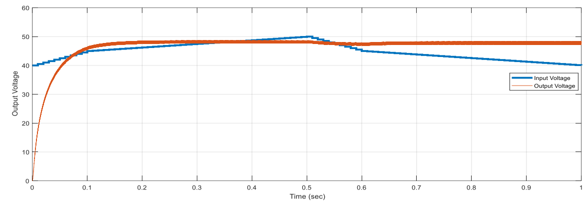

Fig. 11 (b): Variable change in Vin is changed from 10 to 60 V.

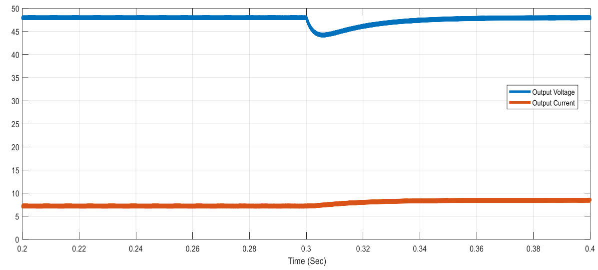

Fig. 12: Voltage response of proposed system when RL changes from 5Ω to 3Ω..

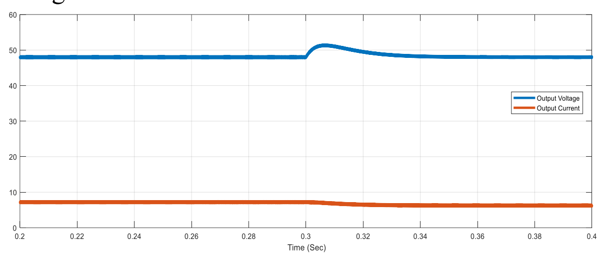

Fig. 13: Voltage response of proposed system when RL is changes from 5 Ω to 8 Ω.

VI. CONCLUSION

Proposed model of SMC is categorized into two sections; one is the linear part that is decided by PI controller and other is the nonlinear part employed by the discrete control of hysteresis. The simulation of buck-boost converter with proposed controller shows absence of overshoot in the voltage profile and inductor current waveform at initial transient and during the line variations except when input voltage has a continuous rate of change. For 60% increase in load resistance, overshoot in output voltage is 3.5 V and settling time is 0.5 seconds and For 60% decrease in load resistance, undershoot in output voltage is 4 V and settling time is 0.1 seconds. Settling time for line variation decreases with the increase in supply voltage, maximum settling time for output voltage is 0.5 seconds in case of continuous variation in input voltage, the minimum settling time is 0.025 seconds when input voltage is 60 volts. Simulation results shows satisfactory operation of buck-boost converter with proposed SMC to withstand all kinds of variations in input voltage due to PV cell

VII. ACKNOWLEDGEMENT

Authors are thankful to Mehran University of Engineering and Technology Jamshoro for providing necessary resources and guidance.

REFERENCES

[1] Mohapatra, T. K., Dey, A. K., Mohapatra, K. K., & Sahu, B. (2019). A novel non-isolated positive output voltage buck-boost converter. World Journal of Engineering, 16(1), 201-211.

[2] Banaei, M. R., & Bonab, H. A. F. (2019). A High Efficiency Non-Isolated Buck-Boost Converter Based on ZETA Converter. IEEE Transactions on Industrial Electronics.

[3] Sahito, A. A., Uqaili, M. A., Larik, A. S., & Mahar, M. A. (2014). Nonlinear controller design for buck converter to minimize transient disturbances. Science International, 26(3), 1033-1037.

[4] Rana, N., & Banerjee, S. (2019). Development of an Improved Input-Parallel Output-Series Buck-Boost Converter and Its Closed-Loop Control. IEEE Transactions on Industrial Electronics.

[5] Chrifi-Alaoui, L. (2016). Second Order Sliding Mode Control of DC-DC Converter used in the Photovoltaic System According an Adaptive MPPT. International Journal of Renewable Energy Research (IJRER), 6(2), 375-383.

[6] Memon, A. H., Baloach, M. H., Sahito, A. A., Soomro, A. M., & Memon, Z. A. (2018). Achieving High Input PF for CRM Buck-Buck/Boost PFC Converter. IEEE Access, 6, 79082-79093.

[7] Barrado, A., Lazaro, A., Pleite, J., Vazquez, R., Vazquez, J., & Olias, E. (2004,). Linear non-linear control (LnLc) for DC-DC buck converters: stability and transient response analysis. In Nineteenth Annual IEEE Applied Power Electronics Conference and Exposition, 2004. APEC'04. (Vol. 2, pp. 1329-1335).

[8] Chonsatidjamroen, S., Areerak, K. N., & Areerak, K. L. (2012). The optimal cascade pi controller design of buck converters. In 2012 9th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (pp. 1-4).

[9] Aharon, I., Kuperman, A., & Shmilovitz, D. (2014). Analysis of dual-carrier modulator for bidirectional noninverting buck–boost converter. IEEE Transactions on Power Electronics, 30(2), 840-848.

[10] Vasanthakumar, D., & Srikanth, V. (2014). DC-DC converter control using IP controller. In 2014 IEEE International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC), 245-249.

[11] Callegaro, L., Ciobotaru, M., Fletcher, J. E., Rios, P. A., & Pagano, D. J. (2016). Design of cascaded control loop for solar power optimizer based on a buck-boost converter. In 2016 IEEE 2nd Annual Southern Power Electronics Conference (SPEC). pp. 1-6.

[12] Cucuzzella, M., Lazzari, R., Trip, S., Rosti, S., Sandroni, C., & Ferrara, A. (2018). Sliding mode voltage control of boost converters in DC microgrids. Control Engineering Practice, 73, 161-170.

[13] Taheri, B., Sedaghat, M., Bagherpour, M. A., & Farhadi, P. (2019). A New Controller for DC-DC Converters Based on Sliding Mode Control Techniques. Journal of Control, Automation and Electrical Systems, 30(1), 63-74.

[14] Taheri, Bahman & Sedaghat, Mahsa & Amin Bagherpour, Mohammad & Farhadi, Payam. (2018). A New Controller for DC-DC Converters Based on Sliding Mode Control Techniques. Journal of Control, Automation and Electrical Systems.

[15] Sahito, A.A.; Uqaili, M.A.; Larik, A.S. and Maher, M.A. "Transient Response Improvement of Buck Converter through Sliding Mode controller", Sindh University Research Journal-SURJ (Science Series), Vol. 47, No. 4, 2015, pp. 559-662.

[16] Birjesh Naik and Axay Mehta Sliding Mode Controller with Modified Sliding Function for Buck Type Converters, IEEE International Symposium on Industrial Electronics (ISIE), Taipei Taiwan, pp. 15, 28-31May 2013.

[17] Bensaada, M., Stambouli, A. B., Bekhti, M., Della Krachai, S., Boukhris, L., Bellar, A., & Nasri, B. (2012). Sliding mode controller for buck DC-DC Converter. In IEE 9th International Multi-Conference on Systems, Signals and Devices (SSD), 1-6.

[18] Memon, M., Memon, H., Jiskani, S., Umer, F., Soomro, A., Sahito, A. (2018). Performance Improvement of Buck Converter with Sliding Mode Controller. In Indian Journal of Science and Technology, 1-7.

[19] Ahmed, M. (2004) "Sliding mode control for switched mode power supplies", PhD Thesis, Lappeenranta University of Technology, Finland

[20] HuangfuYigeng, Wang Bo, Ma Ruiqing and Li Yuren,Comparison for buck converter with PI, Sliding Mode, Dynamic Sliding Mode Control, 15th International Conference on Electrical Machines and Systems (ICEMS), Sapporo, pp. 1-4, 21-24Oct 2012