Proc. of the 1st International Conference on Electrical, Communication and Computer Engineering (ICECCE)
24-25 July 2019, Swat, Pakistan

Performance Enhancement of Power Converters for PV-Based Microgrid using Model Predictive Control

Habib Ur Rahman Habib
Department of Electrical Engineering, University of Engineering and Technology Taxila, Pakistan;
hr.habib@uettaxila.edu.pk

Shaorong Wang
State Key Laboratory of Advanced Electromagnetic Engineering and Technology,Huazhong University of Science and Technology, Wuhan, China
wsrwy96@vip.sina.com

Mahmoud F. Elmorshedy
Department of Electrical Power and Engineering Tanta University, Egypt;
State Key Laboratory of Advanced Electromagnetic Engineering and Technology,HUST, Wuhan, China
https://orcid.org/0000-0001-7900-4351

Asad Waqar
Department of Electrical Engineering, Bahria University, Islamabad, Pakistan
asadwaqar.buic@bahria.edu.pk

Rasool M. Imran
State Key Laboratory of Advanced Electromagnetic Engineering and Technology,Huazhong University of Science and Technology, Wuhan, China
rasool_mhmd@hust.edu.cn

Kotb M. Kotb
Faculty of Engineering, Tanta University, Egypt;
Budapest University of Technology and Economics, Budapest, Hungary
kotb.mohamed@f-eng.tanta.edu.eg

***Abstract*—PV-based renewable energy systems are integrated in microgrids (MGs) throughout power electronic converters. During external disturbances of abrupt load variation and PV generation fluctuation, controllers play the most key role in regulating the system performance. In this paper, a proposed combination control method of model predictive control (MPC) and sliding mode control (SMC) for moderating the power converters is presented. The interlinking inverter is controlled via applying MPC while DC-DC converter is controlled by SMC. MPC is well known as most reliable and modern approach for non-linear systems to compensate noise and handle modeling inaccuracies for efficient load voltage profile. On the other hand, SMC is considered as the most stable controller with highly robust operation for DC-DC converters. Intermittency nature of renewable energy systems and abrupt load variation have a severe impact on load voltage quality. Keeping in view the sophisticated control attributes of MPC and SMC, inner and outer control loops with primary droop control are designed for interlinking converter by using MPC while SMC is designed for the DC-DC boost converter. Controller performance is analyzed through simulations with fluctuating generation, and variable loads. Unlike conventional cascaded PI controller, proposed MPC strategy is simple, robust with fast dynamic response.**

Keywords—model predictive control (MPC), DC-AC interlinking converter, PV, microgrid, renewable energy resources, DC-DC converters, sliding mode control (SMC)

I. INTRODUCTION

Due to the increasing demand of electricity, more and more sources such as PV, wind, hydro, energy storage, modern loads, fuel cells, hybrid AC/DC microgrids in remote islanded and grid-connected are increasing day by day. Efficient usage of renewable energy resources in the world requires reliable and robust control schemes to incorporate more and more energy for fulfilling consumers demand. A variety of control strategies are reported in literature. Conventional PID controller needs tuning and different algorithms are required for this purpose which is time consuming process. Power fluctuation of renewable PV generation can cause voltage variation on DC side of interlinking converter and can effect on the power quality of the AC bus. Traditional PI control techniques has been used in many previous work for controlling the interlinking converters in hybrid microgrid. The conventional PID controls in microgrid are used for both inner current loop and outer voltage loop along with PWM generation to generate the switching sequence for the used converter. Cascade control including primary voltage and current control have been used in PI based control systems which may affect the performance of the droop control [1]. For the hybrid microgrids systems, PID controllers are normally used for both inner current and outer voltage control loops to control DC-DC converters and DC-AC interlinking inverters. In islanded microgrid, DC-DC converters are used to ensure stable DC voltage while the interlinking inverters maintain the voltage and frequency for the AC side of grid. Due to necessity of DC-DC and DC-AC converters in microgrids, conventional cascaded PI control may affect the voltage quality on both DC and AC buses [2]. Moreover, variable generation and demand may not be effectively controlled by conventional PI controllers [3]. Sophisticated advance controllers are therefore required to effectively control hybrid microgrids for stable operation and output power quality.

Recent literature is using MPC for optimal switching states of interlinking DC-AC converters by using well defined cost function. The main advantages of the model predictive control are no need to any tuning process, simple implementation and better performance. In [4], secondary frequency control for two parallel inverters is employed by using MPC and smith predictor (SM) approach for islanded microgrid. Current controlled DC-DC buck-boost converter using MPC is applied for energy storage systems (ESS) [5]. MPC with direct power is simulated to address unbalanced grid voltages without using PWM and PLL phenomenon [6]. For AC islanded microgrid, distributed hierarchical primary control is based on SMC inner current control and H-infinity controller is used for outer voltage loop for grid supporting

978-1-7281-3825-1/19/$31.00 ©2019 IEEE.

inverters (GSI) [7]. PI based primary control is used in [8] for hierarchical control of parallel inverters without using MPC approach. In [9], voltage MPC based inverter is used with constant DC source for islanded grid operation with nonlinear load. Three phase rectifier based on PI-hysteresis control is used as grid-connected converter with DC source as grid voltage. As for as time delay is concerned, MPC is more robust under unknown conditions of communication delays. Reactive power exchanging for dynamic load scenarios is also investigated in [10]. Seamless transition from islanded mode to grid-connected mode for single-phase inverter with MPC algorithm is implemented in [11]. By using model predictive voltage control (MPVC) strategy in [12], electric vehicles are used as DC load for voltage stability in islanded microgrid. Voltage correction approach with multistep prediction phenomenon is implemented by using horizon based MPC [13]. Fuzzy based MPC strategy is applied on bidirectional DC-DC converters for energy storage system (ESS) [14]. PV integrated islanded microgrid is investigated with ESS by incorporating secondary MPC based frequency/voltage control and constant DC source is used for PV generation [15]. PWM based MPC for voltage and power control of photovoltaic energy storage system (PV-ESS) based microgrid in analyzed in [15]. Most of the previous presented papers did not consider intermittent nature of PV generation. To the best of author knowledge, no paper discussed SMC-MPC strategy for controlling DC-DC boost and DC-AC interlinking converters respectively. PV generation need to install solar panels which require huge area. Moreover, MPC based past years researches did not show any practical aspects by highlighting any feasible area for PV generation capacity.

In this paper, hybrid approach consisting of SMC-MPC based control strategy is proposed with practical application of PV integrated micro grid for Taxila Engineering University which is located in Punjab province of Pakistan. Microgrid topology is shown in Fig. 1. The sliding mode control is used as more robust and viable option to mitigate effect of PV fluctuation on DC bus. Variable DC voltage-controlled source is used for practical considerations of PV fluctuating generation. Both DC and AC buses are connected through interlinking converter which is two-level three-phase voltage source inverter (VSI). Moreover, interlinking inverter is then controlled with MPVC algorithm to effectively control voltage under fluctuations and unbalanced load conditions. MPVC avoids inner current and outer voltage loops so that no tuning process is required. SVPWM strategy is part of MPVC algorithm which eliminate chances of complexity within control structure. The main contributions of this paper are as follows:

- For PV generation, PI control is replaced with proposed SMC based control of DC-DC boost converter. By using SMC scheme, better DC voltage can be maintained with less overshoot and DC voltage oscillations under variable and fluctuating PV generation.
- Unlike traditional PID control, MPC strategy is applied for interlinking converter control, which do not need any tuning process or complex modulation. Moreover, better quality voltage on AC side of interlinking converters can also be maintained.
- SMC-MPC cascaded control scheme is proposed.

This paper is organized as follows; section II discusses PV generation, section III presents SMC control strategy for DC-DC boost converter, section IV is focused on MPVC strategy for interlinking converter, section V shows simulation results and finally conclusion is mentioned in section VI.

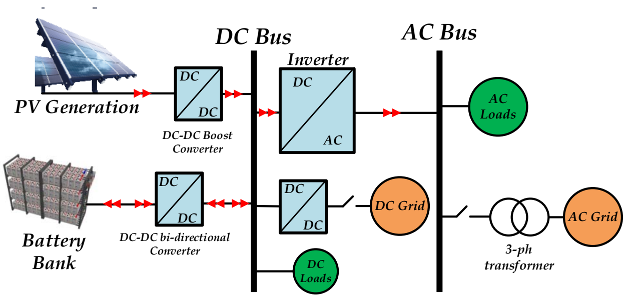

Fig. 1. Typical microgrid topology

II. PV Generation

Solar generation is playing a vital role for the electricity demand with China, USA, and India as the top most countries in PV installation [16]. Due to the lower prices of solar panels, new markets are opened from Africa and the Middle East to Asia and Latin America [17]. Module prices are stabilized, while production costs are continued to fall and solar cell efficiencies increased steadily [18]. Main power generation authorities in Pakistan are WAPDA (Water & Power Development Authority), KESC (Karachi Electric Supply Company), IPPs (Independent Power Producers) and PAEC (Pakistan Atomic Energy Commission) [19]. Due to high transmission losses and very high load demand, these all power producers are unable to fulfill the energy requirements of Pakistan. Therefore, integration of distributed energy resources in distribution network is indispensable. Pakistan is rich of renewable energy resources which include solar, wind, and micro hydro. The city of Taxila is historical place for international community and many umpires were contending for its control with its origination from 1000 BC. It was announced world heritage site of UNESCO in 1980. Taxila is top tourist site from 2006 onwards [20]. It is located 35 km away from the twin cities of Rawalpindi and Islamabad on the main Rawalpindi-Peshawar highway. The university of engineering and technology Taxila is located at Taxila at a distance of 5 km from the city. The campus covers an area of 163 acres [21]. In current scenario, university feeder is connected with main grid and backup two diesel generators of 312 kVA each are already installed during load shedding. 660 V and 878 km long Matiari to Lahore DC transmission line is under construction as part of CPEC (china Pakistan economic corridor) [22] which will begin new horizon for integrated control of microgrid based distributed generations. Detailed analysis still needs deep investigation for effective utilization of these resources in Pakistan.

According to weather in Pakistan, duration of the day varies significantly throughout the year. The longest day is June 20 at 14:24 hours of day while the shortest day is December 21 at 9:55 hours of day. Load is categorized as critical, and non-critical. During insufficient PV generation, non-critical load can be cut-off. Night load will be fed from main grid which is available at proposed location of Taxila University with two stand-by diesel generators. Proposed site area for installation of solar panels is new parking area of the university which is located at 33°46'N, 72°49.4'E. The solar energy at parking area is considered for the simulation. Daily incident solar energy/irradiance available for horizontal surface can be calculated by [23]:

$$H_O = \frac{24.k.L_{SC}}{\pi}\left[\mathrm{Cos}\,\sigma\,\mathrm{Cos}\,\varphi\,\mathrm{Sin}\,w_{sr} + w_{sr}\,\mathrm{Sin}\,\sigma\,\mathrm{Sin}\,\varphi\right] \tag{1}$$

$$L = k.L_{SC} \tag{2}$$

$$k = 1 + 0.033\cos\left(\frac{360N}{365}\right) \tag{3}$$

$$w = w_{sr} \tag{4}$$

where σ is declination, φ is latitude, w is hour angle, k is clearness index, N is day of year, L is solar insolation in kW/m2, LSC is the mean solar constant and is taken as 1.37. The daily incident solar energy/irradiance available on tilted surface where β is tilted angle and is varied every day is represented by:

$$H_{ot} = \frac{24.k.L_{SC}}{\pi}\left[\mathrm{Cos}\,\sigma\,\mathrm{Cos}(\varphi-\beta)\,\mathrm{Sin}\,w_{srt} + w_{srt}\,\mathrm{Sin}\,\sigma\,\mathrm{Sin}(\varphi-\beta)\right] \tag{5}$$

$$w_{sr} = \mathrm{Cos}^{-1}\left(-\tan\sigma\tan\varphi\right) \tag{6}$$

$$w_{sr\beta} = \mathrm{Cos}^{-1}\left(-\tan(\varphi-\beta)\tan\sigma\right) \tag{7}$$

$$w_{srt} = \min(w_{sr}, w_{sr\beta}) \tag{8}$$

PV sizing is calculated using the following relation:

$$Wh_{PV} = \eta.A_i.H_{ot.\min} \tag{9}$$

Parking rooftop PV system is proposed for parking location with the detailed specifications that are listed in Table I.

III. SMC FOR DC-DC BOOST CONVERTER

For variable load conditions, the traditional PI based control techniques do not produce adequate results [24]. Therefore, PWM based SMC is used to control variable structured DC-DC converters[25]. Fig. 2 shows the equivalent circuit of the boost converter with switched ON and OFF conditions. L, C, R, V_i, and V_o are the inductor, capacitor, resistor, input and output voltage. State space modeling of the DC-DC boost converter is as follows [26]:

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} V_{ref} - \beta V_o \\ \frac{d}{dt}(V_{ref} - \beta V_o) \\ \int (V_{ref} - \beta V_o)dt \end{bmatrix} \tag{10}$$

where xi (i=1, 2, 3) are voltage errors, V_{ref} is the reference voltage and β is feedback ratio. The SMC based law for switching function is given by:

$$u = \begin{cases} 1 & when\ S > 0 \\ 0 & when\ S < 0 \end{cases} \tag{11}$$

$$S = \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 \tag{12}$$

where S is state trajectory and α_i (i=1, 2, 3) are the sliding coefficients.

TABLE I. DESIGN SPECIFICATIONS OF PV SYSTEM

Parameter	Value	Units
Average monthly load	250,000	kWh/month
Latitude	33.77	Degree
PV efficiency	16	%
Estate area	13,988.78	m^2
PV panel size	1 x 1.4	m^2
Number of PV panels	100	-
Power per panel	1.2	kW/ m^2
Intrinsic area (Ai)	10,760.6	m^2

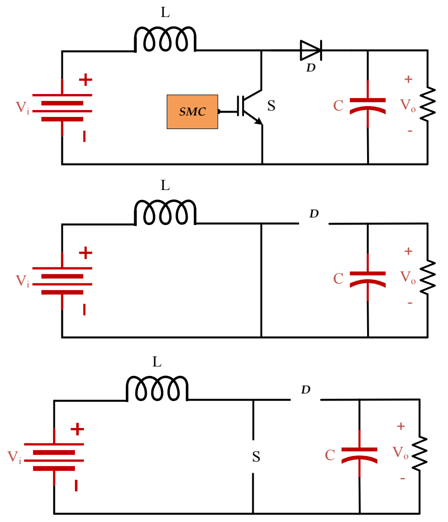

Fig. 2. Boost converter with ON and OFF conditions

Hitting, existence and stability are the three conditions [27] that can be satisfied by selecting suitable values of the sliding coefficients [28]. Fig. 3 shows SMC for boost converter Hitting condition ensures the trajectory of the movement within defined vicinity of sliding plane [26] while existence and stability conditions ensures convergence trajectory and stopping at equilibrium respectively [27]. Control signal for the DC-DC boost converter is based on the following condition [29].

$$0 < -i_C\beta L\left(\frac{\alpha_1}{\alpha_2} - \frac{1}{RC}\right) + \frac{\alpha_3}{\alpha_2}\left(V_{ref} - \beta V_o\right)LC + \beta(V_o - V_i) < \beta(V_o - V_i) \tag{13}$$

$$\begin{aligned} K_{p1} &= \beta L\left(\frac{\alpha_1}{\alpha_2} - \frac{1}{RC}\right) \\ K_{p2} &= \frac{\alpha_3}{\alpha_2}LC \end{aligned} \tag{14}$$

Sliding coefficients are carefully chosen based on system dynamics which depends on setting time (Ts) and damping ratio (ζ) which are:

$$\begin{aligned} T_s &= 5\tau_s \\ \frac{\alpha_1}{\alpha_2} &= \frac{10}{T_s} \\ \frac{\alpha_3}{\alpha_2} &= \frac{25}{\xi_s^2 T_s^2} \end{aligned} \tag{15}$$

where τ_s is time constant and β is tilted angle.

Control diagram for boost converter is shown in Fig. 3. Gain parameters (K_{p1} and K_{p2}) are 1.58 and 1220 respectively. Other design parameters of boost converter are listed in Table II.

TABLE II. DESIGN SPECIFICATIONS OF BOOST CONVERTER

Parameter	Value	Units
Input voltage	500	Volts
AC bus voltage (phase-phase)	380	Volts
Input voltage deviation	100	Volts
Load Resistance	60	Ω
Line resistance	0.6	Ω
Inductance L	300	µH
Inductor resistance	0.14	Ω
Capacitance	220	µF
Capacitor ESR	0.025	Ω
switching frequency	200	kHz
Output voltage	700	Volts

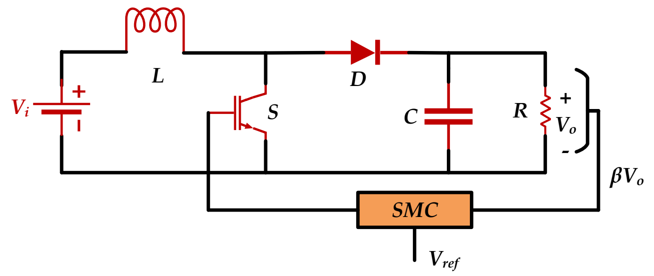

Fig. 3. SMC of DC-DC boost converter

IV. MPC FOR DC-AC CONVERTER

For balanced and smooth output load voltage of isolated microgrid for single interlinking converter, filter capacitor voltage can be controlled through MPVC. Fig. 4 shows microgrid topology with converter.

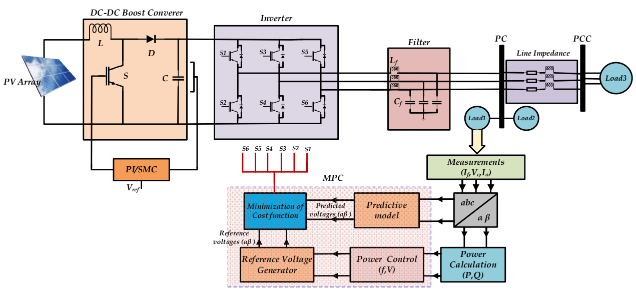

Fig. 4. Simulink diagram of microgrid topology

The mathematical model of the LC filter and inverter are described as follows:

$$C\frac{dV_c}{dt} = I_f - I_o \tag{16}$$

$$V_i = I_f R + C\frac{dI_f}{dt} + V_c \tag{17}$$

Based on the continuous state space model, equations (16) and (17) can be represented as follows:

$$\frac{dx}{dt} = Ax + By \tag{18}$$

$$x = \begin{bmatrix} V_c \\ I_f \end{bmatrix}, \quad y = \begin{bmatrix} V_i \\ I_o \end{bmatrix} \tag{19}$$

$$A = \begin{pmatrix} 0 & \frac{1}{C} \\ -\frac{1}{L} & -\frac{R}{L} \end{pmatrix}, B = \begin{pmatrix} 0 & -\frac{1}{C} \\ \frac{1}{L} & 0 \end{pmatrix} \tag{20}$$

In order to find voltage at next sampling instant, the discrete state space modeling is calculated by

$$x(k+1) = e^{T_s.A}\,.\,x(k) + A^{-1}.(e^{T_s.A} - I_{2X2}).B.y(k) \tag{21}$$

By solving (21) for discrete model, the following equation can be obtained

$$\begin{bmatrix} V_{cj} \\ I_{fj} \end{bmatrix}^{k+1} = A_d \begin{bmatrix} V_{cj} \\ I_{fj} \end{bmatrix}^{k} + B_d \begin{bmatrix} V_{ij} \\ I_{oj} \end{bmatrix}, \quad for\ j = \alpha, \beta \tag{22}$$

where $A_d = e^{T_s A}, B_d = \frac{B}{A}(A_d - I_{2X2})$ and V_i is the voltage vector and it can be expressed as follows [15]:

$$V_i = \begin{bmatrix} S_a V_{dc} - \left(\frac{S_a+S_b+S_c}{3}\right)V_{dc} \\ S_b V_{dc} - \left(\frac{S_a+S_b+S_c}{3}\right)V_{dc} \\ S_c V_{dc} - \left(\frac{S_a+S_b+S_c}{3}\right)V_{dc} \end{bmatrix} = \begin{bmatrix} V_a - V_n \\ V_b - V_n \\ V_c - V_n \end{bmatrix} = \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \tag{23}$$

$$V_i = \begin{cases} \frac{2}{3}V_{dc}e^{j(i-1)\frac{\pi}{3}} & for\ \ i = 1,2,...6 \\ 0 & for\ \ i = 0,7 \end{cases}$$

The cost function can be written as follows:

$$g_v = \sum_{j=1}^{n}\left[(V_{c\alpha}^{ref} - V_{c\alpha}^{k+j})^2 + V_{c\beta}^{ref} - V_{c\beta}^{k+j})^2\right] \tag{24}$$

Cost function minimizes difference between reference and predicted capacitor output voltage vectors in each iteration. Cost function and voltage vector having minimum g_v will be selected for optimal switching of interlinking converter. Block diagram for MPVC based topology is shown in Fig. 4.

V. SIMULATION RESULTS

MATLAB/Simulink toolbox is used to replicate the complete system. SMC of DC-DC boost converter is used to stabilize PV fluctuating output voltage while MPVC of interlinking converter stabilizes the terminal load voltage under load power variations.

Case 1: Algorithm for estimating average solar irradiance

Equations 1 through 4 are used to calculate average solar irradiance for smooth surface while equations 5 through 8 are used for tilted surface with angles ranging from zero to 30 degrees. Figs. 5 shows the annual average solar radiation curves in the previous selected region for both smooth as well as tilted surfaces respectively.

Case 2: Constant DC-bus voltage with SMC control

For the input of boost converter, variable DC source is taken as a fluctuating PV generation. Fig. 6 clearly shows that constant DC voltage is maintained by the proposed SMC control irrespective of the variations in PV generation and load.

Case 3: PWM based -PI control for interlinking inverter

Figs. 7 to 10 show the output load currents and load voltages respectively. Load voltages are not properly controlled with PWM based PI control as the magnitude is continuously varying during dynamic behavior of load. Load currents waveform also shows unequal magnitude of all three phases. Pure sinusoidal waveform is not obtained during PI control where dynamic response is comparatively slow.

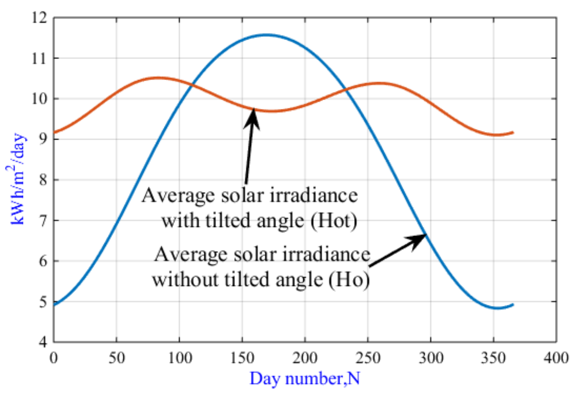

Fig. 5. Average solar irradiance without/with tilted angle

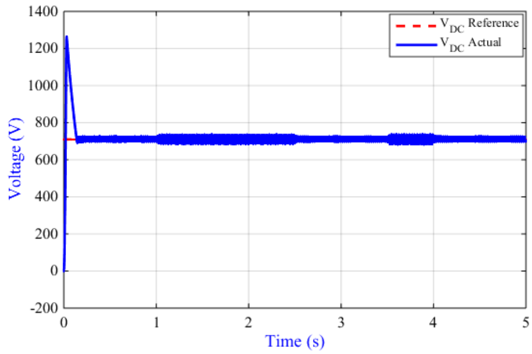

Fig. 6. DC bus voltage due to PV fluctuating

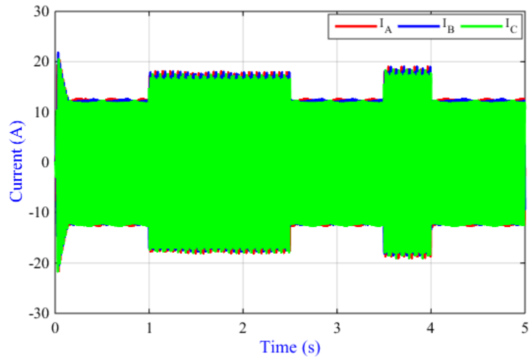

Fig. 7. Three phase Load currents

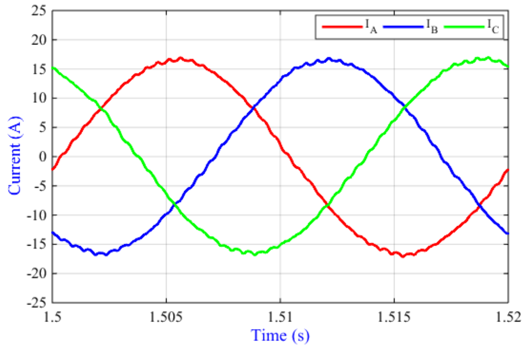

Fig. 8. Zoomed load currents of each phase

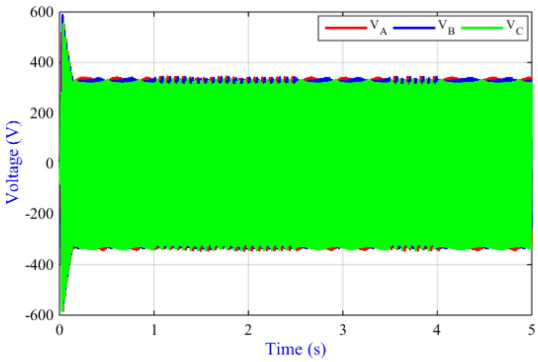

Fig. 9. Three phase output load voltages

TABLE III. THD % FOR BOTH PI AND MPC (311V, 50HZ)

CONTROLLER	THD %
PI	2.23 %
MPC	0.86 %

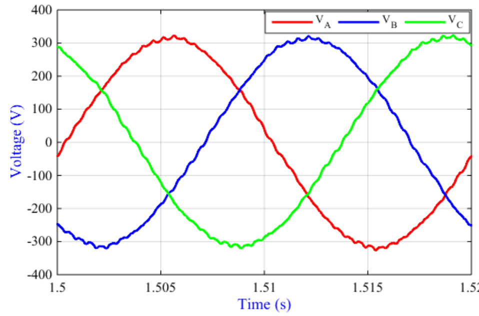

Fig. 10. Zoomed output load voltages of each phase

Case 4: MPVC configuration for interlinking inverter

Only interlinking converter with variable DC input voltage signal is used to check robustness of MPVC algorithm. It is clearly shown that MPVC strategy works well for both scenarios. Fig. 11 and Fig. 12 show the three-phase load currents while Fig. 13 and Fig.14 show the three - phase load voltages. It is evident from simulations results that MPVC control strategy is fast towards dynamic behavior of the system with simple controller as compared to traditional PWM based PI controllers. Table III shows THD values for both PI and MPC controllers.

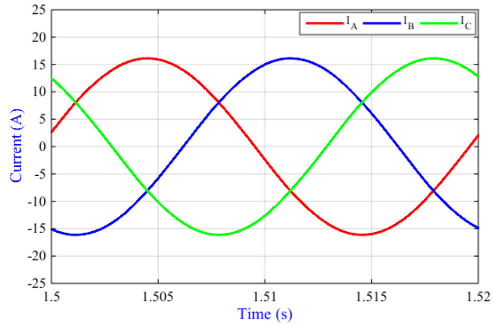

Fig. 11. Zoomed load currents of each phase

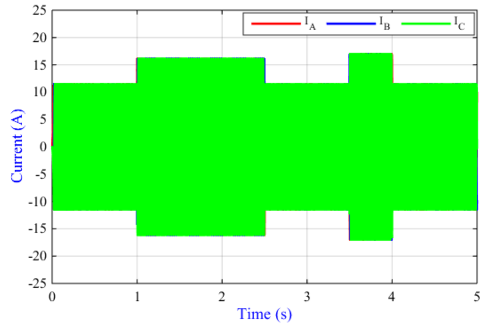

Fig. 12. Three phase Load currents

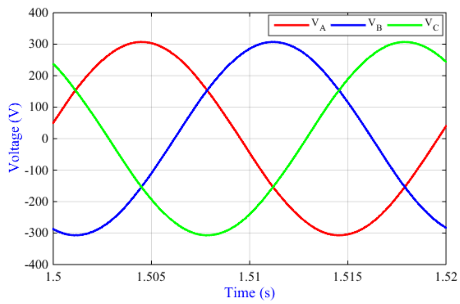

Fig. 13. Zoomed output load voltages of each phase

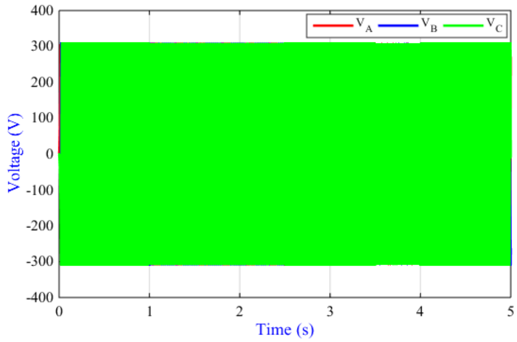

Fig. 14. Three phase output load voltages

VI. CONLUSIONS

Model predictive control and sliding mode control under intermittent source and variable load for PV integrated hybrid microgrid is proposed in this paper. Conventional PI controller scheme is replaced with more robust SMC-MPC control strategy. This strategy avoids complicated feedback loops. Fast dynamic response can be achieved without any time taking tuning mechanism. SMC is used to obtain constant DC bus voltage from fluctuating PV generation while MPVC with primary droop control is used for controlling interlinking inverter for maintaining constant load voltage under variable load conditions. SVPWM based proposed MPC strategy is simple and robust towards power generation fluctuation and variable demand scenarios as compared to PWM based PI control.

REFERENCES

[1] Y. Shan, J. Hu, K. W. Chan, Q. Fu, and J. M. Guerrero, "Model Predictive Control of Bidirectional DC-DC Converters and AC/DC Interlinking Converters - A New Control Method for PV-Wind-Battery Microgrids," *IEEE Trans. Sustain. Energy*, vol. PP, no. c, p. 1, 2018.

[2] A. J. Babqi and A. H. Etemadi, "MPC-based microgrid control with supplementary fault current limitation and smooth transition mechanisms," *IET Gener. Transm. Distrib.*, vol. 11, no. 9, pp. 2164–2172, 2017.

[3] Y. Shan, J. Hu, Z. Li, and J. M. Guerrero, "A Model Predictive Control for Renewable Energy Based AC Microgrids Without Any PID Regulators," *IEEE Trans. Power Electron.*, vol. 33, no. 11, pp. 9122–9126, 2018.

[4] C. Ahumada, R. Cárdenas, D. Sáez, and J. M. Guerrero, "Secondary Control Strategies for Frequency Restoration in Islanded Microgrids With Consideration of Communication Delays," *IEEE Trans. Smart Grid*, vol. 7, no. 3, pp. 1430–1441, 2016.

[5] X. Zhang, B. Wang, U. Manandhar, H. B. Gooi, and G. Foo, "A Model Predictive Current Controlled Bidirectional Three-level DC/DC Converter for Hybrid Energy Storage System in DC Microgrids," *IEEE Trans. Power Electron.*, vol. PP, no. c, p. 1, 2018.

[6] N. Jin, S. Hu, C. Gan, and Z. Ling, "Finite States Model Predictive Control for Fault-Tolerant Operation of a Three-Phase Bidirectional AC/DC Converter under Unbalanced Grid Voltages," *IEEE Trans. Ind. Electron.*, vol. 65, no. 1, pp. 819–829, 2018.

[7] H. Yu, P. Zeng, Z. Li, C. Zang, and S. Li, "Fully Distributed Hierarchical Control of Parallel Grid-Supporting Inverters in Islanded AC Microgrids," *IEEE Trans. Ind. Informatics*, vol. 14, no. 2, pp. 679–690, 2017.

[8] I. Ziouani, D. Boukhetala, A. M. Darcherif, B. Amghar, and I. El Abbassi, "Hierarchical control for flexible microgrid based on three-phase voltage source inverters operated in parallel," *Int. J. Electr. Power Energy Syst.*, vol. 95, pp. 188–201, 2018.

[9] F. Garcia-Torres, C. Bordons, and S. Vazquez, "Voltage predictive control for microgrids in islanded mode based on Fourier transform," *Proc. IEEE Int. Conf. Ind. Technol.*, vol. 2015–June, no. June, pp. 2358–2363, 2015.

[10] Y. Han, H. Li, P. Shen, E. A. A. Coelho, and J. M. Guerrero, "Review of Active and Reactive Power Sharing Strategies in Hierarchical Controlled Microgrids," *IEEE Trans. Power Electron.*, vol. 32, no. 3, pp. 2427–2451, 2017.

[11] X. Li, H. Zhang, M. B. Shadmand, and R. S. Balog, "Model Predictive Control of a Voltage-Source Inverter with Seamless Transition between Islanded and Grid-Connected Operations," *IEEE Trans. Ind. Electron.*, vol. 64, no. 10, pp. 7906–7918, 2017.

[12] B. R. Choi, W. P. Lee, and D. J. Won, "Optimal charging strategy based on model predictive control in electric vehicle parking lots considering voltage stability," *Energies*, vol. 11, no. 7, 2018.

[13] W. Sun, G. Kong, Y. Zhang, M. Liu, W. Zhang, and X. Hu, "Power System Voltage Correction Scheme Based on Adaptive Horizon Model Predictive Control," *Appl. Sci.*, vol. 8, no. 4, p. 641, 2018.

[14] E. Banguero, A. Correcher, Á. Pérez-Navarro, F. Morant, and A. Aristizabal, "A review on battery charging and discharging control strategies: Application to renewable energy systems," *Energies*, vol. 11, no. 4, pp. 1–15, 2018.

[15] M. Jayachandran and G. Ravi, "Decentralized model predictive hierarchical control strategy for islanded AC microgrids," *Electr. Power Syst. Res.*, vol. 170, no. December 2018, pp. 92–100, 2019.

[16] S. Ahmed, A. Mahmood, A. Hasan, G. A. S. Sidhu, and M. F. U. Butt, "A comparative review of China, India and Pakistan renewable energy sectors and sharing opportunities," *Renew. Sustain. Energy Rev.*, vol. 57, pp. 216–225, 2016.

[17] Z. Ming, O. Shaojie, S. Hui, and G. Yujian, "Is the 'sun' still hot in China? the study of the present situation, problems and trends of the photovoltaic industry in China," *Renew. Sustain. Energy Rev.*, vol. 43, pp. 1224–1237, 2015.

[18] C. S. Nalamati, S. M. Ieee, R. Gupta, and S. M. Ieee, "Isolated Bidirectional Battery Converter Control for Standalone Solar PV Applications," *2018 IEEMA Eng. Infin. Conf.*, vol. 22, no. 22, pp. 1–5, 2018.

[19] Islamabad Chamber of Commerce & Industry, "An overview of electricity sector in Pakistan," 2011.

[20] "Taxila History." [Online]. Available: https://en.wikipedia.org/wiki/Taxila. [Accessed: 10-Mar-2019].

[21] H. R. Habib and T. Mahmood, "Optimal planning and design of hybrid energy system for UET Taxila," *2017 Int. Conf. Electr. Eng. ICEE 2017*, pp. 1–9, 2017.

[22] "Matiari–Lahore transmission line." [Online]. Available: https://en.wikipedia.org/wiki/Matiari–Lahore_transmission_line. [Accessed: 10-Mar-2019].

[23] M. Adly and K. Strunz, "Irradiance-Adaptive PV Module Integrated Converter for High Efficiency and Power Quality in Standalone and DC Microgrid Applications," *IEEE Trans. Ind. Electron.*, vol. 65, no. 1, pp. 436–446, 2018.

[24] B. Wang, J. Xu, R. J. Wai, and B. Cao, "Adaptive Sliding-Mode with Hysteresis Control Strategy for Simple Multimode Hybrid Energy Storage System in Electric Vehicles," *IEEE Trans. Ind. Electron.*, vol. 64, no. 2, pp. 1404–1414, 2017.

[25] S. Ding, W. X. Zheng, J. Sun, and J. Wang, "Second-order sliding-mode controller design and its implementation for buck converters," *IEEE Trans. Ind. Informatics*, vol. 14, no. 5, pp. 1990–2000, 2018.

[26] S. C. Tan, Y. M. Lai, M. K. H. Cheung, and C. K. Tse, "On the practical design of a sliding mode voltage controlled buck converter," *IEEE Trans. Power Electron.*, vol. 20, no. 2, pp. 425–437, 2005.

[27] C. S. Sachin and S. G. Nayak, "Design and simulation for sliding mode control in DC-DC boost converter," *Proc. 2nd Int. Conf. Commun. Electron. Syst. ICCES 2017*, vol. 2018–Janua, no. Icces, pp. 440–445, 2018.

[28] T. B. Dc and D. C. Converters, "Second-Order Sliding-Mode Controlled," vol. 65, no. 1, pp. 898–906, 2018.

[29] S. C. Tan, Y. M. Lai, and C. K. Tse, "A unified approach to the design of PWM-based sliding-mode voltage controllers for basic DC-DC converters in continuous conduction mode," *IEEE Trans. Circuits Syst. I Regul. Pap.*, vol. 53, no. 8, pp. 1816–1827, 2006.

[30] S. C. Tan, Y. M. Lai, C. K. Tse, and M. K. H. Cheung, "A fixed-frequency pulsewidth modulation based quasi-sliding-mode controller for buck converters," *IEEE Trans. Power Electron.*, vol. 20, no. 6, pp. 1379–1392, 2005.