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Sliding Mode Controller for Voltage Regulation in DC Micro grid

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Abstract: The variations in loads can be defined as either increment or decrement in the load. Variation in load causes a similar change in the amount of current which produces opposite variation in output voltage. Microgrids typically use renewable energy resources to meet varying load demands of the local area. Such sources need power electronic converters for controlling proper voltage level for efficient operation. Hence it becomes essential to design control scheme for the DC-DC converters to stabilize the voltage in DC micro grids under any type of load variations. This research work proposes a DC micro grid structure in which sliding mode controller based DC-DC converters are implemented. Microgrid structure is then simulated using MATLAB SIMULINK where output voltage regulation is achieved efficiently in case of rise as well as fall in the load connected on DC micro gird.

Keywords: Sliding Mode Controller (SMC), Line Variation, Load Variation, DC micro grid, PV-Cell, Fuel Cell (FC)

1. INTRODUCTION

Solar, wind, fuel cells are increasing rapidly as electricity generation source around the world. Renewable energy resources being eco-friendly are being promoted by various world health and environment organizations. On the other hand, renewables also provide diversity in generation resources. Availability and almost zero fuel cost makes renewables the only choice for power generation (Bayrak and Cebeci, 2014). Solar Photovoltaic (PV) cells are considered as most commonly used renewable energy source. It offers simple installation and low cost for small power applications. PV power generation is dependent upon weather condition and solar irradiance therefore nonlinear PV output needs to be controlled to be supplied to loads (Singh, 2013). Fuel Cell is a power generation device which produce power by chemical reaction of hydrogen and oxygen using electrolyte. Like PV they are intermittent source of generation, because of modularity, fast load response and high efficiency. Unlike battery they are not rechargeable. Fuel for FC is hydrogen and its compounds (El-Shatter *et al.*, 2002).

Most of the Renewables having intermittent nature (solar, wind etc) are used in hybrid combination of two or more sources. This scheme along using alternative energy sources and storage can improve system performance. These hybridized systems are also called micro grids. These micro grids may work independently as isolated systems and may be connected with larger grid to supply loads located at different locations (Nehrir *et al.*, 2011). Nonlinear PV output is overcome by integrating another renewable source like Wind, Storage (i.e battery) and Fuel Cell that ensure uninterruptible high-quality power to load and also a maximum Power Tracking Point (MPPT) controller has been associated with each PV generator in order to obtain an optimal power output under changing climatic condition (Ou and Hong, 2014).

Load on traditional power grid is continuously varying at all times. A micro grid is similar to interconnected grid but on a very small scale. Variations in loads can be defined as either increment or decrement in the load. In case of increment of load, the amount of current drawn from the micro grid would increase which will cause a voltage drop to appear in the line that voltage drop would cause a reduction in output voltage. On the other hand the decrement in load reduces the amount of current extracted from the micro grid and an increment in the output voltage. These voltage variations make it necessary to regulate the voltage in DC micro Grid.

DC-DC converters are suitably used for the purpose of regulation of voltage. To obtain regulated DC voltages, switching noise is being smoothed out by high frequency power conversion circuits. These circuits utilize inductors, transformers, capacitors and high frequency switching. The converters used in this work are DC-DC boost converter and DC-DC buck converter.

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The conventional controller used with DC-DC converters is PID controller. But PID controller has certain drawbacks which can be overcome by using sliding mode controller.

SMC technique is one of the evolved nonlinear control technique that possess advanced property of precise, rigorous, and easily tuned. It can adjust the dynamics of the system by discontinuous control signal, compelling the output of the system to 'slide' with surface named as sliding surface. The specific mode of operation of the system as it slides along the preset borderline of the control system is termed as the sliding mode of the system.

As Suitable control strategy is required to maintain balanced power and voltages at different buses in hybrid generation fed micro grids. Different researchers are contributing in the development of this relatively new technology. (Chettibi and Mellit, 2018) Proposed neural network-based controllers for controlling output of hybrid generation and storage used in grid connected micro grid. (Tejwani and Suthar, 2017) Proposed reactive power compensation for grid connected hybrid PV and FC generation. Voltage source converter guarantees the maximum utilization of PV array the optimal use of FC. (Ahmed *et al.*, 2008) Proposed a hybrid energy system with wind turbine, PV and Fuel Cell to supply standalone loads. They used three individual boost converters to control power flow to load. DC-DC converter is simple and cost-effective method for maximum power tracking from wind and PV system (Nojavan *et al.*, 2017). The uncertainty modeling of load enables operator to make decision to optimize the systems operation against possible changes in load.

In this research work, a PV and FC based hybrid generation system is proposed. Output of the two generations are regulated using DC-DC converters to integrate at a common DC bus of an isolated DC micro grid.

2. SMC FOR DC-DC CONVERTERS

Both the Buck and Boost type converters are used in proposed model of isolated DC micro grid. Buck converter circuit diagram is displayed in **(Fig: 1)**.

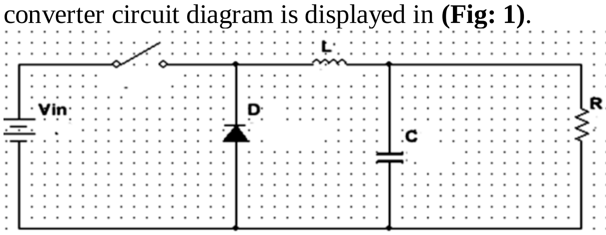

Fig. 1: Buck Converter Circuit

By taking the conditions of switching (ON and OFF) of buck converter, the transfer function can be formulated by equation (1).

$$\frac{v_o}{v_{in}} = \frac{1}{LCs^2+\frac{L}{R}s+1} \tag{1}$$

From Fig. 1, The DC-DC buck converter has two state variables i.e. I_L and V_c. State space equations can be written in matrix form in equation (2).

$$\begin{bmatrix} i_L \\ V_c \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ V_c \end{bmatrix} + \begin{bmatrix} D\frac{x}{L} \\ 0 \end{bmatrix} [V_{in}] \tag{2}$$

The Simulink model developed for the open loop buck converter based on the above state space modelling is shown in **(Fig. 2).**

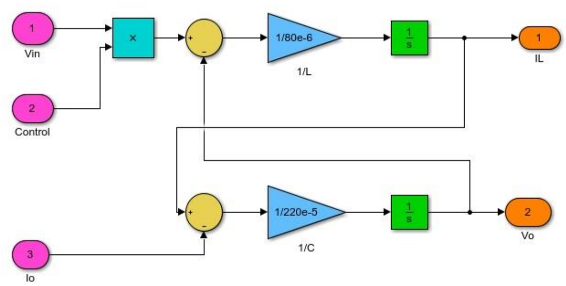

Fig. 2: Simulink State-Space Model for buck converter

In SMC, input state to the systems is decided by utilizing a sliding surface. In case of Sliding Mode Controller, the sliding line chooses the switching states *u*. The explanation of sliding surface. Thus, the switching function can be given in equation (3).

$$\sigma = c_1x_1 + c_2x_2 = C^Tx = 0 \tag{3}$$

Where,$C^T = [c_1, c_2]$is the vector of sliding surface coefficients and$x=[x_1x_2]^T$ are the state variables.

Now,

$$\sigma = c_1x_1 + c_2\dot{x}_1 = 0 \tag{4}$$

Equation (4) shows the sliding mode according to system dynamics. The control law in this case can be defined as given in equation (5),

$$u = \begin{Bmatrix} 1 = ON, when\ \sigma > k \\ 0 = OFF, when\ \sigma < k \end{Bmatrix} \tag{5}$$

Simulink model of SMC based Buck converter used in the DC micro grid is shown in **(Fig: 3).**

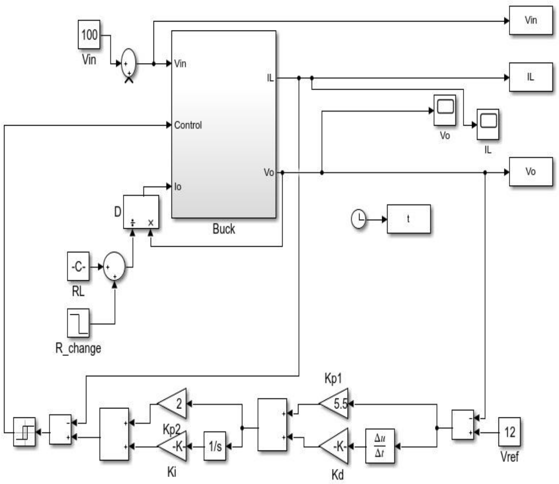

Fig. 3: SMC Model of Buck Converter

(Table 1) provides the parameters for performance analysis of SMC controlled buck converter used in this research work.

Table 1. Buck Converter Parameters

Parameter	Value
Output Voltage (Vo)	12 V
Supply Voltage (Vin)	100 V
Load Resistance (R)	0.144 Ω
Capacitor (C)	220 µF
Inductor (L)	80 µH

The circuit diagram of simple open loop boost converter is shown in the **(Fig: 4)**.

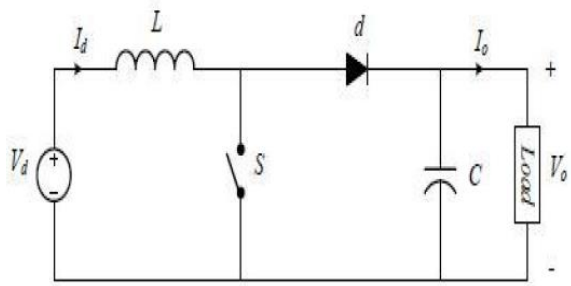

Fig. 4: Boost Converter Circuit

Implementation of the state space averaging method, yields the overall second-order averaging model of the boost converter given in Equation (6).

$$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{du_o}{dt} \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ u_o \end{bmatrix} + \begin{bmatrix} \frac{u_o}{L} \\ -\frac{i_L}{C} \end{bmatrix} S + \begin{bmatrix} \frac{u_i}{L} \\ 0 \end{bmatrix} \quad (6)$$

The state space model of Boost converter is shown in **(Fig. 5).**

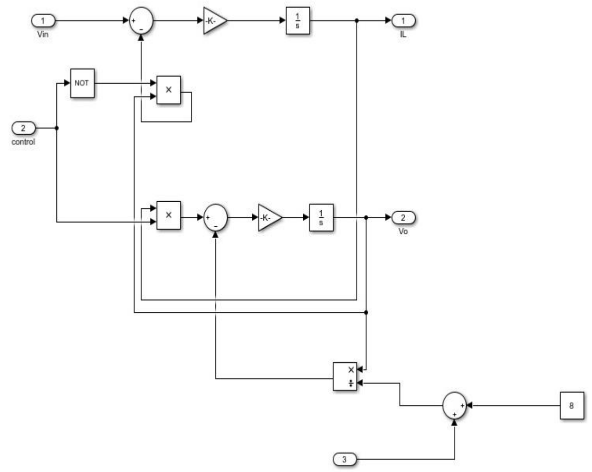

Fig. 5: Simulink State-Space Model of Boost Converter

Simulink model of SMC based Boost converter used in the DC micro grid is shown in **(Fig: 6).** Parameters used to analyze the performance of boost converter in this research work are given in **(Table 2)**.

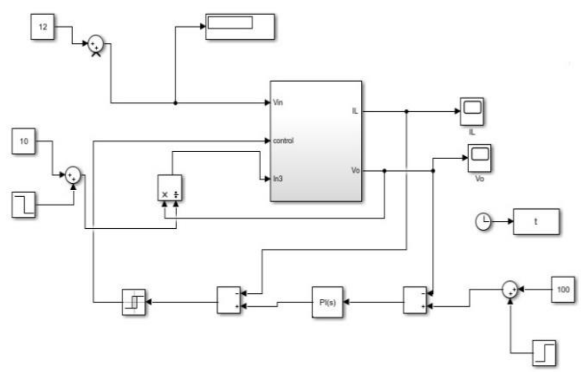

Fig. 6: SMC Model of Boost Converter

Table 2. Boost Converter Parameters

Parameter	Value
Output Voltage (Vo)	100 V
Supply Voltage (Vin)	48 V
Load Resistance (R)	10 Ω
Capacitor (C)	5.1 mF
Inductor (L)	0.82 µH

3. RESEARCH METHODOLOGY

Proposed model of dc micro grid is developed in MATLAB Simulink as shown in **(Fig. 7)**. The model is made to Simulate in order to determine the performance of micro grid. Development of PV model was also done in MATLAB Simulink while designing a hybrid generating system. Standard Test Condition (STC) suggests the normal temperature to be equal to 25 degree C and normal irradiance per meter square of PV is given as 1000W/m^2. Fuel Cell used for simulation analysis is Solid Oxide Fuel Cell (SOFC) type. Which has the maximum power rating of 5KW. The operating temperature of SOFC is given as 650 degree C to 1000 degree C and the electrical efficiency is 56-62%. Their durability is about 4x104 hour. Constant parameters of SOFC are used as inputs in proposed model and output voltage, current and power of model are determined as suggested by (Mattavelli *et al.*, 1993).

As the output of PV and FC is variable in terms of current and voltage, hence SMC controlled Boost converter is used at the output terminals of PV and FC to raise the voltage upto 100V. SMC based Boost converter performs function of voltage regulator and can give better output voltage response than a linear controlled boost converter. Also, voltage is boosted to required level for utilization of heavy loads at HV bus. Output of both sources are connected to a common HV bus to supply a 1kW at 100V load (HV BUS).

Further another DC bus 2 is taken out to feed the line resistance and serves as an input to buck converter. The voltages of DC bus 2 are reduced by Buck converter. Resistive line model is used to represent a section of the distribution line between two 100V DC buses. Buck converter model is connected between buses 2 and 3 to step down DC voltage to 12V to be utilized by consumer appliances. DC-DC converters are controlled though Sliding Mode controllers. Boost converter performs the voltage regulation at HV bus. Buck converter controlled through Sliding mode controller is used at LV bus to perform voltage regulation.

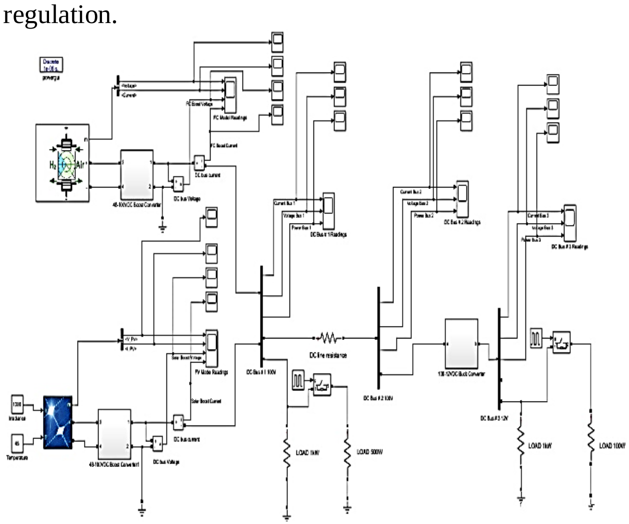

Fig. 7: DC Micro Grid Controlled by SMC

4. RESULTS AND DISCUSSION

Simulations are performed on developed DC micro grid model using MATLAB Simulink as simulation platform. Four different cases of load variations are simulated to obtain results of variation in output voltage.

Case 1: In this case, Load connected on HV bus is 1 kW. When load on HV bus is increased from 1 kW to 1.5 kW at the instant of 0.05 sec, Voltage undershoot of 1V occurs which gets settled in 1.8 ms. Meanwhile the change in current is 10A to 15A. Result Waveforms of Power, Voltage and Current are shown in **(Fig. 8, 9** and **10)** respectively.

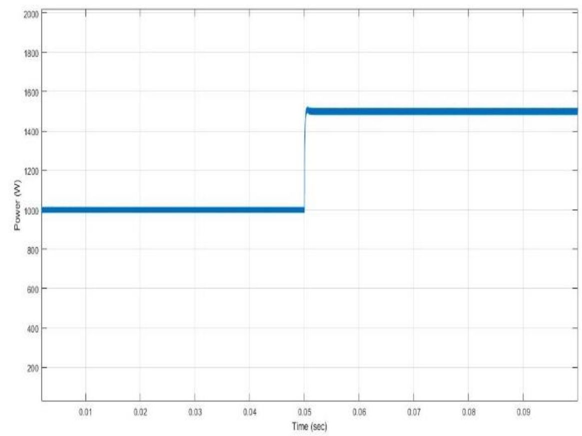

Fig. 8: Power Increment at HV bus

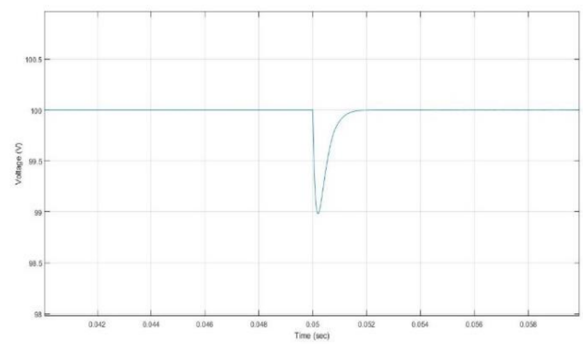

Fig. 9: Voltage Regulation at HV bus

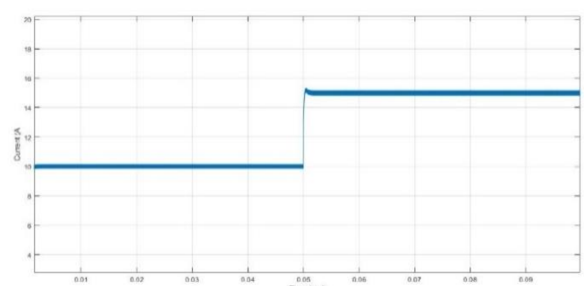

Fig. 10: Current Rise on HV bus

CASE 2: In this case, same load of 1 kW is connected on HV bus. When load is decreased from 1 kW to 750W, Voltage overshoot of 0.51V occurs which gets settled in 1.8 msec. Decrement in current is from 10A to 7.5A. Results Waveforms of Power, Voltage and Current are shown in **(Fig. 11, 12 and 13)** respectively.

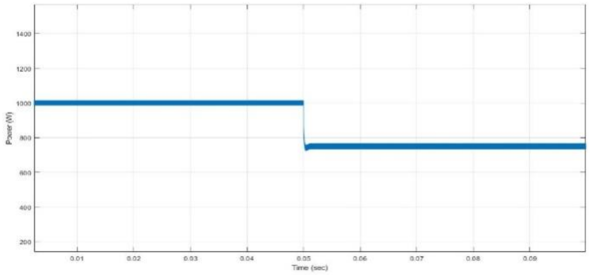

Fig. 11: Power Decrement at HV bus

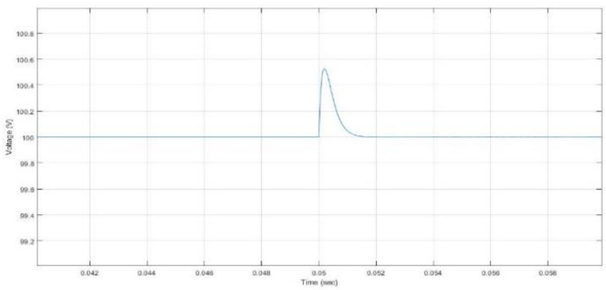

Fig. 12: Voltage Regulation at HV bus

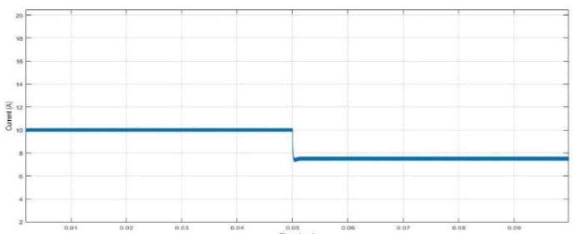

Fig. 13: Current fall on HV bus

CASE 3:

In this case, load of 1 kW is connected on LV bus. When load is increased from 1 kW to 1.1kW, Voltage undershoot of 0.35V occurs which is settled in 5.5 msec. While the current rises from 83.33A to 91.66 A. Results of this case are shown in **(Fig. 14, 15** and **16**) respectively.

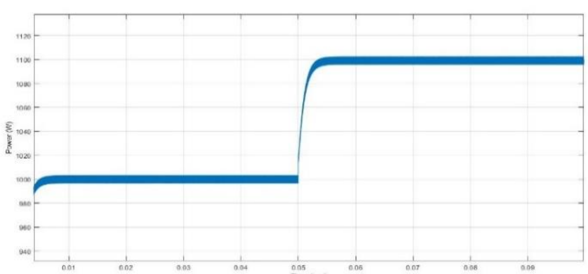

Fig. 14: Power Increment at LV bus

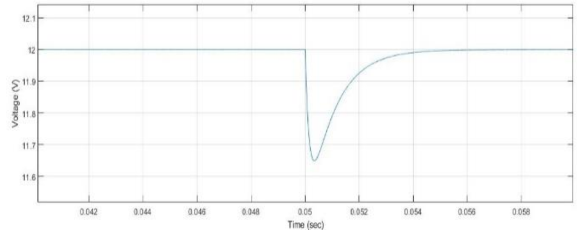

Fig. 15: Voltage Regulation at LV bus

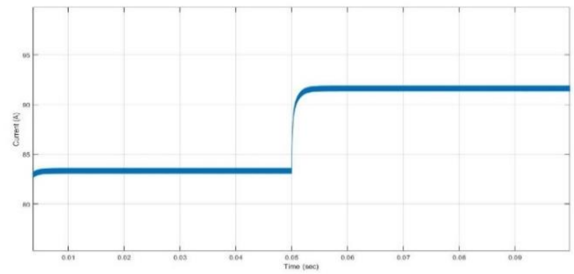

Fig. 16: Current Rise on LV bus

CASE 4:

In this case, same load of 1kW is connected on LV bus. When load is decreased from 1 kW to 920W. Voltage overshoot of 0.305V occurs which is settled in 4.2 msec. While the current drops from 83.33A to 76.66A. Results of this case are shown in **(Fig. 17, 18** and **19**) respectively.

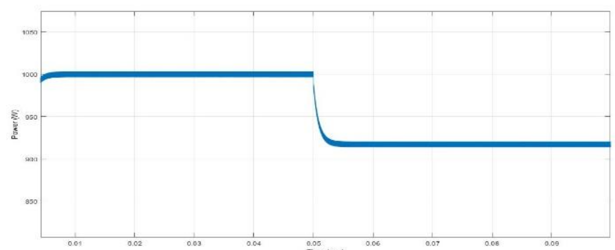

Fig. 17: Power Decrement at LV bus

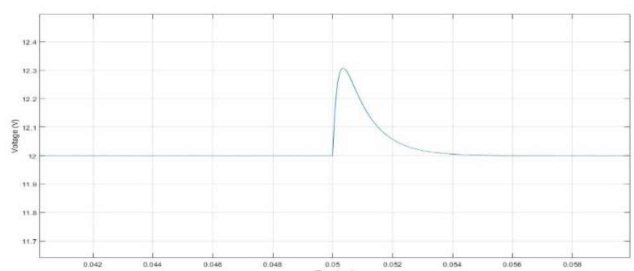

Fig. 18: Voltage Regulation at LV bus

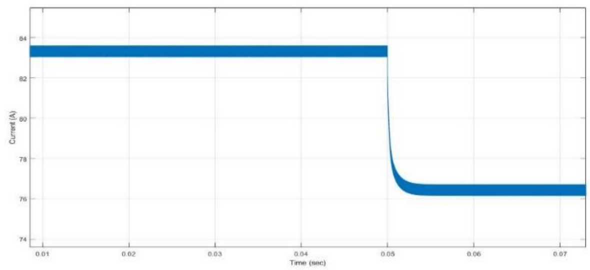

Fig. 19: Current fall on LV bus

5. CONCLUSION

Linear PI controllers are unable to control the load variation occurring in buck as well as boost converters. SMC is observed to be an effective nonlinear controller for DC-DC converters. In this research paper SMC is proposed to control variation occurring at HV and LV buses of the DC micro grid. Simulation of boost converter with proposed SMC for load variation at HV bus shows undershoot of 1V for 100V output on 50% load rise with a settling time of 1.8ms. While it shows an overshoot of 0.51V for 100V output on 25% load fall with a settling time of 1.8ms.

Simulation for load variation at LV bus shows undershoot of 0.35V for 12V output on 10% load rise with a settling time of 5.5ms. While it shows an overshoot of 0.305V for 12V output on 8% load fall with a settling time of 4.2ms.
Simulation results confirm effectiveness of proposed SMC for dc microgrid.

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