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A Solar PV Fed Switched Capacitor Boost Circuit for DC Microgrid

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***Abstract** - This work deliberates the implementation of a DC-DC converter that offers high gain. The converter is fed from solar Photo Voltaic (PV) appropriate for DC microgrid. DC microgrid has numerous benefits in rural areas where supplying power by typical AC grid is not viable. The low output obtained from solar PV is boosted into 400 V suitable for DC microgrids used for data centers. The converter is tested for line and load variations in open-loop conditions. To maintain the output voltage at 400 V, a typical proportional-integral (PI) controller is employed, and its performance is verified in MATLAB, and simulation results are presented. It can be observed that the PI controller can maintain DC link voltage in transient conditions.*

Keywords — *Switched capacitor DC-DC converter, DC Microgrid, PI controller.*

I. INTRODUCTION

The ever-increasing power demand and fossil fuel depletion preceded the development of DC microgrids powered by Renewable Energy Resources (RES) [1]. The DC microgrids are most suited for electrification of remote areas as it offers high efficiency. Also, there is no need for power conversion from DC to AC when solar PV and fuel cells are used to energize the DC microgrid. An added benefit of DC microgrids is the availability of DC loads in the market appropriate for rural applications. Sonia Moussa et al. proposed a method to choose an optimum voltage level for DC nano grids based on several factors such as the size of cable used, consumption of power, losses, etc. [2]. Dinesh Kumar et al. elaborated on the challenges in implementing DC microgrids in numerous applications. Also, he updated the recent innovations in microgrid technology and emphasized the need for its standardization [3]. A minimal cost DC microgrid structural design compared to the available design is proposed in [4]. The developed microgrid structure offers high efficacy, consistent power management, and less cost online supervising strategy. As solar PV delivers clean energy compared to other green energy sources, this work proposes the use of solar PV for providing voltage to DC microgrids.

In literature, several converters were proposed to step up the DC voltage [5-6]. A buck-boost converter that provides voltage for the DC nano grid is proposed in [7]. A basic PI controller is utilized here to sustain DC voltage. Karthikeyan et al. proposed a switched capacitor DC-DC converter that steps up DC voltage and offers high efficiency. To validate the performance of the proposed converter, a prototype model was developed, and the results obtained were verified [8]. A high gain high power DC-DC converter which can be employed as a power conditioning unit in RES fed DC microgrid, was proposed in [9]. This work utilizes a Switched Capacitor (SC) DC-DC converter proposed in [10] that offers high step-up DC voltage from low DC voltage gained from solar PV.

A DC microgrid voltage of 400 V obtained from the converter is regulated underline and load variations with the help of a PI controller. The presentation of the paper is as given. Section 1introduces the basics of DC microgrids and the different suitable converter topologies available in the literature. The operation of the converter is detailed in section 2 with relevant equations. The controller implementation is explained in section 3, preceded by simulation results in section 4. Lastly, in section 5, concluding notes are presented.

II. STRUCTURE OF THE PROPOSED WORK

Fig. 1 portrays the proposed work structure. The high gain SC converter steps up the voltage obtained from solar PV. A traditional PI controller is employed to take care of the fluctuations in voltage. Thus, a constant DC voltage suitable for the DC microgrid is obtained.

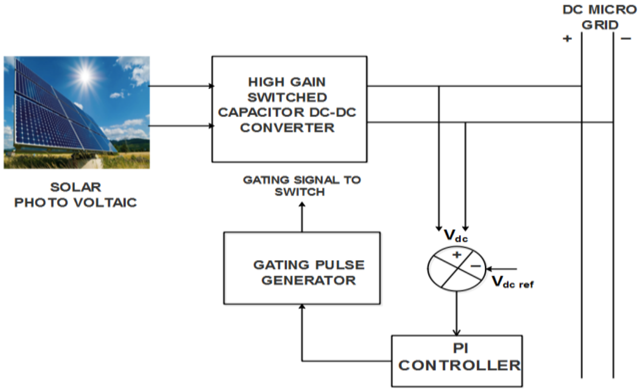

Fig. 1: Block diagram of the proposed work

III. SWITCHED CAPACITOR DC-DC CONVERTER OPERATING MODES

The SC converter employed to step up the voltage obtained from solar PV is presented in Fig. 2.

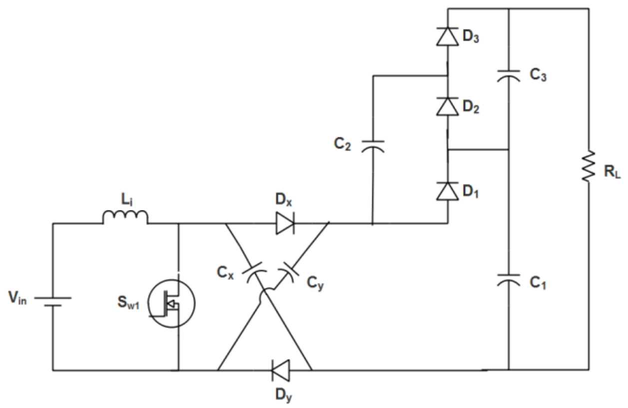

Fig. 2: SC converter circuit diagram

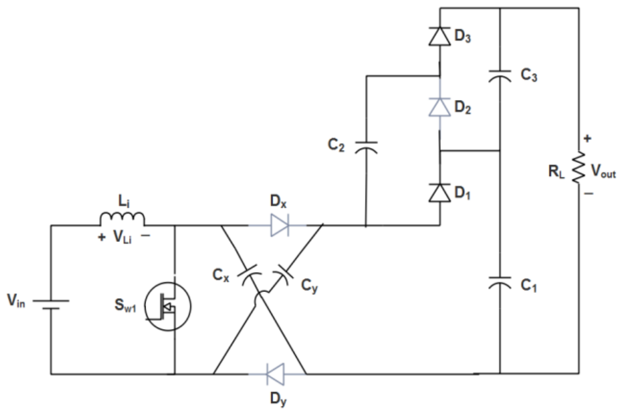

Fig. 3: Mode of operation when S_{w1} is ON

Figure 3 shows the mode of operation when S_{w1} is ON. In this mode, D_1 and D_3 conduct, and the inductor gets charged. The voltage relations obtained are given in equations (1) to (3).

$$V_{in} = V_{Li} \tag{1}$$

$$V_{c1} = V_{cx} + V_{cy} \tag{2}$$

$$V_{c2} = V_{c3} \tag{3}$$

Figure 4 shows the mode of operation when S_{w1} is OFF. Diodes D_2, D_x, and D_y conduct, and energy stored in the inductor are transferred to the load. The corresponding voltage relations are given in equations (4) to (6).

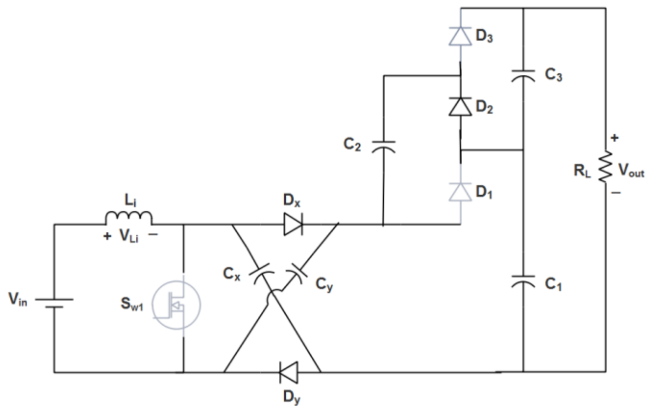

Fig. 4: Mode of operation when S_{w2} is OFF

$$V_{Li} = V_{in} - V_{Cx} \tag{4}$$

$$V_{Cx} = V_{Cy} \tag{5}$$

$$V_{out} = V_{c1} + V_{c3} \tag{6}$$

In this work, the input voltage V_{in} of the converter is obtained from solar PV.

IV. CONTROL METHODOLOGY

As output obtained from solar PV is of varying in nature, the SC converter output also varies. However, in this work, converter output needs to be maintained at 400 V, suitable for DC microgrids. So, it is imperative to use a controller to maintain a fixed output voltage. This work employs a simple PI controller for this purpose. It compares reference and actual DC voltage and accordingly produces a control signal. A pulse generator produces gating pulses based on this control signal. Figure 5 shows the block diagram of a typical PI controller.

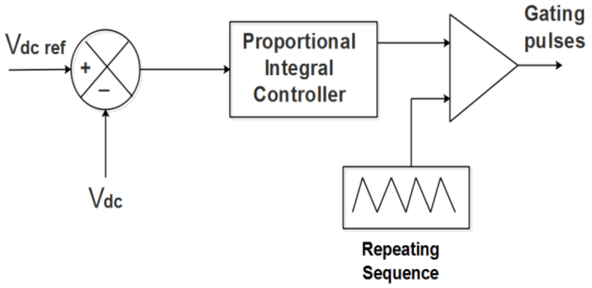

Fig. 5: PI controller structure

V. RESULTS AND DISCUSSIONS

The model of step-up SC converter supplied from solar PV is implemented in MATLAB to assess its functioning underline and load variations, and the findings are presented. The parameters used in the simulation are specified in Table I. Figure 6 shows the Simulink model of the proposed system.

TABLE I. Simulation parameters

Parameters	Values
V_{in}	48 V
V_{out}	400 V
Switching frequency	20 kHz
L_i	0.4 mH
C_1	470 µF
C_x, C_y, C_2, C_3	220 µF
Output power P_{out}	1 kW

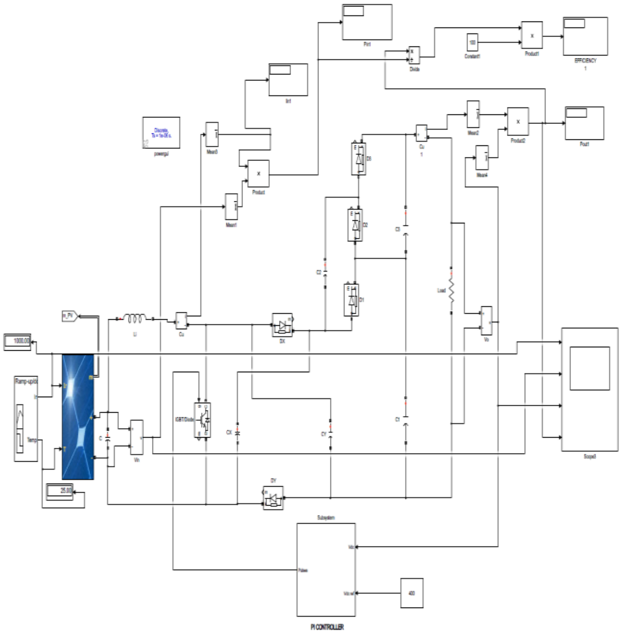

Fig. 6: Simulink model of the proposed system

Tables II and III portray the open-loop simulation findings obtained when there are an increase and decrease in input voltage and load. From Table II, it can be inferred that variation in input voltage obtained from solar PV leads to corresponding variations in output voltage. Table III reveals that with the change in load, there is a corresponding variation in output power.

TABLE II. Open Loop Results for Variation in input voltage

S. No	V_{in} (V)	I_{in} (A)	P_{in} (W)	V_{out} (V)	I_{out} (A)	P_{out} (w)	%Efficiency
1	24	10.91	261.84	196.6	1.22	239.85	91.60
2	30	13.74	412.2	246.2	1.54	379.15	91.98
3	36	16.56	596.16	296.8	1.85	549.08	92.10
4	42	19.38	813.96	347.4	2.17	753.86	92.61
5	48	22.2	1065.6	398	2.48	987.04	92.63

TABLE III. Open Loop Results for Load Variation

S. No	Load %	I_{in} (A)	P_{in} (W)	V_{out} (V)	I_{out} (A)	P_{out} (w)	%Efficiency
1	20	5.2	249.6	402.9	0.5	201.45	80.71
2	40	9.49	455.52	401.7	1	401.7	88.18
3	60	13.74	659.52	400.5	1.5	600.75	91.08
4	80	17.99	863.52	399.2	1.99	794.41	91.99
5	100	22.2	1065.6	398	2.48	987.04	92.63

Figures 7 and 8 show the open-loop results obtained when there is an increase or decrease in the input voltage, which shows when the input voltage is increased or decreased at t=1 s, the output voltage also gets increased or decreased. Figures 9 and 10 reveal when the load is increased or decreased at t=1 s, the load power is increased or decreased correspondingly.

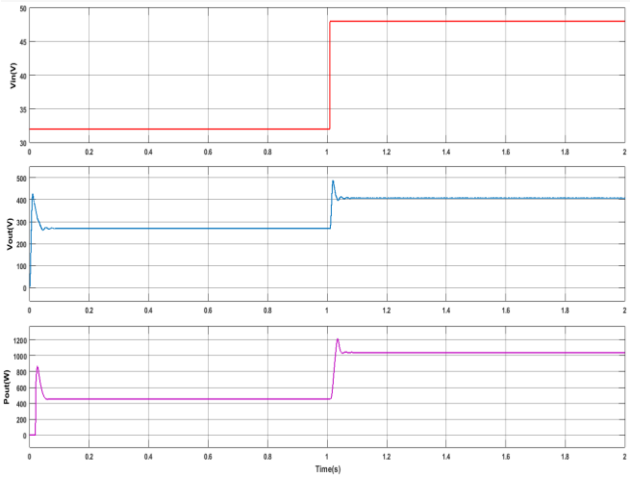

Fig. 7: Open-loop results for an increase in voltage

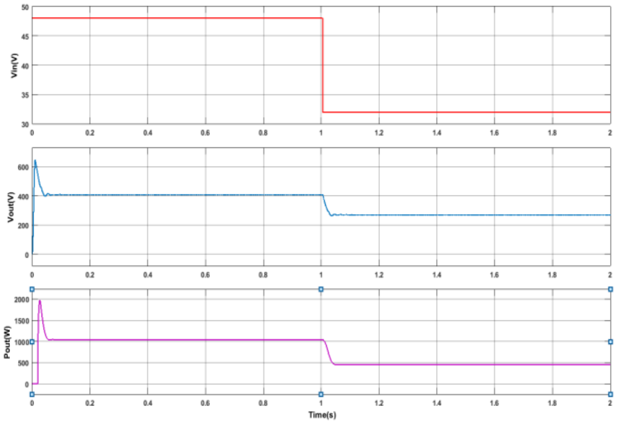

Fig. 8: Open-loop results for the decrease in voltage

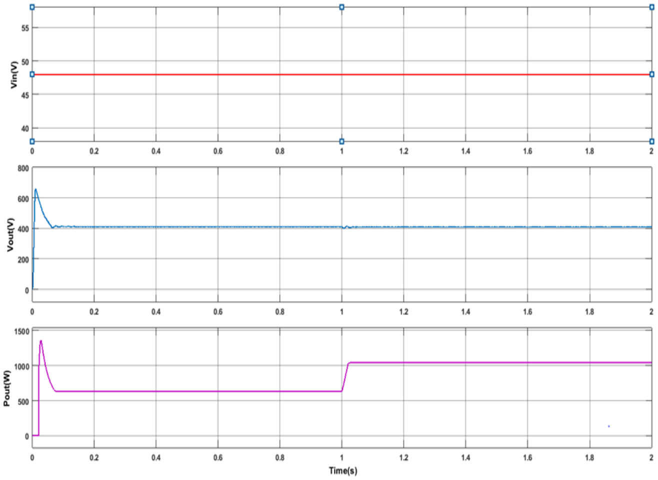

Fig. 9: Open-loop results for an increase in load

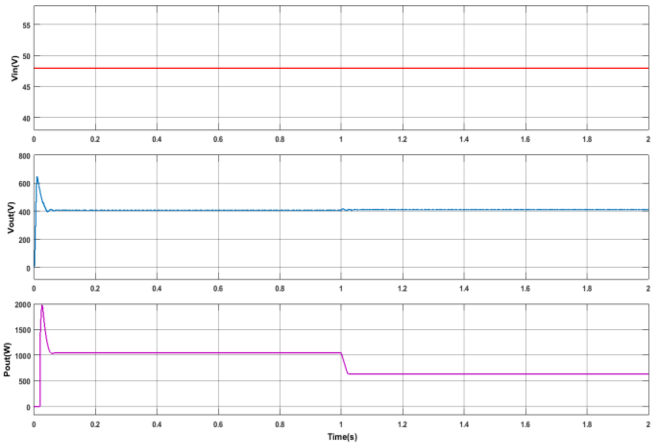

Fig. 10: Open-loop results for the decrease in load

Table IV and V portray the closed-loop simulation findings obtained when there are an increase and decrease in input voltage and load. From Table IV, it can be inferred that variation load leads to corresponding variations in output power. Table V reveals that with a change in load, there is a corresponding variation in output power.

TABLE IV. Closed Loop Results for Variation in input voltage

S. No.	V_{in} (V)	I_{in} (A)	P_{in} (W)	V_{out} (V)	I_{out} (A)	P_{out} (W)	%EFFICIENCY
1	24	46.9	1125.6	399.9	2.48	992.2	88.15
2	30	36.13	1084	399.9	2.44	976.2	90
3	36	30.26	1089.36	400.1	2.47	988.4	90.73
4	42	25.95	1090	400.2	2.513	1006	92.29
5	48	22.37	1073.76	400	2.496	998.7	93

TABLE V. Closed Loop Results for Load Variation

S. No.	Load %	I_{in} (A)	P_{in} (W)	V_{out} (V)	I_{out} (A)	P_{out} (W)	%Efficiency
1	20	4.90	235.2	399.9	0.499	199.55	84.84
2	40	9.28	445.44	400	0.995	398	89.34
3	60	13.54	649.92	400.1	1.49	596.15	91.72
4	80	17.91	859.7	399.9	1.99	795.8	92.56
5	100	22.37	1073.7	400	2.496	998.7	93

Figure 11 and 12 portrays the closed-loop result obtained when there is an increase or decrease in the input voltage. When the input voltage is increased or decreased at t=1 s, the output voltage is maintained constant. Figure 13 and 14 reveals the closed-loop results obtained when the load is increased or decreased at t=1 s.

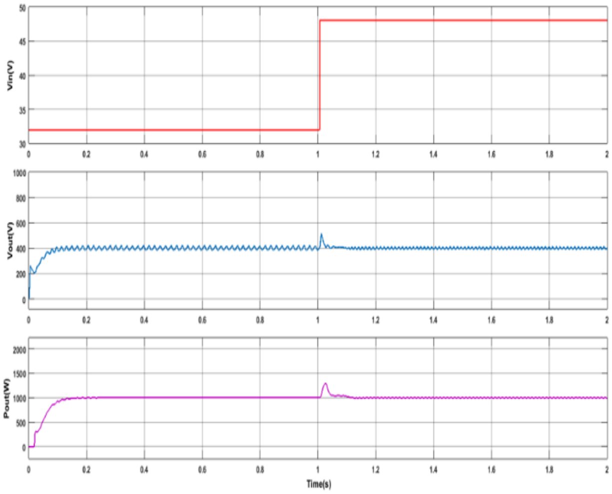

Fig. 11: Closed-loop results for an increase in voltage

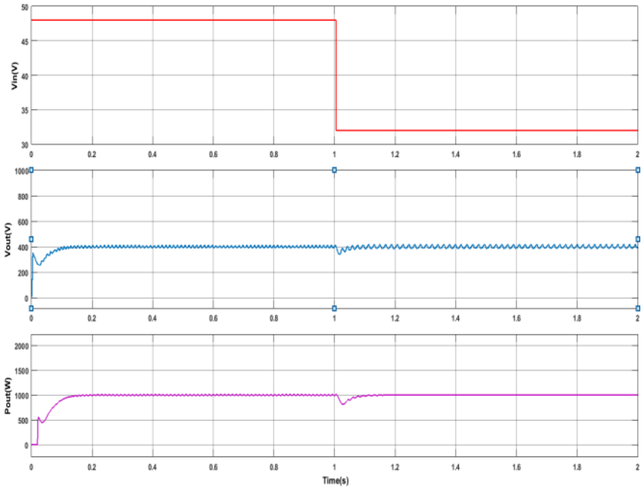

Fig. 12: Closed-loop results for the decrease in voltage

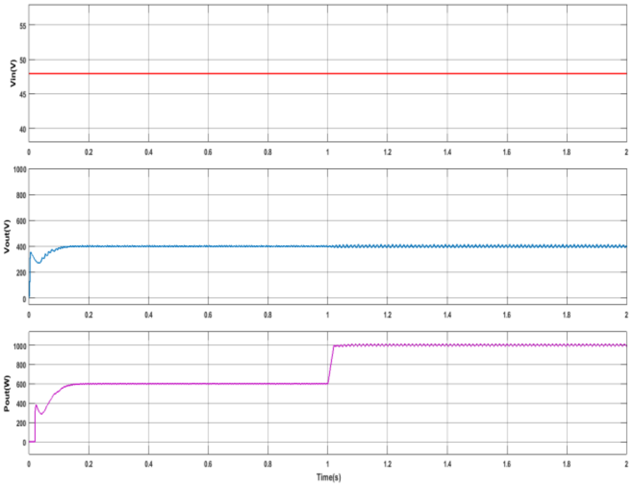

Fig. 13: Closed-loop results for an increase in load

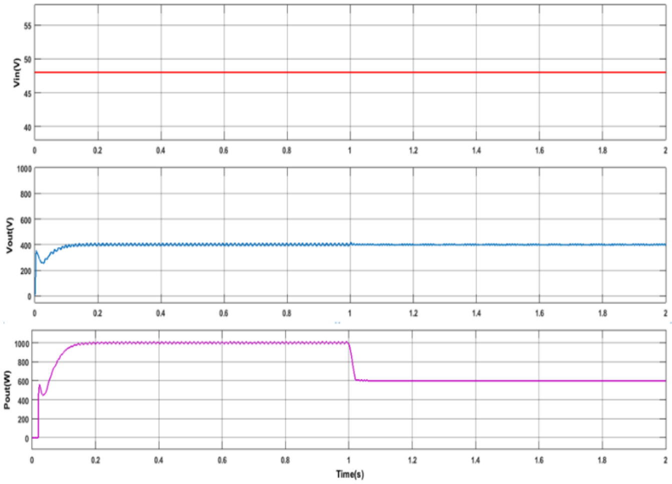

Fig. 14: Closed-loop results for the decrease in load

IV. CONCLUSION

In this work, a high gain SC converter fed from solar PV is employed to output a constant DC voltage of 400 V suitable for the DC microgrid. The proposed system is implemented in MATLAB to verify its functioning under random variations in load current and input voltage fed from solar PV. The simulation results are presented, and it can be verified a PI controller maintains steady output voltage irrespective of variations in input voltage. The work can be further extended by considering intelligent controllers to reduce the steady-state error obtained with the PI controller.

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