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DC-Microgrid Voltage Regulation Using DAB Based Series Voltage Regulator

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Abstract **- In this paper, the Dual active bridge (DAB) followed by full bridge DC-DC converter-based series voltage regulator (SVR) in five bus DC-microgrid is proposed to improve the voltage profile. The dynamic voltage output from the SVR is injected to the dc grid in order to compensate for the resistive drop over the network. As a result of consequence, the voltage level at different buses becomes independent of the load change and remains within the defined grid voltage limit. In this work, the SVR is connected in middle of the dc grid to regulate the voltage at 380V. The complete system is modeled and simulated in MATLAB/Simulink. Simulation results shows that proposed SVR gives good dynamic performance and voltage regulation under different load conditions.**

Index Terms **- Dual active bridge, DC-microgrid, Series Voltage Regulator, full-bridge dc-dc converter.**

I.INTRODUCTION

Recent advances and trends in power consumption and power generation clearly show a growing use of DC in end-user machines and equipment. A dc system allows the simple integration of renewables sources of energy and a direct link of battery banks and Super Capacitors [1], [2]. The distributed power generation (solar, wind etc.) are more advantageous as compare to conventional power generation (nuclear, hydro etc.). A dc distribution system consists of supplementary number of buses with considerable space [3]. The power flow in grid is from source bus to load buses in one direction. The voltage level of grid at different location is dependent on load power due to voltage drop over the network. This creates the requirement of voltage controlling devices or voltage regulator in the lines.

The DGs are connected to the DC micro grid through some suitable converter system involving Power Electronics. The major problem encountered in the implementation of voltage regulator is its voltage drop in dc lines. The series voltage regulator compensates this drop in lines. The series voltage regulator is consisting of Dual Active Bridge (DAB) [4] and full wave dc-dc convertor. DAB choose for regulation is to provide isolation between input and output, high efficiency, and reasonable power rating. DAB also provide the unipolar dc voltage and dc-dc convertor regulates the output voltage as per requirements. The series voltage regulator provides bidirectional power flow [5], [6].

In this work, we have proposed an SVR which output a dynamic voltage in series with the dc microgrid. This injected voltage compensates the network resistive drop and improve the voltage profile of the dc grid. As a result of this bus voltages remains within the limits of 380V. The DAB is selected for this application because it provides isolation between the input and output side and high efficiency.

II. SYSTEM CONFIGURATION

Fig. 1 shows the proposed configuration of the Dc microgrid with SVR. At bus-0 different sources of energy are connected on the common bus whereas on remaining all buses loads are connected. This configuration shows the radial network so the extend of the load at the load branches is easy. The voltage at the bus-3 and bus-4 is lower compared to other buses as they far away from the generation unit. So, it

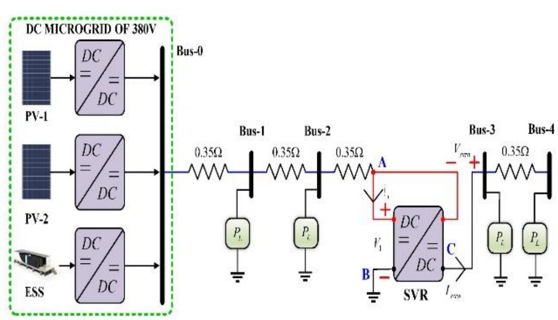

Fig. 1 DC microgrid with SVR

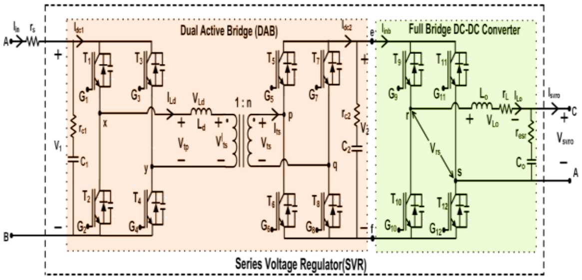

Fig. 2 SVR topology

becomes important to place the SVR at appropriate position. In this work, we have selected between bus-2 and bus-3. The input of the SVR that is point A and B is connected across the dc grid and output is connected in series with the grid between bus-2 and bus-3. Input of the SVR handles the line voltage (V_1) and lower input current (I_{in}) and output of SVR is lower voltage (V_{svro}) of order of required compensation voltage drop and rated line current (I_{svro}).

III. SVR TOPOLOGY

Fig. 2 shows the proposed SVR circuit topology. The SVR includes a DAB and a full-bridge dc-dc converter. The two bridges in DAB are operated to generate high-frequency square-wave voltage at the transformer terminals [7]. The phase shift between two square-waves can be adjusted to control power flow from V_1 to V_2 or vice versa. Power flow always happens from the bridge generating leading square-wave to the other bridge [8]. Note that the DAB is operated in power control mode. The output voltage of DAB (V_2) is always maintained to its reference value under the variation of output current (I_{inb}) and input voltage (V_1). The constant output voltage of DAB is connected to the input of the full bridge dc-dc converter. The full bridge is operated in voltage control mode with unipolar modulation [9] to generate an adjustable dc voltage (V_{svro}). So, under steady state, as well as transient conditions, the required amount of voltage with suitable polarity can be added in series with the dc grid. In this proposed configuration, the SVR regulates the voltage at bus-3 by adding controlled series voltage with appropriate polarity.
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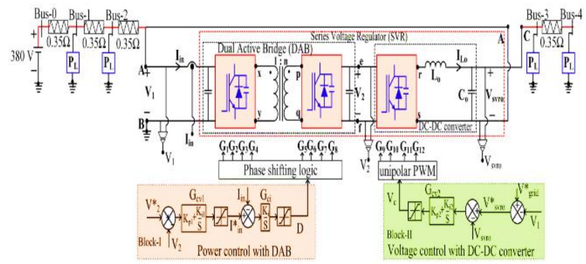

Fig.3 SVR with control block

IV. SVR CONTROL

Fig. 3 shows the proposed control block for the SVR control. The control scheme consists of two control blocks, which ensures that voltage level at bus-3 within the specified limit for different loading conditions. The Block-I maintains the constant voltage of 24V at the output of DAB. The Block-II control the full bridge dc-dc converter to operate in variable output voltage control mode which compensate the line voltage drop.
The controller of the full bridge dc-dc converter outputs the V_{svro} as shown in Fig. 3. As a reference to the controller voltage drop across the bus-3 is given to controller. The generated voltage reference is given by following equation.

$$V_{svro}{}^{*} = V_{grid}{}^{*} - V_1 \quad (1)$$

The error is formed in between the reference and actual output voltage (i.e. $e = V_{svro}{}^{*} - V_{svro}$) which is fed to a PI controller. The PI controller provides the control signal (i.e., V_c) to generate PWM signals for switches T_9 to T_{12}.

V. SIMULATION RESULTS AND DISCUSSION

The 380V voltage level radial dc micro grid is considered having five buses, among which bus-0 is the main generating bus. At remaining each bus variable resistive load is connected along with the equivalent transmission line resistance of 0.35Ω is considered for this simulation study. Sudden increase in load is considered in this study.

In this case study, load at all buses increased in step manner. Simulation study is carried out with and without SVR. Firstly, proposed DC micro grid is simulated without SVR. Secondly, simulated with SVR. At simulation time 0.4 s load in increased.

A. Without SVR results

Fig. 4 shows the bus voltages at step increase load. The voltage drops are shown in Fig. 5. Fig. 6 shows the load current. Power change is shown in Fig. 7

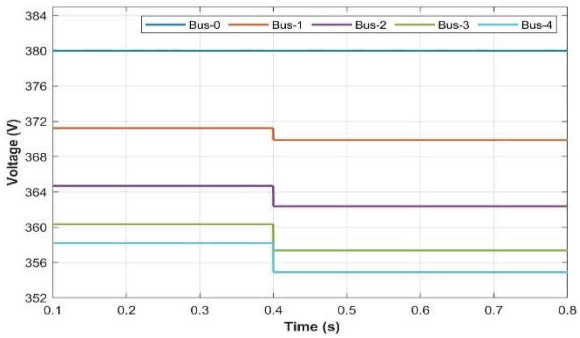

Fig. 4 Bus voltages without SVR at step increase load

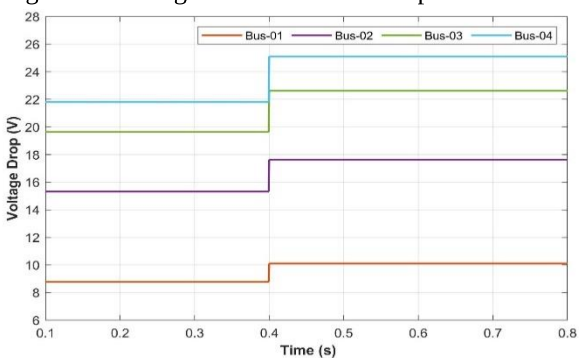

Fig. 5 Bus voltage drops without SVR at step increase load

B. With SVR results

Fig. 8 shows the bus voltages at step increase load with SVR. The voltage drops with SVR are shown in Fig. 9. Fig. 10 shows the load current with SVR. Power change with SVR is shown in Fig. 11.

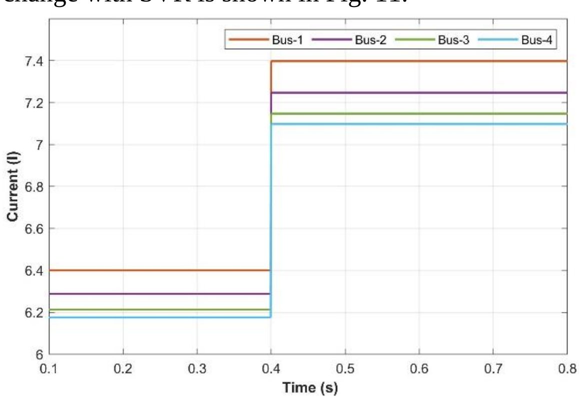

Fig. 6 Load currents without SVR at step increase load

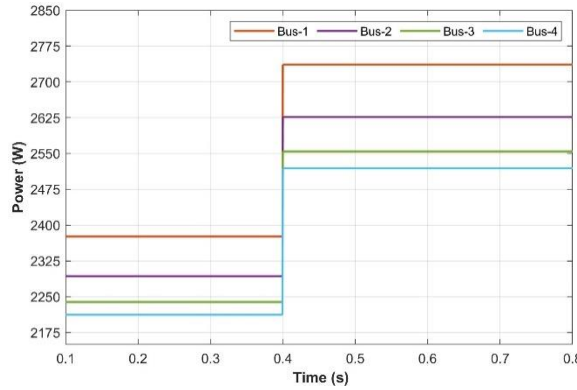

Fig. 7 Load power without SVR at step increase load

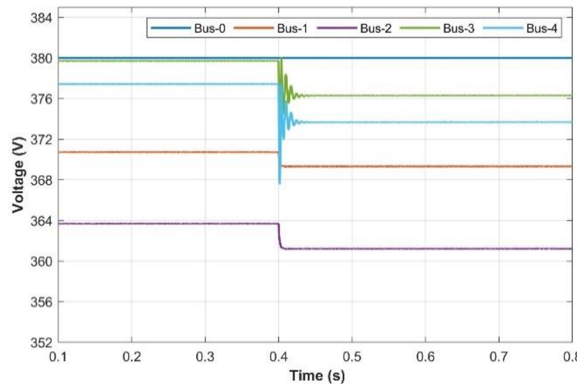

Fig. 8 Bus voltages with SVR at step increase load

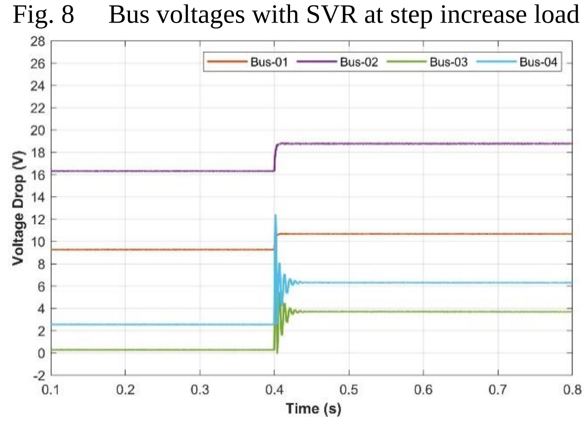

Fig. 9 Bus voltage drops with SVR at step increase load

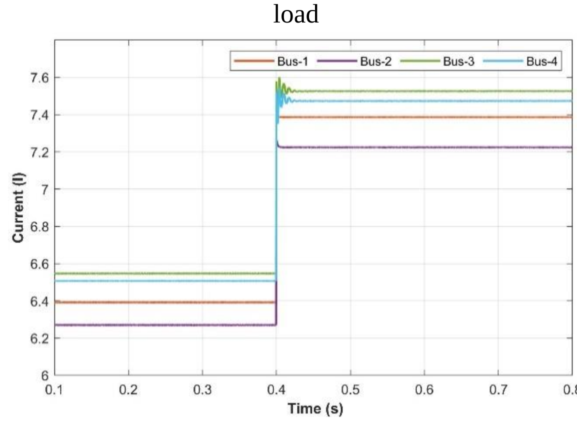

Fig. 10 Load currents with SVR at step increase load

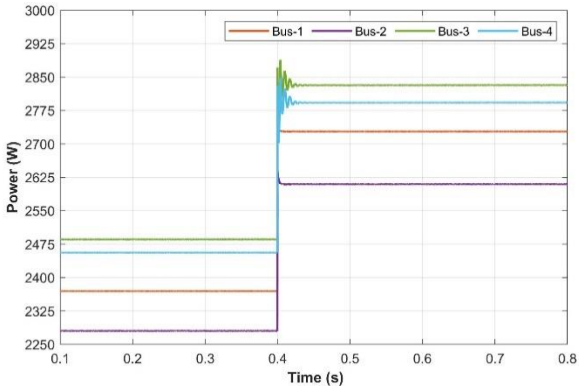

Fig. 11 Load power with SVR at step increase load

C. Comparison with and without SVR results

In this section, simulated result of with and without SVR at step increased load is discussed. As SVR is connected between bus-2 and bus-3, this comparison study mainly focused on bus-3.

Fig. 12 shows the bus-3 voltage comparison with and without SVR. Load step increase occurs at 0.4 s, voltage details are shown in Table I. Fig. 13 represents the voltage drop at bus-3 with and without SVR at step increase load. Table II shows the details of voltage drop before and after step load change.

Fig. 14 represents the load current at bus-3 connected load with and without SVR at step increase load. Table III shows the details of load current before and after step load change.

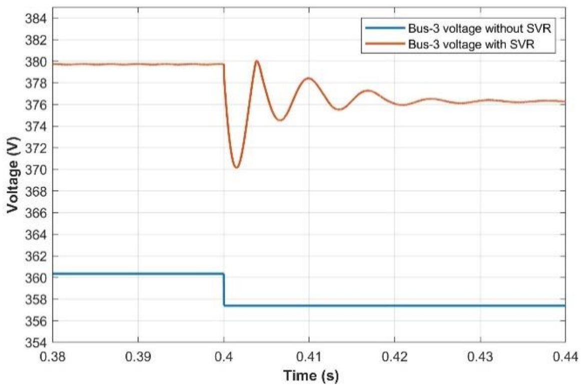

Fig. 12 Bus-3 voltage comparison at step increase load

TABLE I BUS-3 VOLTAGE COMPARISON WITH AND WITHOUT SVR AT STEP INCREASE LOAD

Bus-3 voltage without SVR (volt)		Bus-3 voltage with SVR (volt)	
Before 0.4 s	After 0.4 s	Before 0.4 s	After 0.4 s
360.4	357.4	379.7	376.3

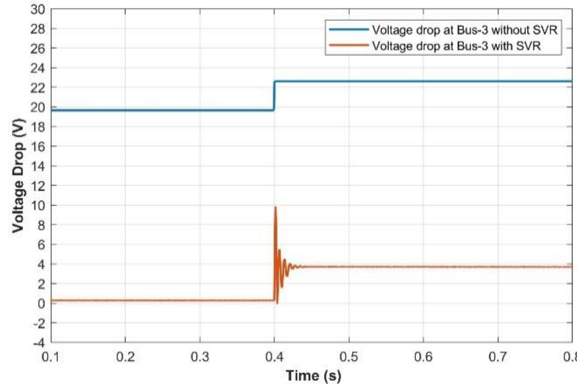

Fig. 13 Bus-3 voltage drop comparison at step increase load

TABLE II BUS-3 VOLTAGE DROP WITH RESPECT TO BUS-0 WITH AND WITHOUT SVR AT STEP INCREASE LOAD

Voltage drop at Bus-3 without SVR (volt)		Voltage drop at Bus-3 with SVR (volt)	
Before 0.4 s	After 0.4 s	Before 0.4 s	After 0.4 s
19.65	22.62	0.24	3.70

Fig. 15 represents the load power at bus-3 connected load with and without SVR at step increase load. Table IV shows the details of load power before and after step load change.

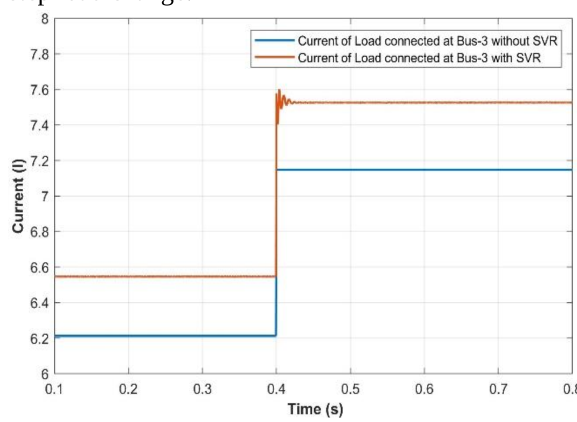

Fig. 14 Current comparison of Bus-3 connected load at step increase load

TABLE III LOAD CURRENT AT BUS-3 CONNECTED LOAD WITH AND WITHOUT SVR AT STEP INCREASE LOAD

Load current at Bus-3 connected load without SVR (in A)		Load current at Bus-3 connected load with SVR (in A)	
Before 0.4 s	After 0.4 s	Before 0.4 s	After 0.4 s
6.21	7.14	6.54	7.52

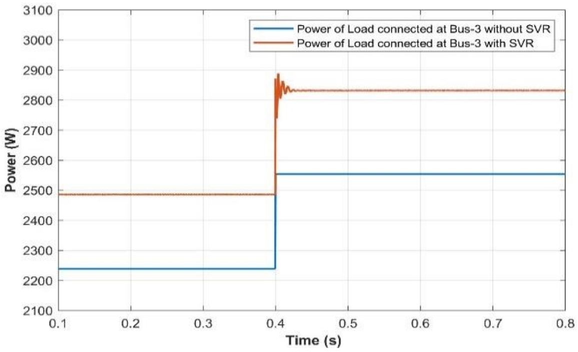

Fig. 15 Power comparison of Bus-3 connected load at step increase load.

TABLE IV LOAD POWER AT BUS-3 CONNECTED LOAD WITH AND WITHOUT SVR AT STEP INCREASE LOAD

Load power at Bus-3 connected load without SVR (in W)		Load power at Bus-3 connected load with SVR (in W)	
Before 0.4 s	After 0.4 s	Before 0.4 s	After 0.4 s
2239	2554	2486	2832

As seen from the Table I, Table II, Table III and table IV proposed SVR shows very good dynamic response and performance.

Fig. 16 shows the input voltage of DAB at step increase load. Output voltage of the DAB is shown in Fig.17. Output voltage of the full bridge DC-DC converter is shown in Fig.18. Fig.19 shows the output current of the full bridge DC-DC converter.

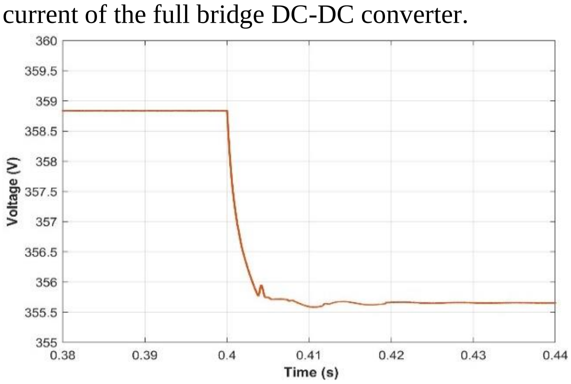

Fig. 16 Input voltage of DAB at step increase load

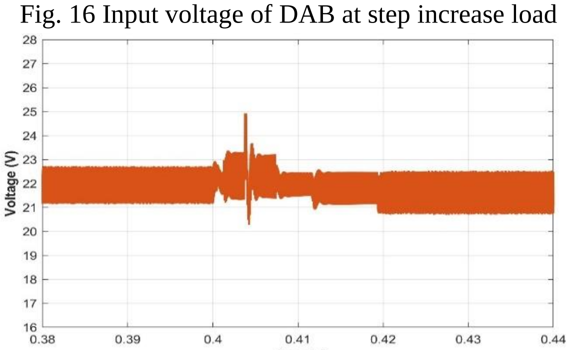

Fig. 17 Output voltage of DAB at step increase load

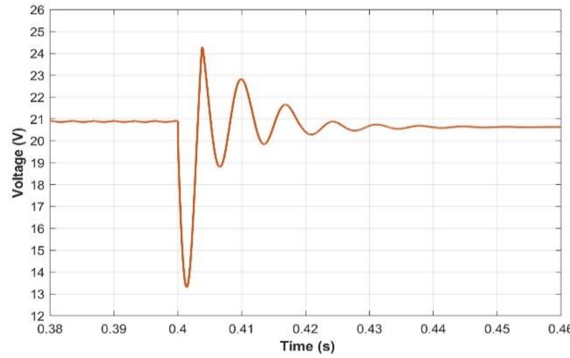

Fig. 18 Output voltage of full bridge DC-DC converter at step increase load

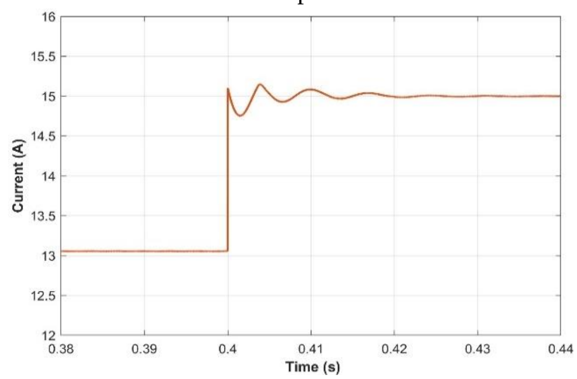

Fig. 19 Output current of full bridge DC-DC converter at step increase load

VI. CONCLUSION

This paper presents the dual active bridge followed by full bridge DC-DC converter-based series voltage regulator in five bus DC-microgrid to improve the voltage profile. Complete model is modelled and simulated in MATLAB/Simulink. Two control blocks are used to control the SVR, Block-I for the DAB output voltage control and Block-II for compensation of voltage drop across the line. To analyze the performance of the proposed SVR increased load condition is considered. Simulation results shows that using the SVR the line voltage before load change improved to 5.35% and after load change improved to 5.28%. This SVR can be further used in large radial DC microgrid with optimal placement.

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