Buck and Boost Multiple Output Voltage Balancer

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ABSTRACT: Micro-dc grid is a novel power system focused on the development of renewable resources. However, two-wire transmitting power mode is generally accepted in a micro-dc grid, which is usually not suitable for the requirements of the input voltage levels of different power converters and loads. In order to meet the requirements, a half-bridge voltage balancer was introduced in a micro-dc grid, which can convert a two-wire mode into a three-wire mode in a micro-dc grid via a neutral line. However, the shoot-through problem existing in bridge-type converters degrades the reliability of the voltage balancer. In this paper, a buck and boost multiple output voltage balancer and a control strategy is presented, which can avoid the shoot-through problem. And, it is found that, a bucked multiple output of 110V DC and boosted multiple output of 300V DC was obtained when an input of 220V DC is given.

KEYWORDS: micro grid, voltage balancer, buck converter, boost converter.

I.   INTRODUCTION

Micro dc grid based on distributed generation system, which can supply super high quality electric power, is widely focused on in recent years with the development of renewable resource generations. The use of the direct current allows simplifying the insertion between the distribution generation and the network [4]. It needs only one interface converter with alternating current grid to make the operation in islanding mode easier, without compromising the safety of the public network, and it has a distinct benefit of line loss reduction [6] [5]. A micro-dc grid usually has only one voltage level in two-wire dc distribution system [3]. It is impossible to supply some types of loads at half voltage or higher voltage such as dc/ac inverters needing a neutral line, converters with input voltage balancing like half-bridge converter and three-level half-bridge converter, and so on [2]. In particular, when a micro-dc grid is used in domestic and office places, a neutral line connected to ground is favourable to the security of the persons. Obviously, in practice, with a micro-dc grid two-wire power system, it is impossible to meet the requirements of all electronic devices. Thus, a half-bridge voltage balancer was introduced to build a neutral line, which can easily convert a two-wire dc grid into a three-wire dc grid by a neutral line [1].

In practice, the voltage balancer may be dispersedly used in any place where the voltage balance is needed, and of course, it can be placed at the output side of the power supply centre for building a whole three-wire dc grid [7]. It is thus evident that the voltage balancer improves the quality and flexibility of power supply in a micro dc grid [8]. The converter can avoid the shoot-through problem since the freewheeling current goes through the independent freewheeling diodes instead of the body diode of the switches, and all the switches and diodes are operated at half of the line cycle. Thus the efficiency can be improved. In this paper, a buck and boost multiple output voltage balancer is presented. For meeting the characteristic of the multiple output voltage balancer, a control strategy for driving the two bridge legs of the voltage balancer to work at a high efficiency is also presented.

II.   TOPOLOGY AND CONTROL STRATEGY OF THE VOLTAGE BALANCER
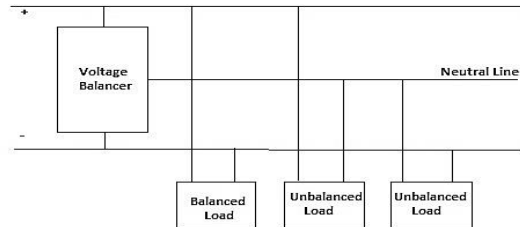

Fig 1 voltage balancer in dc grid

A typical structure of a micro-dc grid with a voltage balancer is shown in Fig. 1, where the voltage balancer is used to construct a neutral line to achieve two same voltage levels for the requirements of different types of loads, such as unbalanced loads, half-bridge converter and inverter etc.
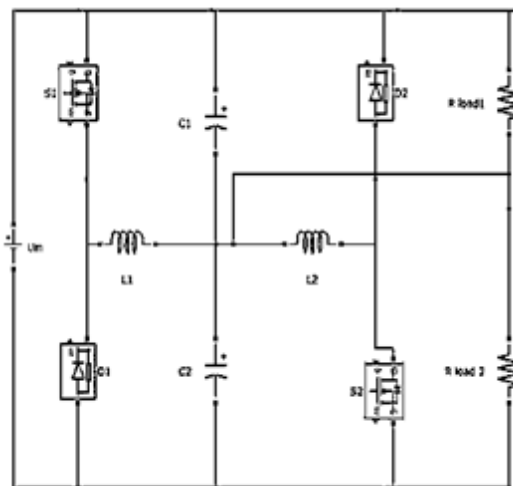
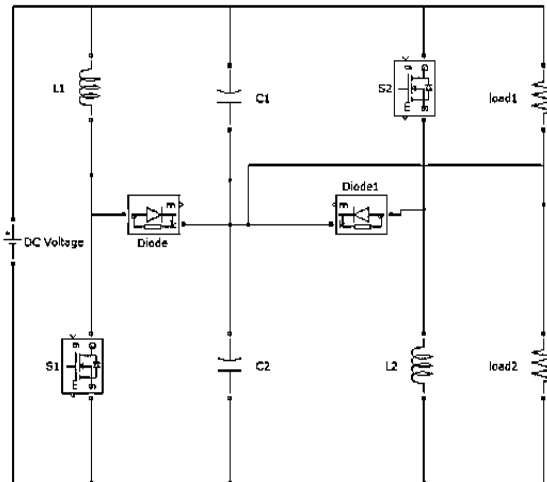*A. Proposed Voltage Balancer*

Fig 2 buck voltage balancer   Fig 3 boost voltage balancer

A buck multiple output voltage balancer is shown in Fig. 2 and a boost multiple output voltage balancer is shown in Fig 3 , which are made up of a left bridge leg (S_1,D_1, L_1), a right bridge leg (S_2,D_2, L_2), and a neutral line $L_N$usually connected to the earth ground. If the complementary driving technology is adopted between the switches $S_1$and S_2, the two-inductor currents i_{L1} and i_{L2}will always exist during a switching period, and the unbalanced load current value ($i_{RLoad2}- i_{RLoad1}$) is equal to the difference value between the current average value $i_{L1}$and i_{L2}. Thus, the two inductor currents will cause additional power losses. Obviously, the complementary operational technology does not improve the system efficiency. It is very expected to have a control strategy that can drive the left bridge leg and the right bridge leg, respectively, based on the different power quantity of the unbalanced loads.
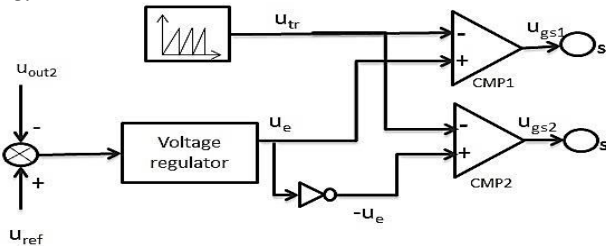
B. Proposed Control Strategy

Fig 4 control strategy

The proposed control strategy is presented in Fig. 4. The output signal u_e of the voltage regulator is directly sent to control the switch S_1, and its negative value ($-u_e$) controls the switch S_2. Combining Fig. 2, Fig. 3 and Fig. 4 it may be concluded that, when R_{Load2} is lower than R_{Load1}, the signal u_e is positive and the left bridge leg will be driven while the right bridge leg will not work, and on the contrary, when the signal u_e is negative, the right bridge leg will be driven. It is thus clear that only one of the two bridge legs will work during every switching period and the loss of the other bridge leg will be avoided compared with the complementary driving technology.

III.   OPERATING PRINCIPLE BASED ON THE PROPOSED CONTROL STRATEGY

As similar to a buck converter, each bridge leg maybe operates in continuous conduction mode (CCM) and discontinuous mode operation (DCM). For simplifying the analysis of the operational principle, some assumptions are made:

1) All inductors and capacitors are ideal, $C_1 = C_2 = C$, and $L_2 = L_2 = L$

2) The output voltages u_{out1} and u_{out2} are not changed during each switching process.

3) All power switches and diodes are the ideal devices with ignored switching time and conduction voltage drop. As the operating procedures of the right bridge leg are the same as those of the left bridge leg, only the analysing principle of the left bridge leg is given.
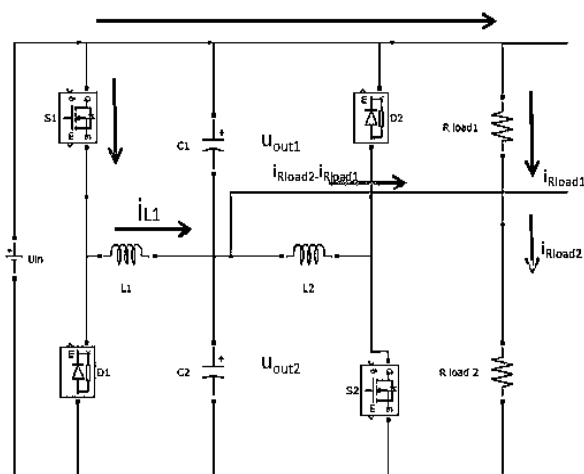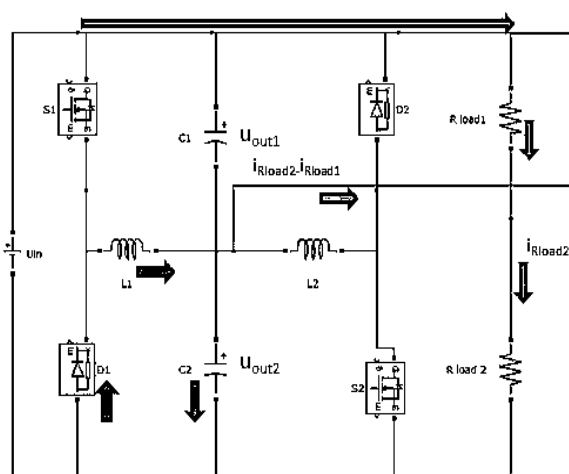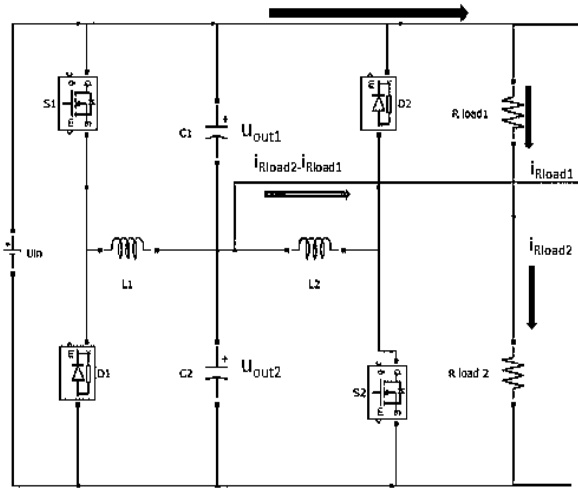

Fig 5 mode1 operation
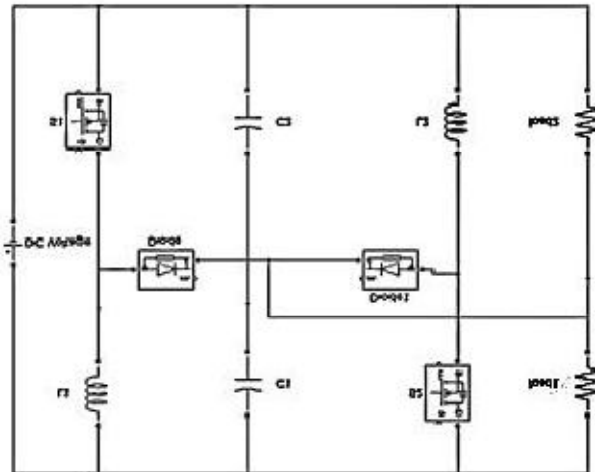

Fig 6 mode2 operation

Fig 7 mode3 operation

Fig 8 boost operation

A. CCM of Left Bridge Leg of Buck Converter
The driving signal u_{gs1}, the current i_{L1}, and the equivalent circuits are shown in Fig. 4 and Fig. 5, respectively, during CCM. From Fig. 4, there are only two main operating modes during each switching period.

1) Mode 1 [t_0, t_1] : The switch $S_1$is turned on at the time t_0, and the current i_{L1}increases linearly. During this mode, the input voltage u_{in}sends additional energy to the load R_{Load2}through the inductor L_1. The voltage stress of the freewheeling diode $D_1$is the input voltage u_{in}.

2) Mode 2 [t_1, t_2] : The switch S_1 is turned off at the time t_1, and the current i_{L1}will continue to run through the freewheeling diode D_1. The current i_{L1} decreases linearly. The procedure will end when the $S_1$is turned on again at the time t_2. During this mode, the voltage stress of the switch S_1 is also the input voltage u_{in}. From the time t_2, a next operating period will start.

B. DCM of Left Bridge Leg of Buck Converter
There are three operating modes under DCM. It can be concluded that the mode 1and the mode 2are in accordance with the two modes under CCM, respectively. Therefore, only the mode 3is given.
Mode 3 [t_2, t_3] :From the time t_2, the loads $R_{Load1}$and $R_{Load2}$are supplied by the voltage sources $u_{out1}$and u_{out2}because the current i_{L1}decreases to zero.

C. CCM of Left Bridge Leg of Boost Converter
The driving signal u_{gs1}, the current i_{L1}, and the equivalent circuits are shown in Fig 4 andFig 8respectively, during CCM. From Fig. 4, there are only two main operating modes during each switching period.
1) Mode 1 [t_0, t_1] : The switch $S_1$is turned on at the time t_0, and the current i_{L1}increases linearly. And, energy is stored in the inductor.
2) Mode 2 [t_1, t_2] : The switch $S_1$is turned off at the time t_1, and the current i_{L1}will continue to run through the diode D_1. The current i_{L1} decreases linearly. The procedure will end when the $S_1$is turned on again at the time t_2. From the time t_2, a next operating period will start.

D. DCM of Left Bridge Leg of Boost Converter
There are three operating modes under DCM. It can be concluded that the mode 1and the mode 2are in accordance with the two modes under CCM, respectively. Therefore, only the mode 3is given.
Mode 3 [t_2, t_3] :From the time t_2, the loads $R_{Load1}$and $R_{Load2}$are supplied by the voltage sources $u_{out1}$and u_{out2}because the current i_{L1}decreases to zero.

IV.   MATLAB / SIMULINK MODEL

The proposed direct buck and boost multiple output voltage balancer circuit is simulated using corresponding SIMULINK model of the circuit in MATLAB. Both buck loop and boost operation of the circuit is modeled and simulated. The simulation is done for obtaining a dual dc output voltage, V_o=110V under balanced buck operation and 300V under balanced boost operation from a DC input voltage of, V_p =220V.

A micro grid having distribution voltage of 220V DC is considered in this study for verification of the proposed converter topology .The micro grid is designed as an 220V DC voltage source .Circuit parameters used for the simulation model are L_1=230µH,L_2=230µH,C_1=470µF,C_2=.470µF, switching frequency of 25Khz
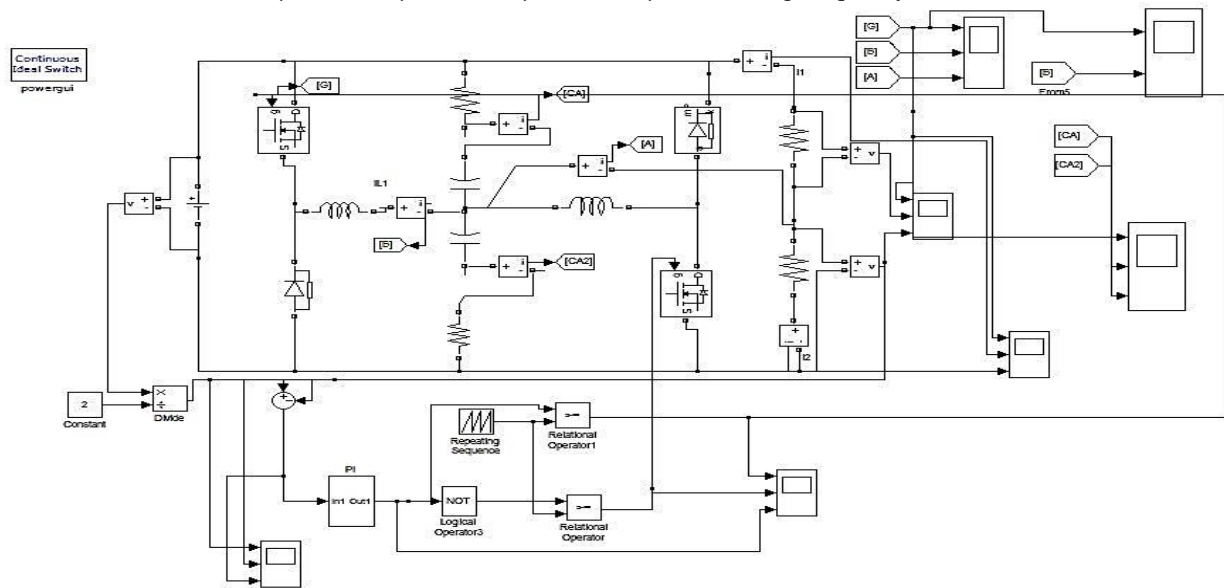
Fig 9 MATLAB / Simulink model of buck multiple output voltage balancer

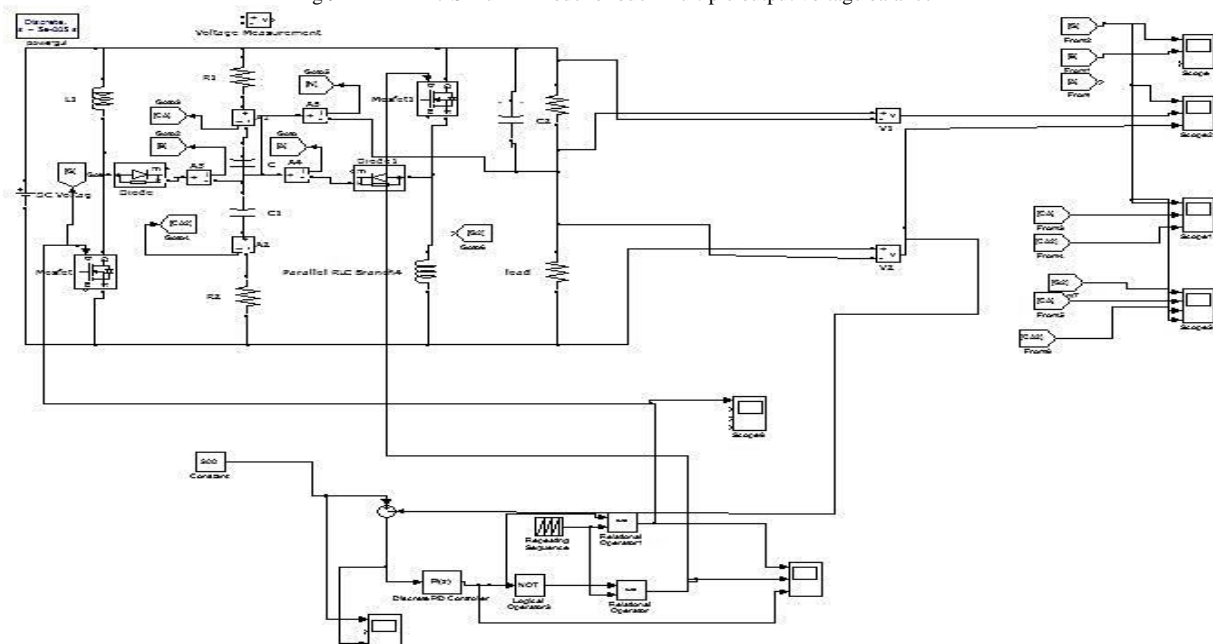Fig 10 MATLAB / Simulink model of boost multiple output voltage balancer

V.   SIMULATION RESULTS

The following waveforms were obtained while simulating the buck and boost multiple output voltage balancer. An input of 220V DC was given and balanced buck voltage of 110V DC and boost output of 300V DC were obtained under balanced and unbalanced load conditions. An output power of 1000W was obtained across each load under balanced conditions.
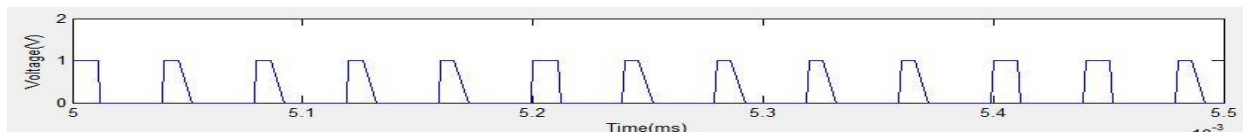

Fig 11 Gate pulse

Fig 11 shows the gate pulses used to switch the switches S_1. Only one switch S_1 or S_2 is triggered with the help of gate pulse according to the u_e signal.
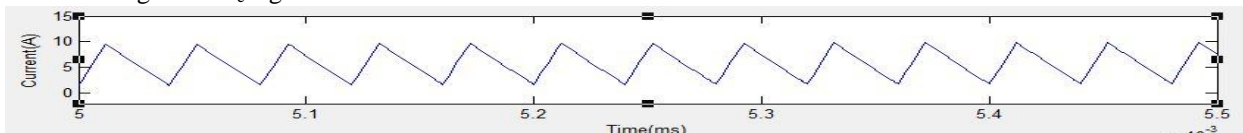

Fig 12 Inductor current

Fig 12 shows the inductor current. You can see the charging and discharging of the inductive current in CCM. Energy is stored in inductor during charging and stored energy is delivered to load during discharging.
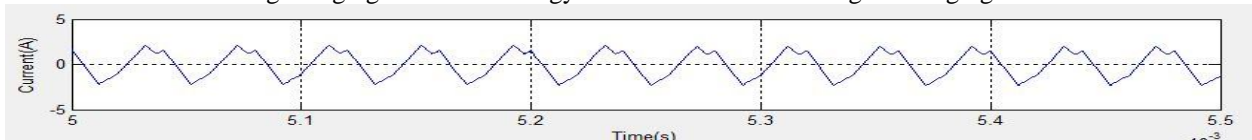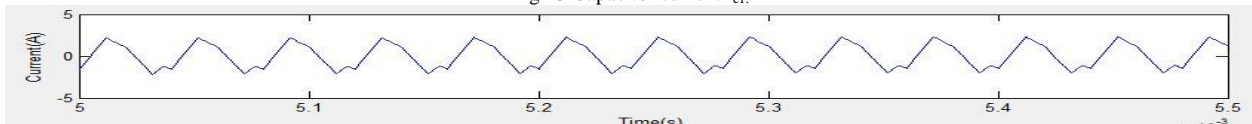

Fig 13 Capacitor current $I_{c1.}$

Fig 14 Capacitor current I_{c2}

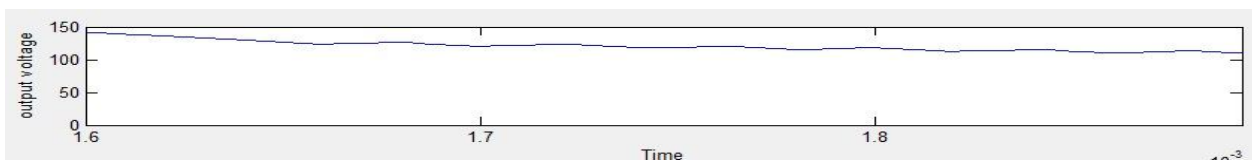Fig 13 and Fig 14 shows the charging and discharging of capacitors C_1 and C_2

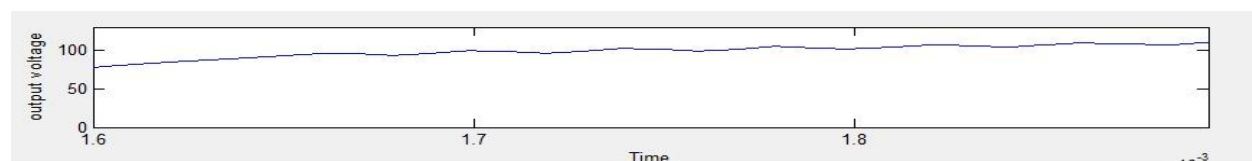Fig 15 output voltage under buck operation R_{load1}

Fig 16 output voltage under buck operation R_{load2}

Fig 15 and Fig 16 shows that when a 220V input DC voltage is given, a balanced bucked voltage of 110V is obtained at the output.
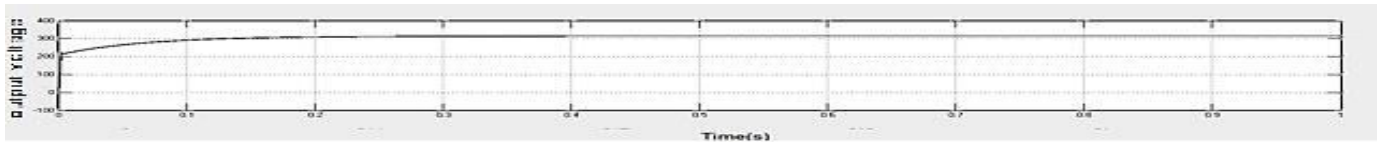

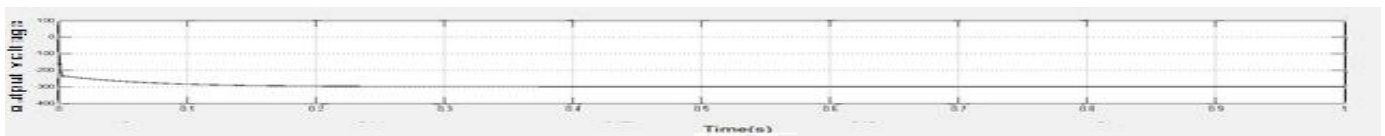Fig 17 output voltage under boost operation R$_{load1}$

Fig 18 output voltage under boost operation R$_{load2}$

Fig 17 and Fig 18 shows that when a 220V input DC voltage is given, a balanced boost voltage of 300V is obtained at the output.

VI.   CONCLUSION

In this paper, a buck and boost multiple output voltage balancer and its control strategy is presented. The multiple output voltage balancer can resolve the shoot through problem which was present in the conventional voltage balancer circuit. It built a neutral line to balance two output voltages for different loads in a micro dc grid. A simplified control scheme is also done for the buck and boost voltage balancer circuit for high efficiency operation. The simulation results are done in order to illustrate the multiple output voltage balancer.A bucked multiple output of 110V DC and boosted multiple output of 300V DC was obtained when an input of 220V DC is given. As future scope, two level buck-boost converter can also be developed with increased flexibility of the dc micro-grid to supply various loads.

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