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Dual-Buck Half-Bridge Voltage Balancer

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Abstract— **Micro-dc grid is new power system for smooth installation of many distributed generations (DGs) . Most of the micro grids adopt ac distribution as well as conventional systems, dc micro grids are proposed for the good connection with dc output type sources such as photovoltaic (PV) system, fuel cell, and secondary battery. Super high quality power with three-wire distribution can be achieved by half bridge voltage balancer, which can convert two wire modes into a three wire mode via a neutral line. Super capacitors are chosen as main energy storage.**

In this paper, a dual-buck half-bridge voltage balancer and a control strategy are proposed, which can avoid the shoot-through problem. The current relationships of the inductors; the capacitors and the unbalanced loads are analyzed particularly. Pulse width-modulation (PWM) technique is used to avoid shoot through thereby good ability of balancing voltage by building a neutral line.

Keywords-*:* Micro-dc grid, buck converter, voltage balancer, dc distribution system, grid-connected inverter.

I. INTRODUCTION

This paper presents a number of distributed generations are being installed into the utility grid, introducing renewable energy generations such as photovoltaic cells, wind-powers etc [1]. Energy and environmental problems are concerned in recent years, such as green house gas, growth of energy demand and depletion of energy resources. If many distributed generations (DGs) are installed into utility grid they can cause problems such as voltage rise and protection problem [2]. It needs one interface converter with alternating current grid to make the operation in islanding mode easier. Micro-grid with two wire power system has to meet the all electronic devices hence, voltage balancer introduced to build neutral line helps in quality improvement and flexibility. The topology of some converters may be suffer from shoot-through risk hence, dual-buck half bridge converter avoids shoot-through problem thus efficiency may be improved [3]. The dc grid is also dependent on interfacing converters such as dc converter [4], grid-connected inverter [5]. Dual-buck half bride voltage balancer can avoid the shoot through problem, the freewheeling current flows through the independent freewheeling diodes instead of the external well-matched freewheeling diodes of the switches, and all the switches and diodes are operated at half of the line cycle; so, the efficiency can be improved due to no biased current [6]. The high voltage across switch leads to get spark at the switch contacts which dissipates stored energy when diode subjected to high reverse voltage may damage in this process, to avoid this flywheel or freewheeling diode is connected across load.

In order to satisfy high quality power supply and efficiency we proposed dual buck half bridge voltage balancer. In this, dc power distributed through 2 wires via neutral line and it may also convert to required ac or dc voltages by load side converters. If any voltage sag occurs in utility grid the dc grid can supply power stably, while inverters of distributed generations in ac grids has to be tripped unless they occur fault-ride through capability [11-13]. The control parameters and the current relationships of the inductors; the capacitors and the unbalanced loads are analyzed particularly for good reliability by building a neutral line. A PWM technique was introduced to generate the switching signal. Snubber circuit containing Rs, Cs, Ds is used to control the over voltage across the switches due to the leakage inductances. The converter's main characteristics are reduced input ripple current, high frequency isolating transformer, reduced output voltage ripple. DC converter that acts as a variable resistance to the load can produce an output voltage from 0 to Vs . Although a dc converter can be operated either at a fixed or variable frequency, it is usually operated at a fixed frequency with a variable duty cycle. Hysteresis current control achieves accurate tracking of inductor current as it is a non-linear control method, simple realization circuit, inherent current-limiting capability and fast dynamic response [11-13]. The output voltage contains harmonics and a dc filter is needed to smooth out the ripples. Ultra capacitors are fast dynamic storage systems with high power exchange capabilities hence they are suitable for the optimal charging of the battery and for supplying peak power to the grid if necessary, but their energy density is low. If ultra capacitors are overloaded excess PV power cannot be stored in them, so the produced PV power must be limited. If the load is inductive an anti parallel diode known as freewheeling diode must be connected across the load to provide a path for the inductive current to flow.

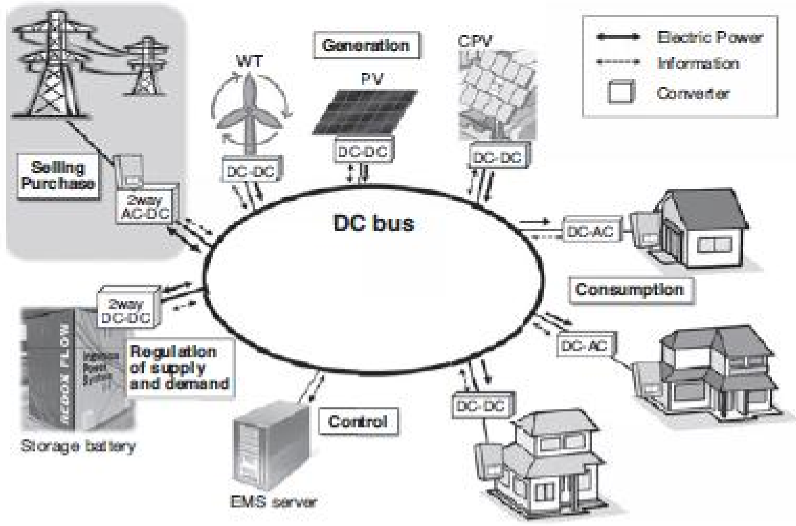


Figure 1: Various interfaces of DC bus.

II. MICRO GRID

Micro grid is defined as a cluster of distributed loads, distributed storage devices and distributed generation sources that operate to improve the reliability and quality of the local power supply in a controlled manner. The main components of a micro grid are: (i) distributed generation sources such as photovoltaic panels, small wind turbines, fuel cells, diesel and gas micro turbines etc., (ii) distributed energy storage devices such as batteries, super capacitors, flywheels etc., and (iii) critical and non-critical loads. Energy storage devices are employed to compensate for the power shortage or surplus within the micro grid. They also prevent transient instability of the micro grid by providing power in transient. The transient power shortage in a micro grid can be compensated for by fast energy storage devices in the micro grid, or by the utility grid through a bidirectional power converter when operating in grid-connected mode.

There are two operation modes for a micro grid: (i) grid - connected, and (ii) islanded mode.

In the grid-connected mode, power management is performed in a complementary manner between storage devices and as a result a DC micro grid can operate safely and efficiently. During the islanded mode, the battery plays in regulating the DC link voltage level, and the super capacitor plays a secondary role in responding of the sudden power requirement as an auxiliary source/sag, i.e. for peak shaving during transients. Micro grid control must insure that: (i) distributed generation and storage systems can be added or removed from the micro grid seamlessly, (ii) equal and stable current sharing between parallel power converters (i.e. sources) is enabled, (iii) output voltage fluctuations can be corrected, and (iv) desired power flow from/to the micro grid together with technically and economically viable operation is enabled. The main benefits of micro grids are high energy efficiency, high quality and reliability of the delivered electric power, more flexible power network operation, and environmental and economical benefits. The schematic structure of dc micro-grid with voltage balancer is shown in fig. 1, where voltage balancer develops a neutral line for types of loads, such as unbalanced loads, grid-connected inverter and soon. High dc bus voltages are necessary to ensure that power flows to the grid. Dc micro grid is resistant to disasters. When power failure occurs in commercial grid, the dc micro grid works independently supplying power that is disconnected from the commercial grid. Batteries may be connected with a dc bus via a dc-dc converter to control charge and discharge.

Characteristics of DC micro-grid can be summarized as follows:

- Distributed scheme of load side converters contributes to provide a super high quality power supplying. For instance, even if a short circuit occurs at one load side, it does not affect other loads.
- If power consumption becomes more than a power production during long term isolation, DC micro-grid can stop supplying power for some loads intentionality by load side converters in order to continue supplying power for high quality loads.

The advantages of dc micro grids are as follows:

1) The system efficiency becomes higher because of the reduction of conversion losses of inverters between dc output sources and loads.
2) There is no need to consider about synchronization with the utility grid and reactive power.
3) Higher efficiency than ac micro grid.

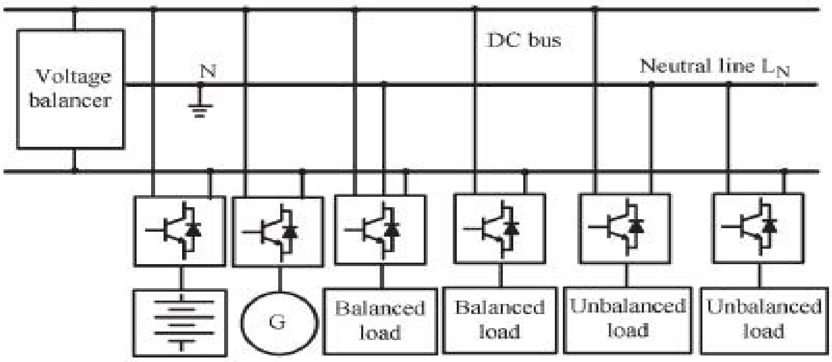


Figure 2: Schematic structure of micro-dc grid.

A. Voltage Balancer

A Dual-buck half bridge voltage balancer is shown in figure 2, consists of two legs namely left bridge and right bridge. The neutral line L_N connected to the earth ground. Each bridge consists of switch, diode and inductor. The inductor currents will cause additional power losses. The control strategy that drive two bridges, based on different power quality of the unbalanced loads. Hence voltage balancer is placed near a converter to balance positive and negative voltages. It is also possible to place it near load side.

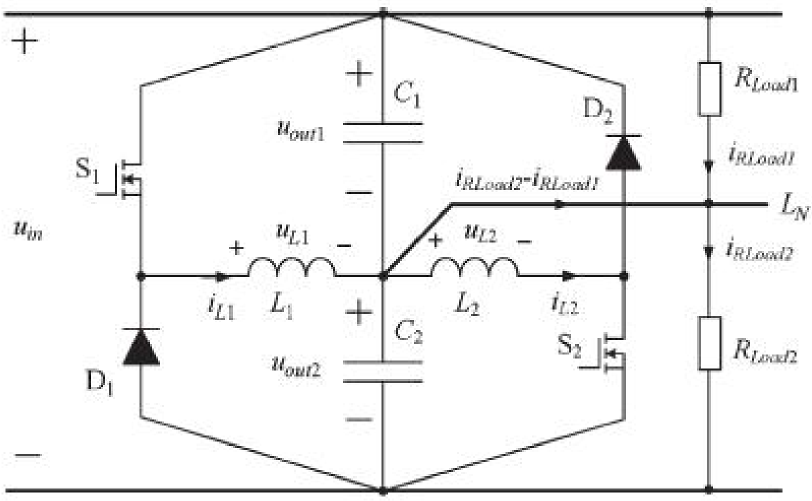


Figure 3: Dual bulk half-bridge voltage balancer.

B. Control Strategy

The control strategy is presented in figure 3. The output signal of voltage regulator i,e PI controller is directly sent to switches. The PI algorithm used for feedback of current controller. Left bridge will on if RLoad1 is greater than RLoad2 while right bridge is off. Right bridge will be on if RLoad1 is lower than RLoad2 when left bridge is off. This indicates only one of the two bridge legs will work for every switching period.

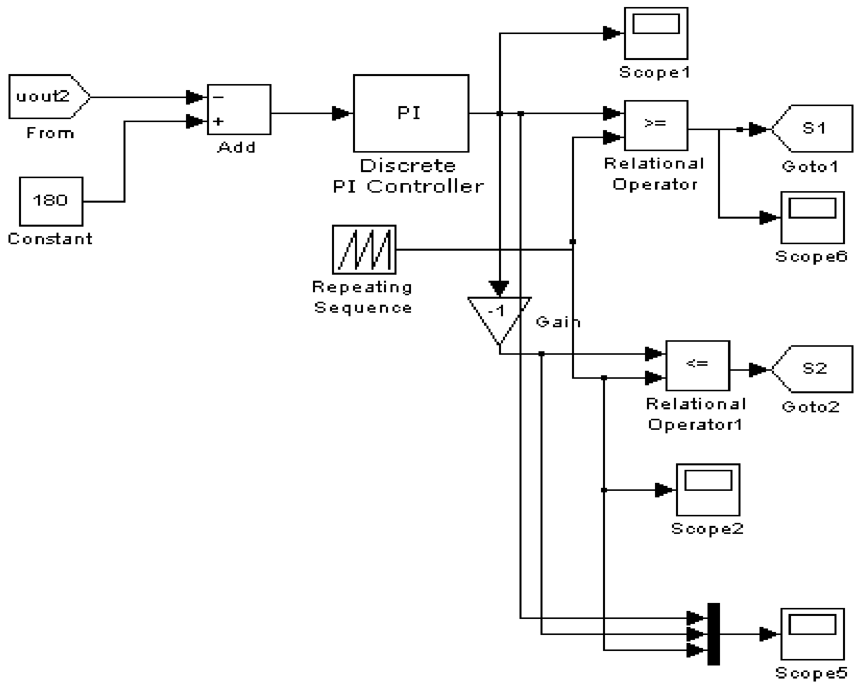


Figure 4: Diagram of control strategy.

III. OPERATING PRINCIPLE BASED ON THE CONTROL STRATEGY

A buck converter is the basic SMPS topology. It is widely employed in the industry to convert a higher input voltage into a lower output voltage. The buck converter (voltage step-down converter) is a non isolated converter, hence galvanic isolation between input and output is not given. The function of output capacitor is to filter the inductor current ripple and deliver a stable output voltage. The buck converter is used and regulation is normally achieved by pulse width modulation (PWM) at a fixed frequency and switching device is Mosfet which is a voltage controlled device and requires only a small input current hence it is unipolar device. The ripple content is normally reduced by an LC filter. The switching speed is very high and switching times are of the order of nanoseconds. MOSFET find application in low power high frequency converters. MOSFET requires low gate energy and have low switching losses. Each bridge operates in continuous conduction mode (CCM) and discontinuous conduction mode (DCM). For analysis following assumptions are given.

a) All power switches and diodes are ideal with ignored switching time and conduction voltage drop.

b) All inductors and capacitors are ideal.

$$C = C_1 = C_2 \text{ and } L_1 = L_2 = L$$

c) The output voltages are not changed during each switching process.The analyzing principles of left bridge is given as right bridge has same procedure.

A. CCM Operation

1) *Mode 1:* During this time interval [t_0, t_1] the switch S_1 is on at t=0 and the current i_{L1} increases linearly. The input current which rises flows through filter inductor L, filter capacitor C, and load resistor. The voltage stress of the free wheeling diode D1 is the input voltage.

$$L1\frac{di_{L1}}{dt} = u_{in} - u_{out1}$$

2) *Mode 2 :* During this time interval [t_1, t_2] the switch S1 is turned off at t = t1 and the current iL1 decreases linearly.

$$L1\frac{di_{L1}}{dt} = -u_{out2}$$

The freewheeling diode D1 conducts due to energy stored in the inductor, and the inductor current continous to flow through L,C, load and diode D1. The inductor current falls until switch S1 on again in next cycle.

Depending on switching frequency filter inductance and capacitance, the inductor current could be discontinuous.The time (t1-t0) is equal to the time (t2-t1) , i,e the turn on time is equal to the turn off time.

$$uout1(t1 - t0) = uout2(t2 - t1)$$

B. DCM Operation

There are three operating modes.It can be known that mode1 and mode 2 are in accordance with the two modes under CCM. Therefore, only the mode3 [t_2,t_3] is given.

Mode 3: During this time interval [t2,t3] ,the loads RLoad1 and RLoad2 are supplied by the voltage sources Uout1 and Uout2 because energy stored in inductor is zero. The energy stored in the capacitor is discharged to the load.

$$uout_1(t_1 - t_0) = uout_2(t_2 - t_1)$$

Here time, turn on time (t1-t0) is smaller than the turn off time (t3-t1).

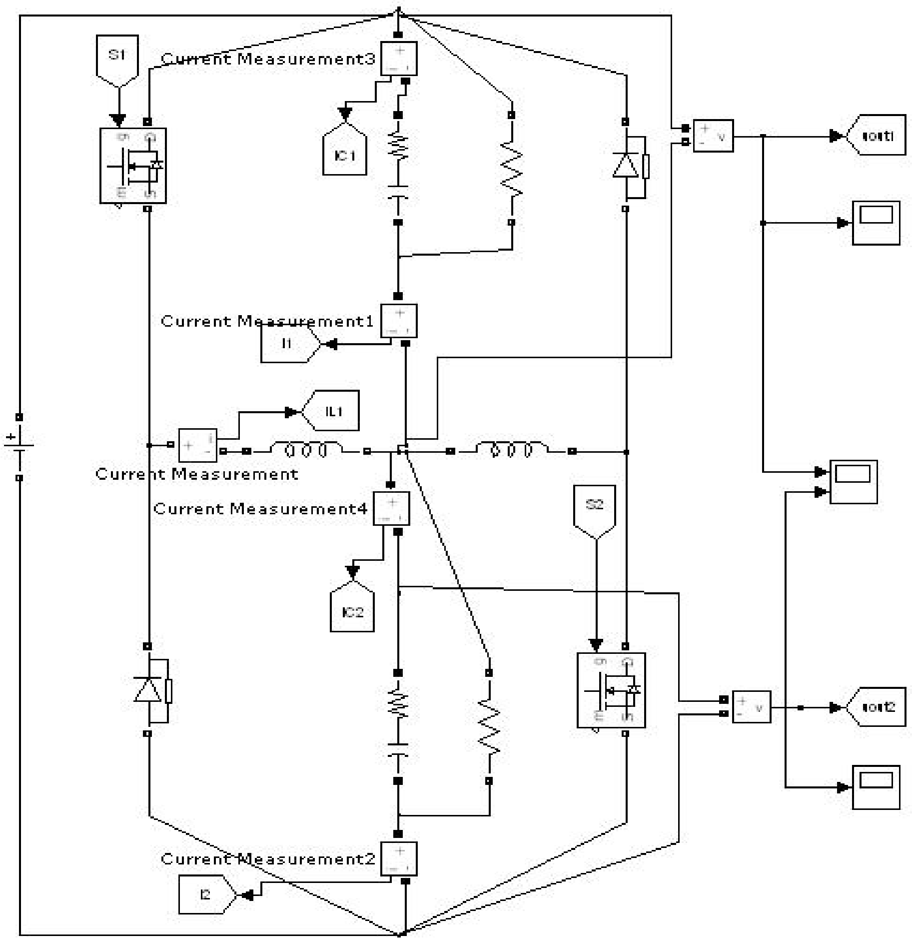


Figure 5: Simulation of CCM and DCM operation.

C. Transient Operation

If the behavior of voltage or current changed from one state to other known as transient state, occurs due to energy storage elements which delivers energy for resistance, the response changes with time and gets saturated after some time called as transient response. The transient response occurs in both inductive and capacitive circuits.

When switch is closed, the response reaches to steady state after a time interval, here transition period is defined as time taken for current to reach its steady state value from its initial value.

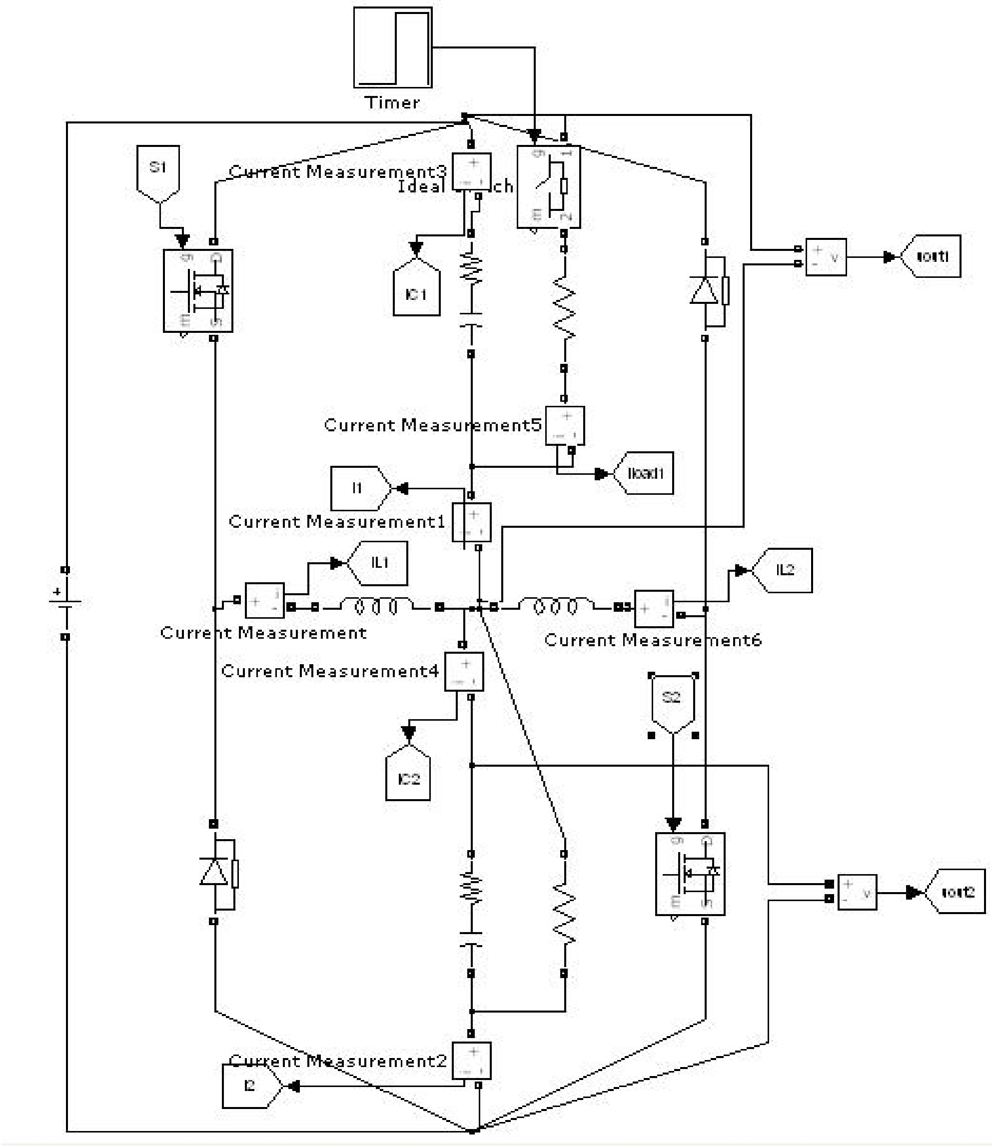
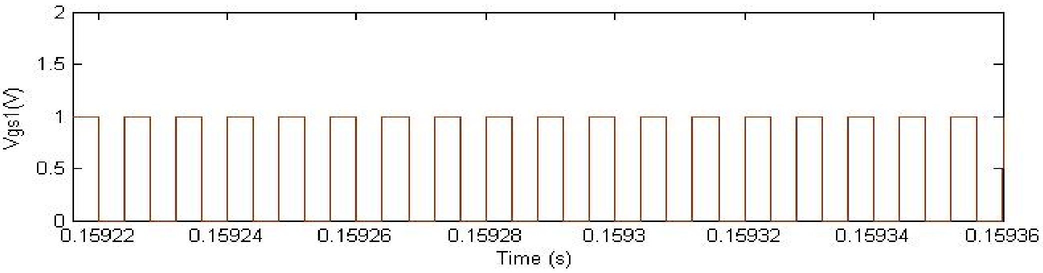


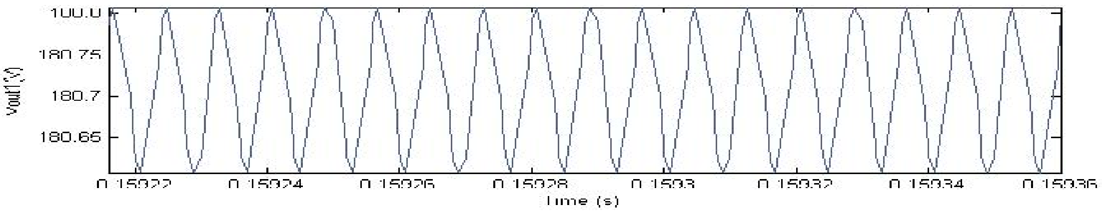
Figure 6: Simulation of loads transiently changing operation.

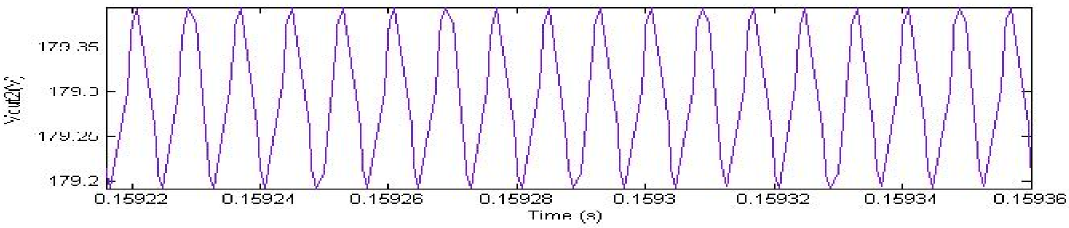
IV. SIMULATION RESULTS

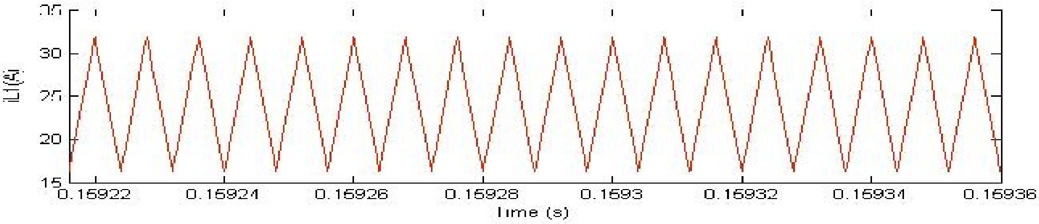
In order to confirm the analysis, the computer simulations of the main current relationships and the loads transiently changing are carried out by using MATLAB. Considering single phase 110 V for a half-bridge inverter and single phase 220 V for a full-bridge inverter, the dc bus voltage (input voltage u_{in}) is selected to be 360 V. The other main simulation parameters are listed: switching frequency of 25 kHz, L1 =L2 = 230μH, and C1 = C2 = 470μF.

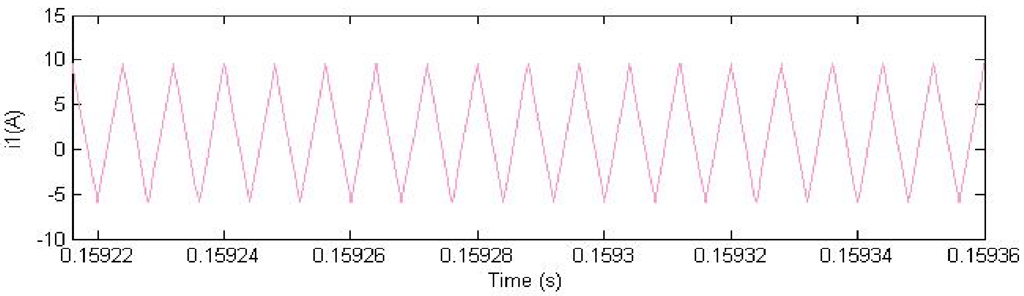
In this section, only the simulation results of the current relationships of the left bridge leg are given. The simulation results of the current relationships are given below. In figure it includes CCM [*R*Load1 = 100 Ω and *R*Load2 = 10 Ω] and DCM [*R*Load1 = 40 Ω and *R*Load2 = 30 Ω].

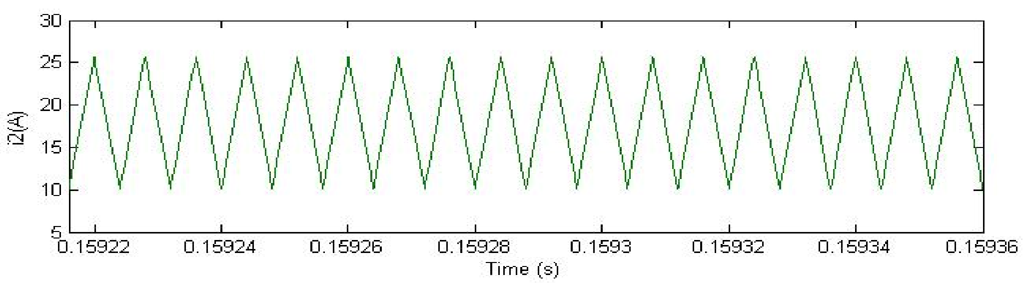












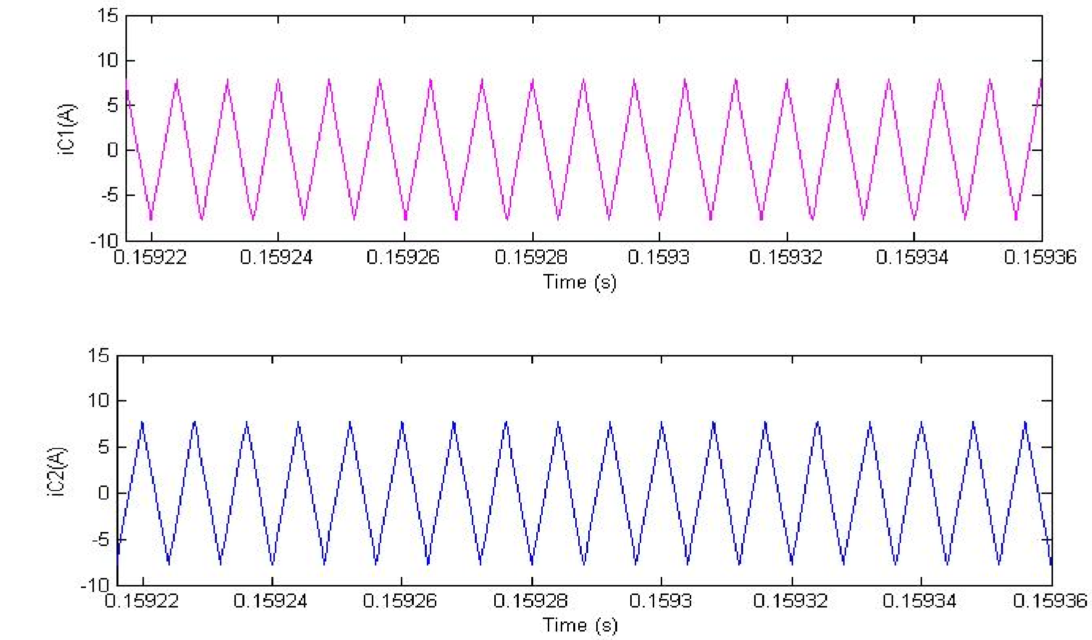
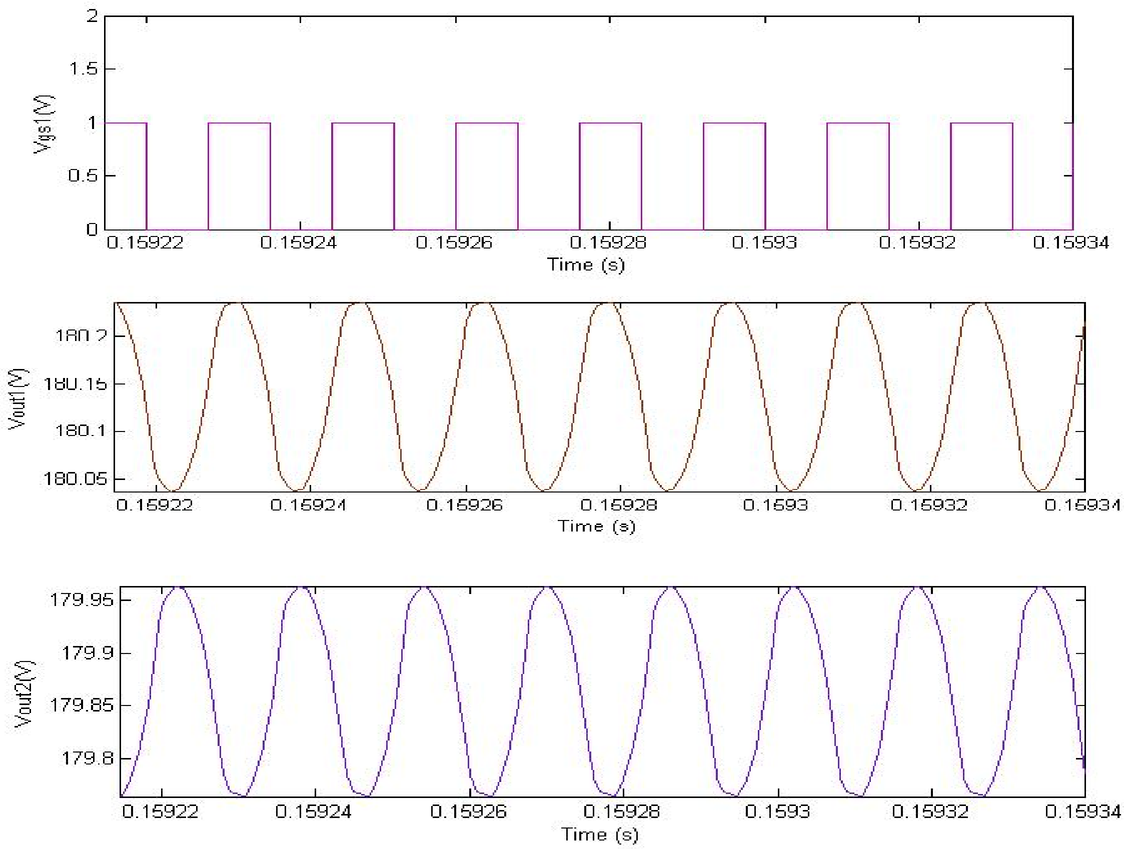


Figure 7: Simulation results of CCM operation.



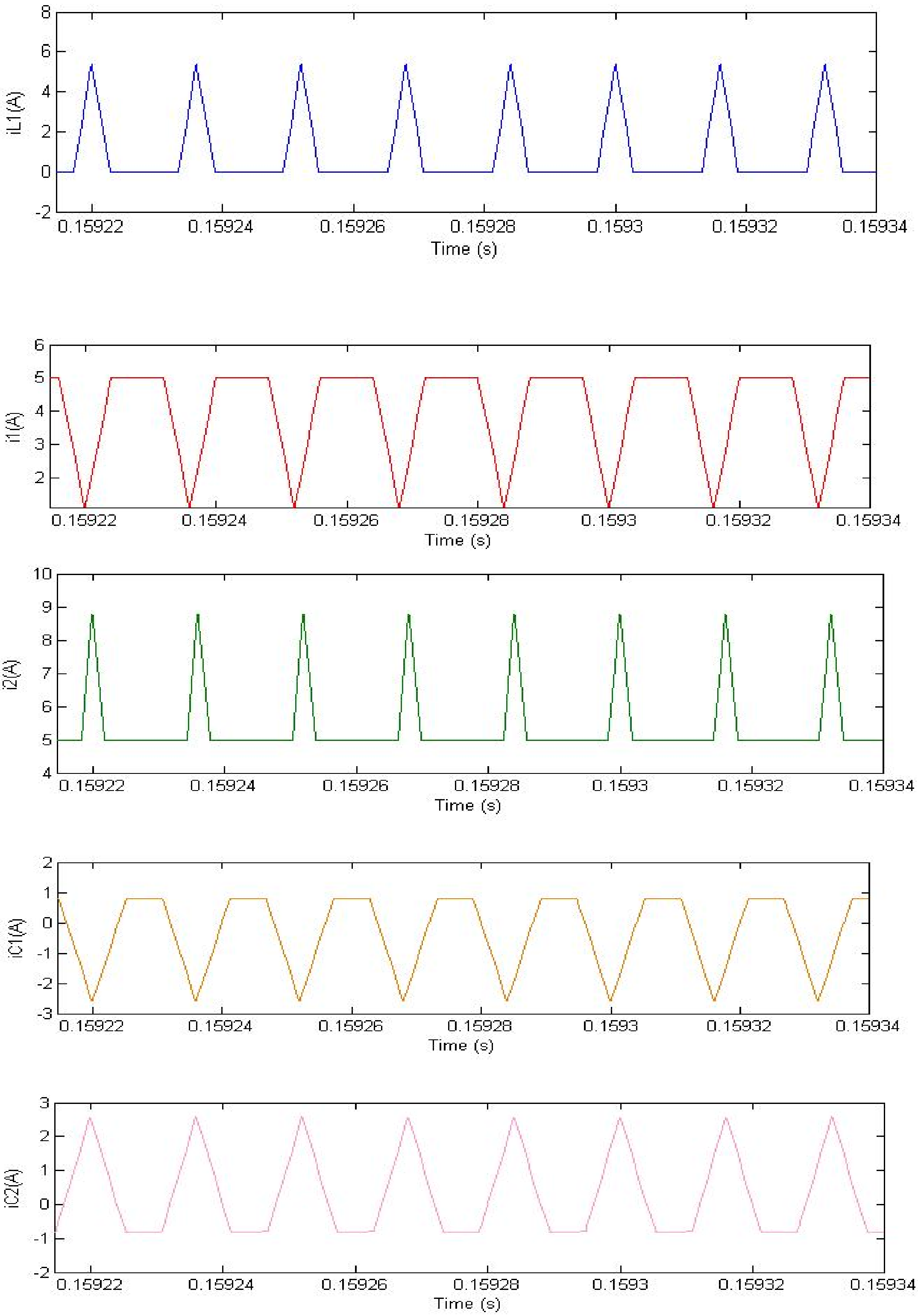


Figure 8: Simulation results of DCM operation.

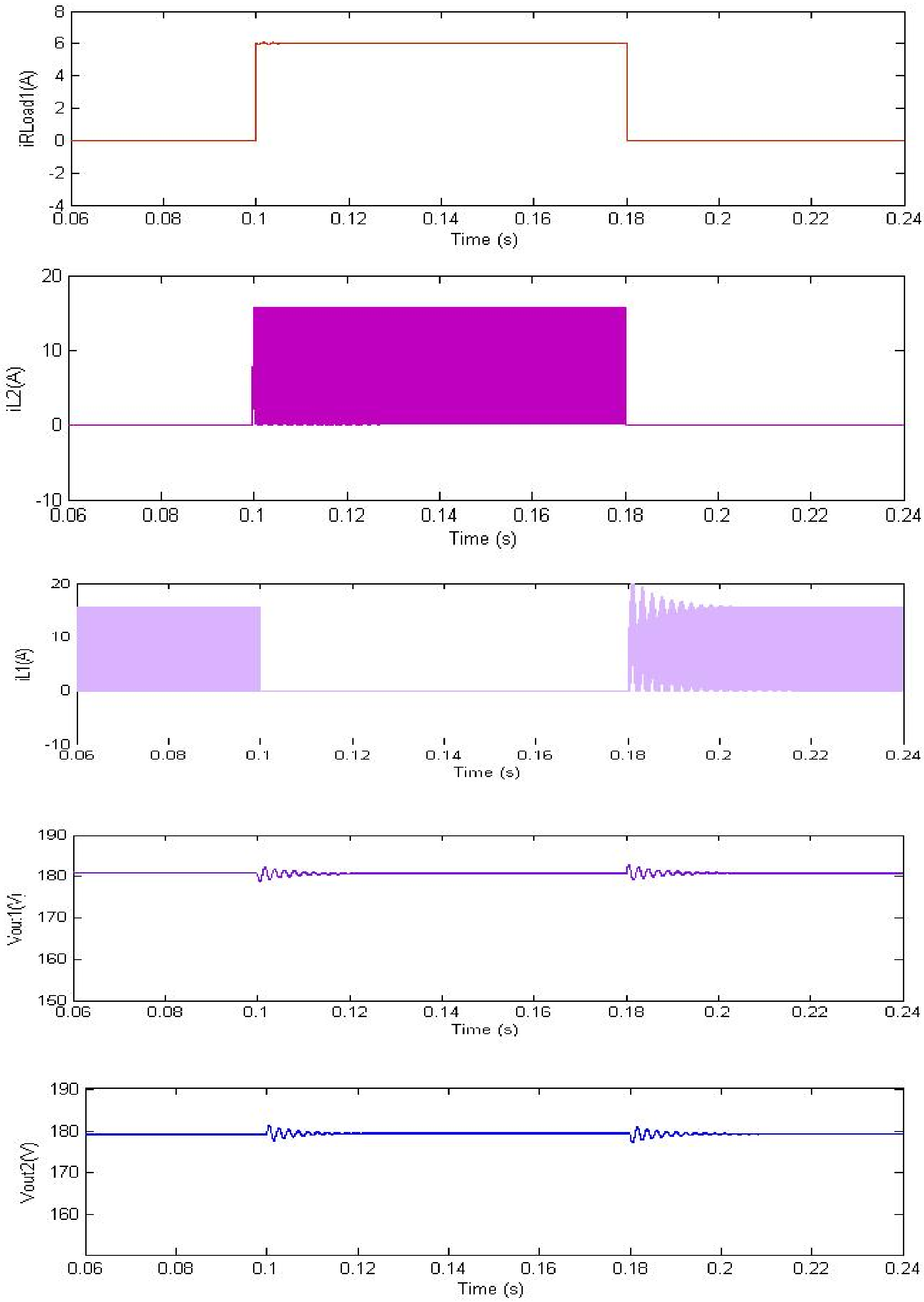
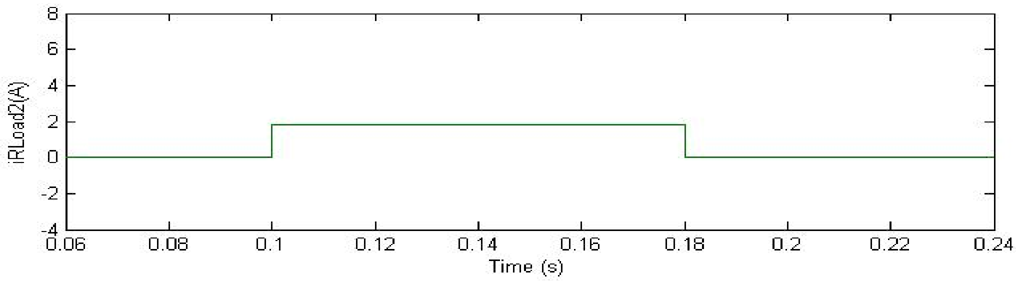


Figure 9: Simulation results of transiently changing load R_{Load1} operation.



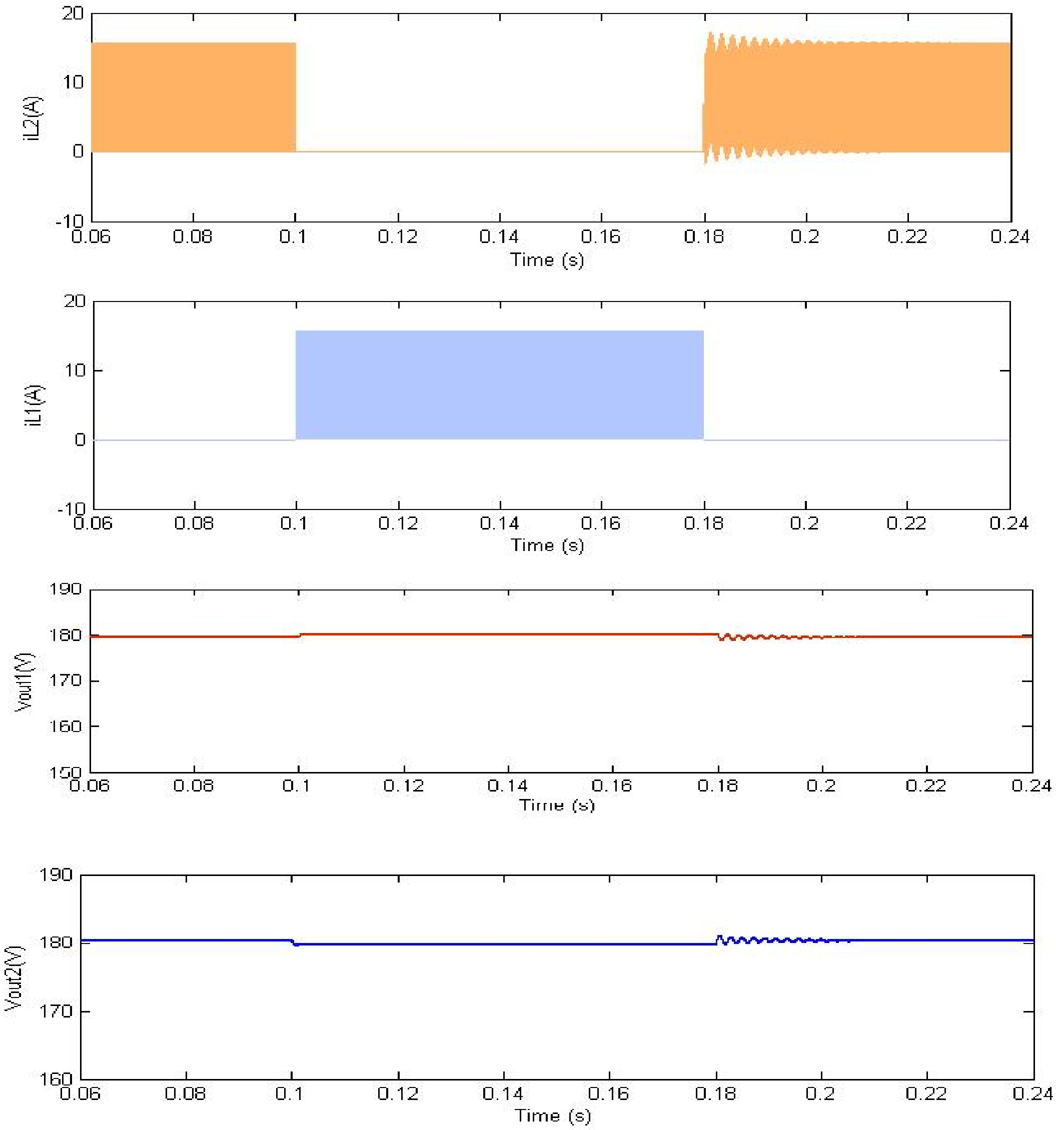


Figure 10: Simulation results of transiently changing load R_{Load2} operation.

CONCLUSION

In this paper, voltage balancer and its control strategy are proposed can well resolve the shoot-through problem through building a neutral line to balance two output voltages for different loads in a micro-dc grid. The voltage balancer having a good ability of balancing output voltage even if under the different input voltage, unbalanced loads, and transiently changing loads. Super capacitors are chosen as main energy storage.

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