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DESIGN AND ANALYSIS OF MULTIPLEXER DC-DC CONVERTER

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ABSTRACT

Usage of renewable energy resources have increased significantly in the past decade. Traditional system would adopt multiple separate single-input systems to be connected to a common bus. By using this multiple separate single-inputs the system would become more complex and the cost will also be high. So instead of using several single-input systems, the above system can be optimized by using a single multiple-input system. The system must be able to operate under any kind of dc input voltage application. The voltage analysis and power control strategy of this converter is studied.

KEYWORDS: Renewable energy, Multiple sources, Power management, Multiple input system.

I. INTRODUCTION

Applications with renewable energy such as photovoltaic (PV) energy and wind energy have been increased significantly during the past decade.[1,2] As some kinds of renewable energy serve acts as substitute, it is likely preferred to apply them together to deliver continuous power. Since these dc voltage sources have different magnitudes and hence cannot be connected directly in parallel, series-connected active switches are used for connecting them in parallel. It also allows only one power source to transfer energy to the load at a time, thus preventing more than two dc voltage sources from being connected in parallel. Multiple-input controller (MIC) has been proposed, which can successfully transfer power from the different voltage sources to the load individually or simultaneously.[3,4] The MIC is an integration of a buck converter and a buck-boost converter, where the inductor and capacitor are shared by the two converters, thereby reducing the number of passive elements.

Batteries, ultra capacitors, fuel cells and solar arrays are widely used as energy storage units. In the structure of the electric power system of modern EVs/HVs more than one of these units are used to improve the performance and efficiency, therefore multiple input DC-DC converter is inevitable to obtain a regulated bus DC voltage.[5,6] As the available DC voltage sources have different magnitudes, they cannot be connected in parallel. Hence, they are connected in parallel through a series-connected active switch.

II. Operating Principle of The Proposed Multiple-Input Single Output DC-DC Converter

The schematic diagram of the proposed multiple-input converter is shown in Fig.1. It consists of buck/ boost/ buck-boost converters cascaded into a multiple input DC-DC converter. The input DC voltage sources include Battery, Solar Energy, Fuel Cell, Wind energy etc. A typical MIC contains more than one input sources and a single load, and the input power of each input source should be controlled and can be transferred to the load either simultaneously or individually.[7,8]

The MIC is an integration of a buck converter and a buck-boost converter, where the inductor and capacitor are shared by the two converters, thus leading to a reduced number of passive elements.[9]-[12] The proposed MIC can be used in many hybrid renewable power systems. The three power sources in this converter can deliver energy to the load independently or simultaneously in one switching period. Detailed operation principles and power management strategy of this three-input DC-DC converter will be illustrated in Section II and III respectively.

A. Three-input Buck /Boost /Buck-Boost Converter

This buck/boost/buck-boost three-input converter, shown as Fig. 2, is composed of three parallel connection parts, a boost cell and two hybrid cells, on bipolar point C, D of capacitors C_f. The hybrid cell is composed of a buck-boost cell built-in a buck cell. V_{in1}, V_{in2}, V_{in3}, $V_{in4}$and V_{in5} are voltages of five sources. L_3 is boost inductor. L_{b1} and L_{b2} is a buffer inductor. C_f is an output filter capacitors. R_{Ld} is the load. Note that the switches operate at the same switching frequency, the turn-on instant of the switches will be obliged to be synchronous.

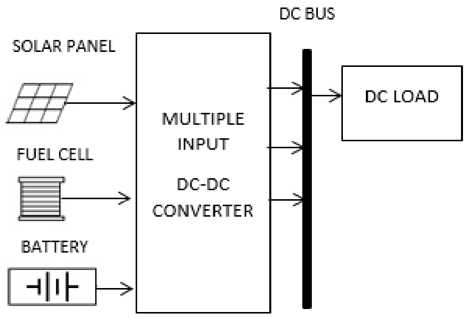

Fig. 1: Renewable power system with multiple input single output DC-DC converter.

The boost cell consists of the boost converter. The hybrid cell consists of buck-boost cell built in a buck cell. The DC voltage bus on the load side is maintained constant, whereas is varied according to which the supply sources satisfy the demand.

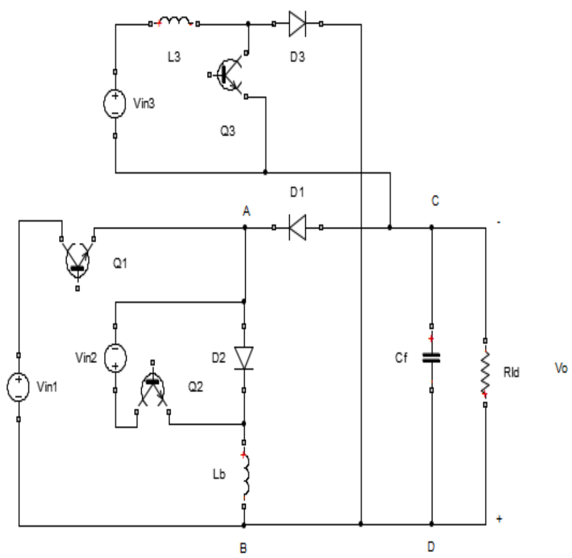

Fig. 2: Circuit Diagram for Multiple Input Single OutputDC-DC Converter.

B. Working of MISO Converter

There are different operating stages based on the states of three switches during one switching period.[13] Let us consider,

CASE I: When all the three sources are turned ON (V_{in1}, V_{in2}, V_{in3} is ON), the voltage between the point A and B is,

$V_{ab} = V_{in1} + V_{in2}$. L_b and L_3 are charged.

$i_{Lb} = \frac{V_{in1}+V_{in2}}{L_b}$,$i_{L3} = \frac{V_{in3}}{L_3}$

Inductor currents increase linearly.

Turning ON of all three devices, activates both the hybrid and the boost cell. The output is matched as per the demand needed.

CASE II: When Vin1 turns OFF, Vin2 and Vin3 are still ON. The inductor currents are,

$i_{Lb} = \frac{V_{in2}-V_0}{L_b}$, $i_{L3} = \frac{V_{in3}}{L_3}$

When $V_0<V_{in2}$, i_{Lb} increases linearly;

When $V_0>V_{in2}$, i_{Lb} decreases linearly.

During CASE II, the load may require a lesser demand which facilitates the turning ON of only two devices and turning OFF V_{in1}.

CASE III: Both V_{in1} and V_{in2} are OFF, V_{in3} is ON. L_b keeps its current steady through diodes D1 and D2,

$V_{ab} = 0$.

$i_{Lb} = -\frac{V_0}{L_b}$, i_{Lb} decreases linearly.

$i_{L3} = \frac{V_{in3}}{L_3}$, i_{L3} increases linearly.

A much lesser load turns ON only the third source leaving other two in OFF state.

CASE IV: When V_{in1}, V_{in2} and V_{in3} are OFF. L_b keeps its current steady by diodes D1 and D2.

$i_{Lb} = -\frac{V_0}{L_b}$, i_{Lb} decreases linearly.

$i_{L3} = \frac{V_0-V_{in3}}{L_3}$, i_{L3} increases linearly.

$$V_0 = V_{in1}.\frac{D_{y1}}{1-D_{y1}} + V_{in2}.\frac{D_{y2}}{1-D_{y1}} \quad (1)$$

$$V_0 = \frac{V_s}{1-D_{y3}}$$

The output current is given by,

$$I_0 = I_{03} + I_{012} \quad (2)$$

Where I_0 is the output current, I_{03} is the output current of source 3, I_{012} is the output current of hybrid cell of source1&2.

Output Power is expressed by,

$$P_0 = P_{12} + P_3 \quad (3)$$

$$P_{12} = V_0 . V_{012} \quad (4)$$

$$P_{12} = \left(V_{in1} . \frac{D_{y1}}{1-D_{y1}} + V_{in2} . \frac{D_{y2}}{1-D_{y1}}\right) . I_{012} \quad (5)$$

$$P_{12} = V_{in1} . I_{in1} + V_{in2} . I_{12}$$

Where Po is the output power, P_3 is the input power of source 3, and P_{12} is the input power sum of the source1 and 2.According to Eqns. (4) and (5), input currents of thethree sources are given as following,

$$I_{in1} = \frac{D_{y1}}{1 - D_{y1}} . I_{012}$$

$$I_{in2} = \frac{D_{y2}}{1-D_{y1}} . I_{012} \quad (6)$$

$$I_{in3} = \frac{1}{D_{y3}} . I_{03}$$

WhereI_{in1}, I_{in2}, and I_{in3} are input currents of sources 1, 2 and3.

III. Control Strategy for the Proposed Converter

As mentioned in introduction section, the basic motivation to develop multiple-input converters is their ability to supply power to the load from multiple sources. A multiple - input converter should be able to change the amount of power drawn from each source, without changing the total power delivered to the load and while keeping the output voltage constant.

For the three-input dc/dc converter, we can control the input power by managing their input currents of sources. In a solar-wind complementary power system, the energy of solar battery should have the priority in use. Consequently, the solar array is the major power source (source 1), with the fuel cell being back-up source (source 2) and the battery being another back-up source (source 3). When the load power is more than summation power of source 1 and 2, and the remnant power will be poured by source 3. When the load power is more than power of source 1, the remnant power will be poured by source 2 and source 3 is out of work. Fig.4 shows block diagram of control system of this three-input buck/boost/buck-boost dc/dc converter.

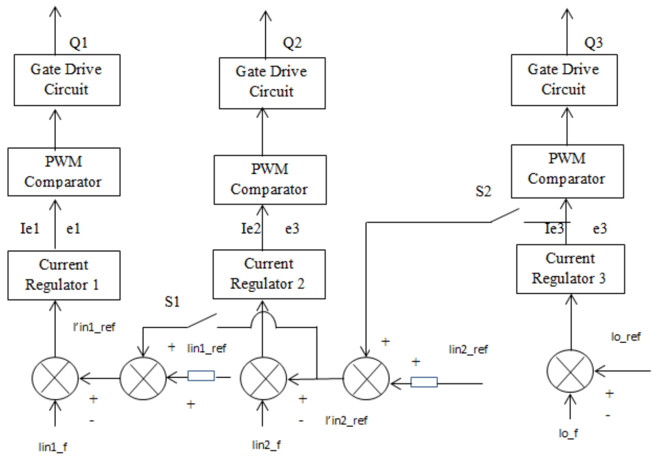

Fig. 4 Block diagram of control system.

When the input voltage of one source is provided, the control of the input power of the power source can be achieved by controlling its input current. So the control system is composed of source 1 input current loop and output voltage loop.

Mode I

When $P_{in1\_max} + P_{in2\_max} < P_o < P_{in1\_max} + P_{in2\_max} + P_{in3\_max}$ (where P_o is the output power, P_{in1_max} is the maximal power of source 1, P_{in2_max} is the maximal power of source 2, P_{in3_max} is the maximal power of source, the same below), these three sources provide energy to the load. In this case, output of voltage regulator I_e is positive, with switch S_1 and S_2 off. Then the voltage regulator and the two current regulators work independently. And I_{in1_ref} is the input current reference value depending on the max power of source 1, which makes it provide the max power; I_{in2_ref} is the input current reference value depending on the max power of source 2, which makes it provide its max; voltage regulator keeps output voltage steady when source 3 covers the rest power that the load need.

Mode II

The power of load decrease, which is $P_{in1\_max} < P_o < P_{in1\_max} + P_{in2\_max}$. Source 1 provides the max power, where the rest is provided by source 2. In this case, I_e is negative, which turns Q_3 off and enables S_2 on. Then, the sum of output of I_e and I_{in2_ref}, allow input current of source 2 decrease. S_1 is still off.

At this time, voltage regulator and current regulator 2 constitute a double closed loop, where current loop is inner loop and voltage loop is the outer one. Voltage loop could accommodate duty-cycle of Q_2 to get source 2 to cover the rest power that the load need, keeping stabilization of output voltage.

Mode III

The power of load decrease further, which is $P_o<P_{in1\_max}$. In this circumstance, Ie is negative, which enables Q_3 off and enables S_2 on. The sum of Ie and I_{in2_ref}, is negative, turns off Q_2, namely shutting down source 2. S_1 is on, diminishing I_{in1_ref}, which diminish input current. At this time, voltage regulator and current regulator 1 constitute a double closed loop, where current loop is inner loop and voltage loop is the outer one. Voltage loop could accommodate duty-cycle of Q_1 to alter output power according to the load, keeping stabilization of output voltage.

Mode IV

When source 1could not pour out power, such as breaking down, switch Q_1 should be taken off at once and source 2 and 3 support the load. At this time, current regulator 2 accommodates duty-cycle of Q_2, and voltage regulator accommodates duty-cycle of Q_3, keeping stabilization of output voltage.

Mode V

When source 2 could not pour out power, such as breaking down,switch Q_2 should be taken off directly and source 1 and 3support energy to the load. Current regulator 1 accommodates duty-cycle of Q_1, managing output power of source 1. Voltage regulator accommodates duty-cycle of Q_3, keeping stabilization of output voltage.

Mode VI

When both source 1 and 2 could not pour out power, such as breaking down, switch Q_1 and Q_2 should be turned off directly and source 3 supports the load along. At this time, voltage regulator accommodates duty-cycle of Q_3, keeping stabilization of output voltage.

IV. SIMULATION RESULTS

Taking this buck/boost/buck-boost three-input DC-DC converter as an illustration, here is the experimental result of a prototype.

- Input voltage of source 1: V_{in1} = 12 V;
- Input voltage of source 2: V_{in2}= 12 V;
- Input voltage of source 3: V_{in3} = 12 V;

- Input current reference of source1; I_{in1_ref}= 1A;
  P_{in1_ref} = 12W.
- Input current reference of source2; I_{in2_ref}= 1A;
- P_{in2_ref} = 12W.
- Output voltage: Vo = 23.2 V;
- Switching frequency: f_s = 10 kHz.

Fig. 5: Shows the output waveform obtained when all the sources are turned ON (i.e) CASE I under section II. B to supply a load of 23.2V.

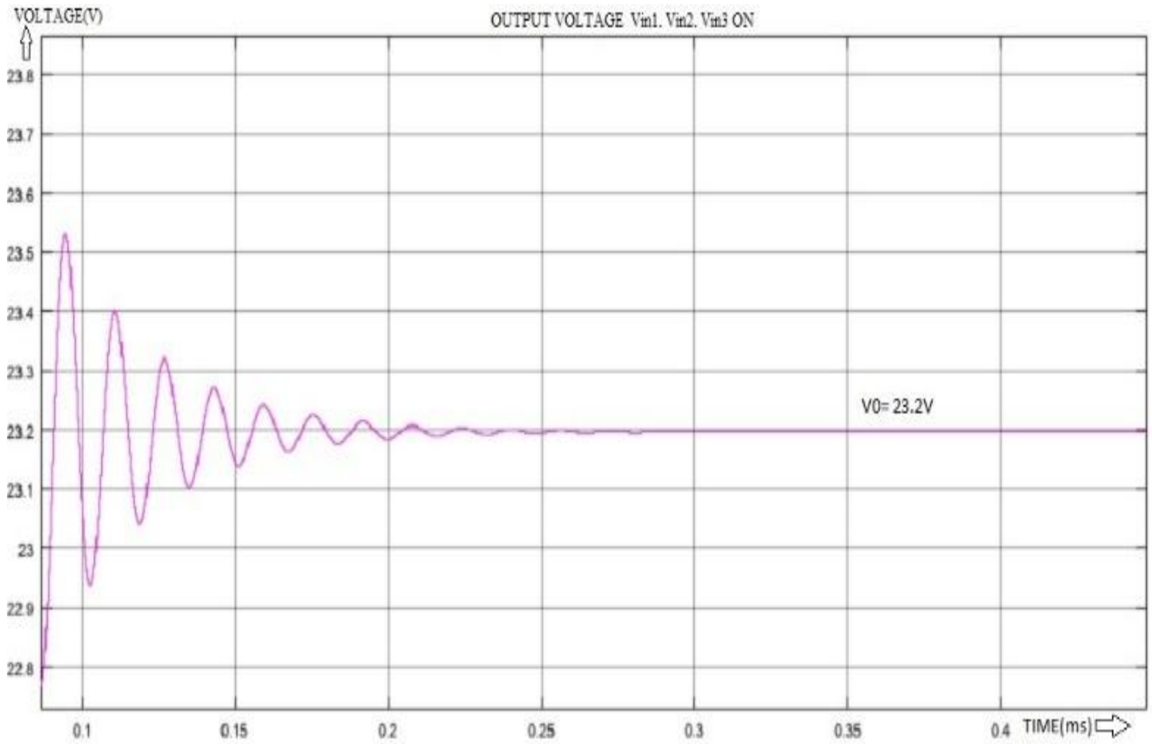

Fig. 5: Output Voltage waveform when V_{in1}, V_{in2}, V_{in3} is ON.

Similarly, the output voltage waveform when one of the sources is removed is considered (i.e) when Vin2 is given in Fig. 6. It can be observed that even without ONE source turned ON, the system was able to satisfy the demand of the load of 23.2V.

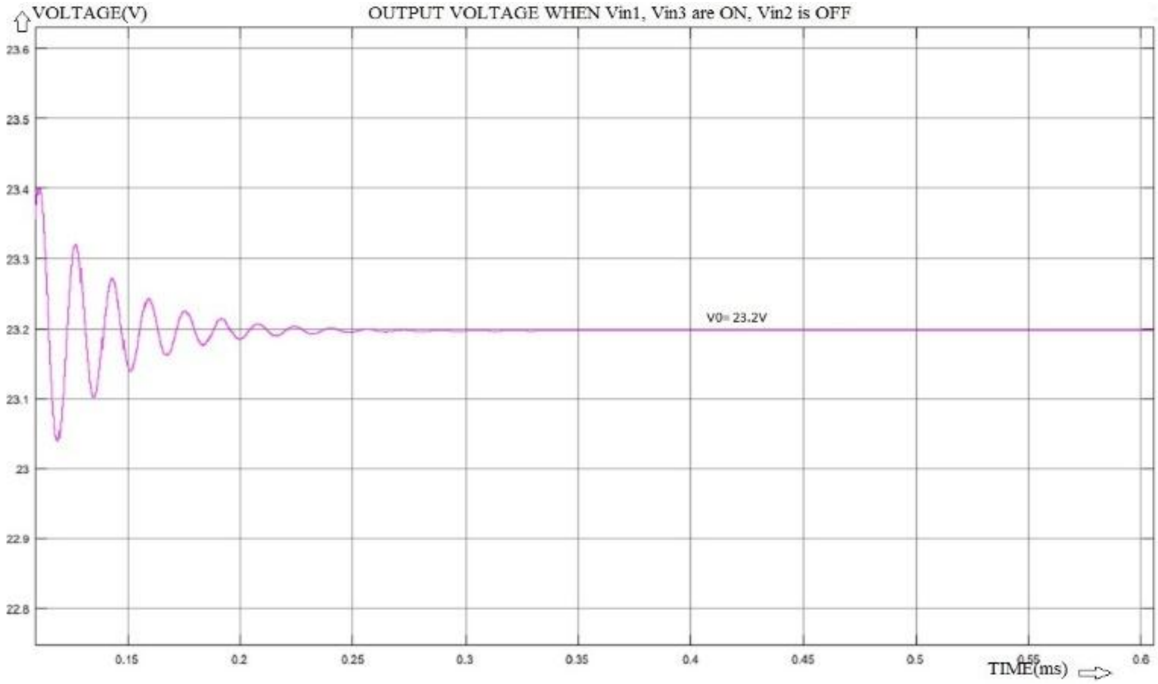

Fig. 6: Output Voltage waveform when V_{in1}, Vi_{n3}- ON V_{in2}- OFF.

Now another case to be considered is when the third source is removed. The output voltage obtained under such case is given the Fig. 7. It can be observed that the without the third source being ON, the system is not able to satisfy the load conditions, and generates a minimum voltage of 2.71V.

In order to improvise the output voltage, a corrected voltage of 10V is applied to the source 3 of the system and the output waveform is obtained. In this case, we are able to supply a voltage of 9.2V. The graphical representation of this is shown in the Fig. 8.

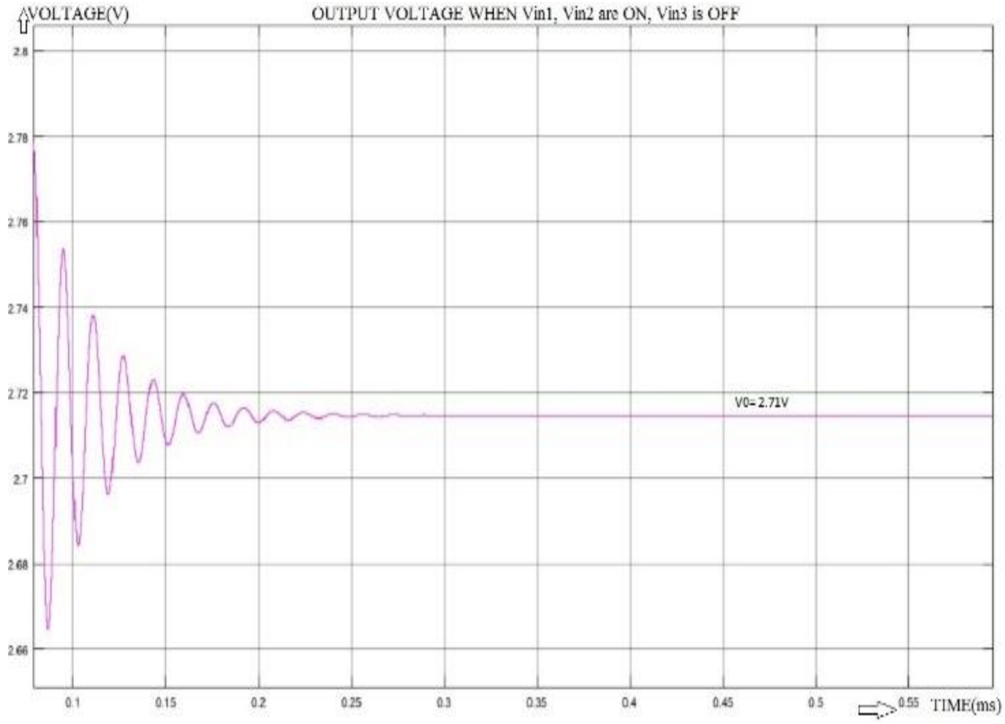

Fig. 7: Output Voltage waveform when V_{in1}, Vi_{n2}- ON V_{in3}- OFF.

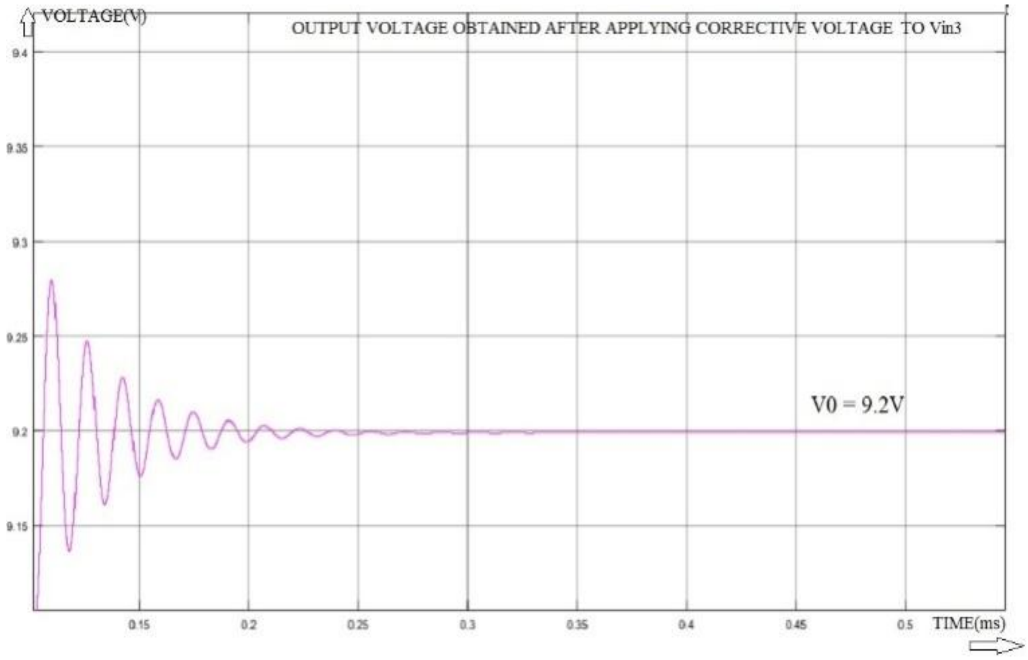

Fig. 8: Output Voltage waveform when V_{in1}, Vi_{n2}- ON V_{in3}- Min. Voltage applied

V. Analysis of the output voltage under different load conditions

The above proposed converter is furthermore analyzed of the output voltage obtained under different load conditions. Initially a constant voltage of 23.2V is maintained on the load side and the power is 26.9W. Now the power is reduced for two readings below and above, the output voltage is checked. Fig.9 show the final analysis obtained after this experiment.

Table 1: Tabulation for the results obtained after the analysis.

Load	Power	Voltage
1	17.94W	23.2V
2	21.52W	23.2V
3	26.9W	23.2V
4	35.86W	23.2V
5	53.78W	23.2V

The waveforms explaining the above tabulation are given below,

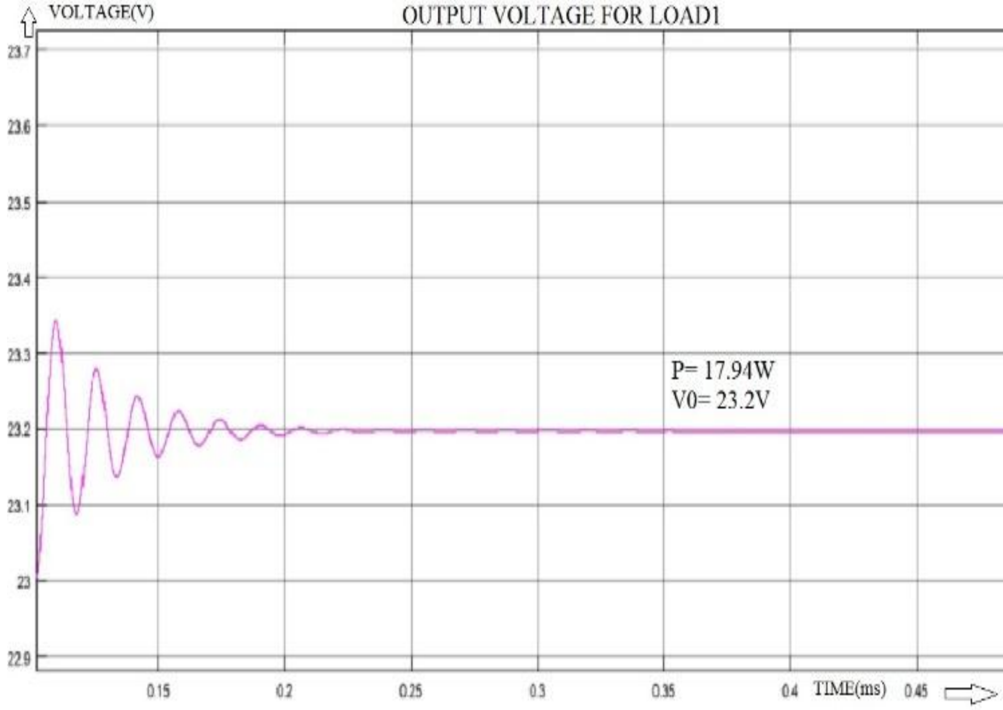

Fig. 10: Output voltage for LOAD1.

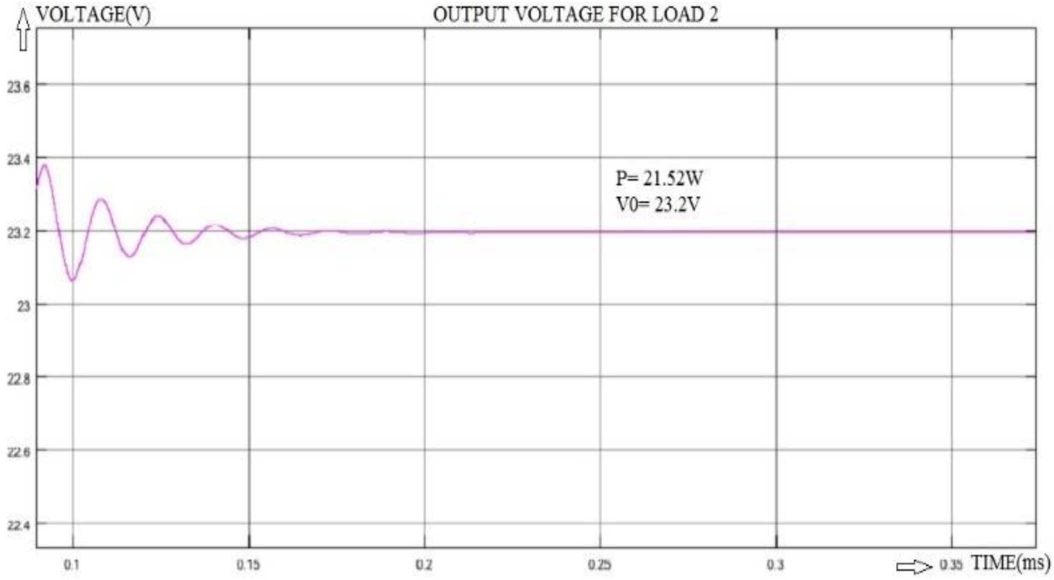

Fig. 11: Output voltage for LOAD2.

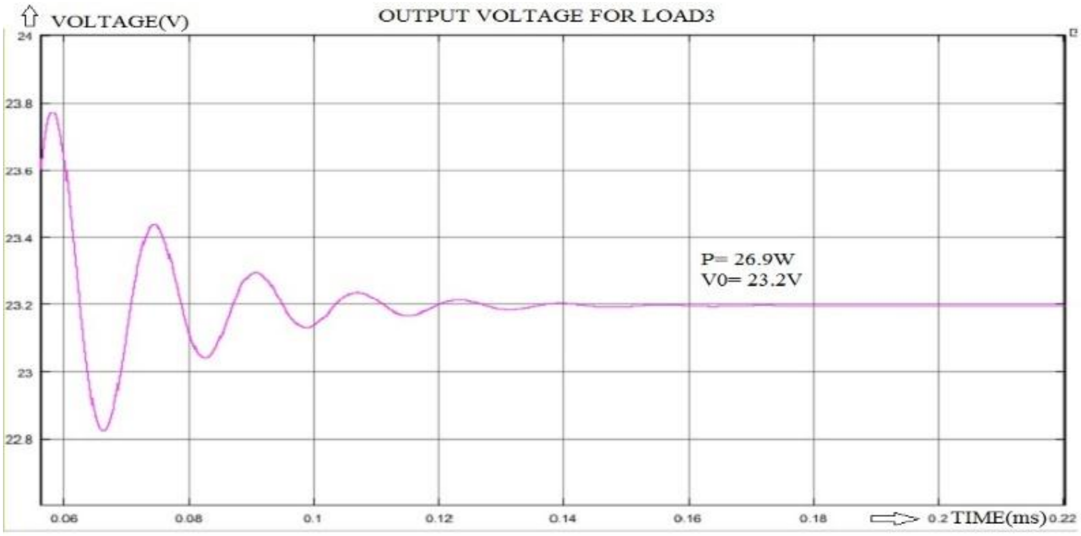

Fig. 12: Output voltage for LOAD3.

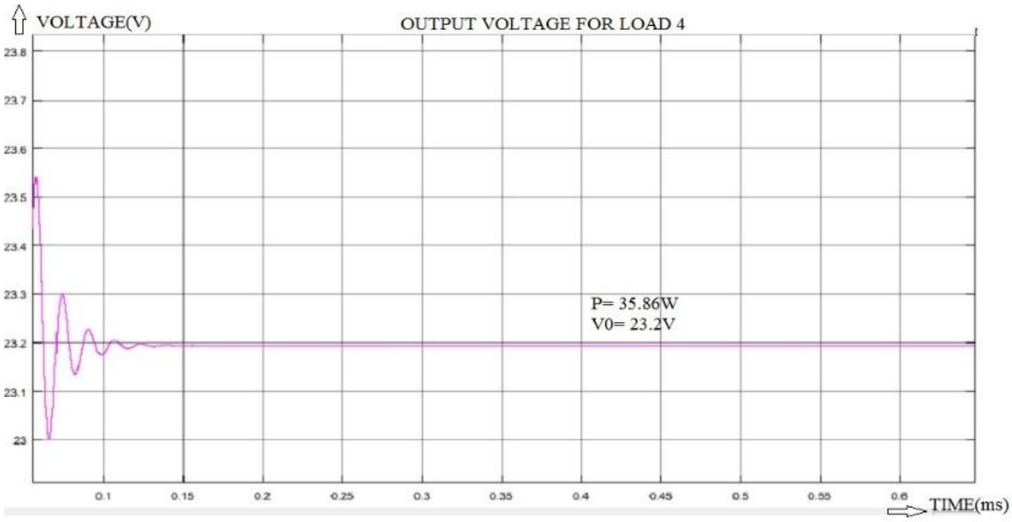

Fig. 13: Output voltage for LOAD4.

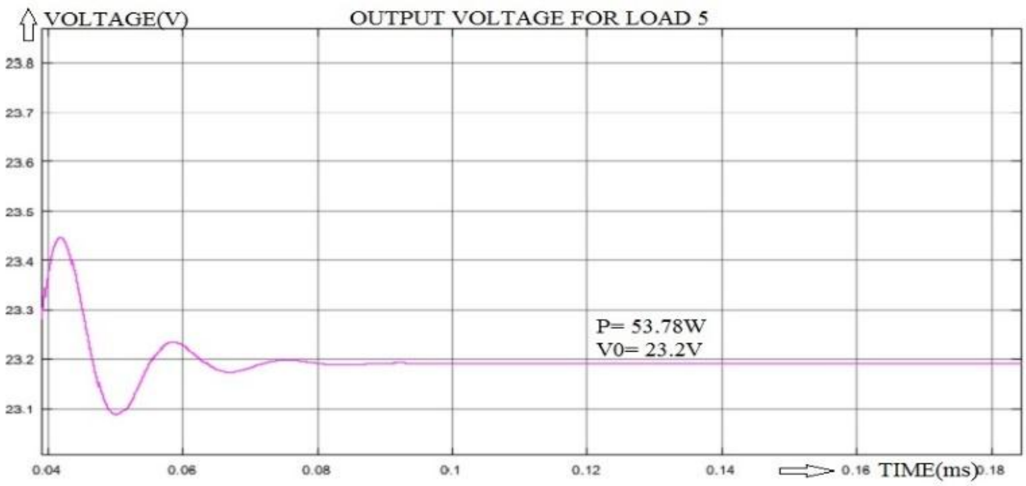

Fig. 14: Output voltage for LOAD5.

VI. CONCLUSION

A Multiple Input Single Output DC-DC Converter is proposed in this paper, can be applied to all kinds of DC input voltage applications. All the power sources in this converter can deliver power to the load either simultaneously or individually in one switching period. The detailed power control strategy and the analysis of MISO converter have been shown in this paper. The experimental results show that the system can operate stable at various modes and can transit smoothly among the multiple operation modes.

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