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Self Powered AC-DC Step-up Converter for Low Voltage Energy Harvesting

Saranya Anand[1], Bindhu Aleyas[2], Jisha Kuruvilla[3]

M.Tech Student, M. A.College of Engineering, Kothamangalam, Kerala, India[1]

Associate Professor, M. A.College of Engineering, Kothamangalam, Kerala, India[2,3]

ABSTRACT: An efficient AC to DC power converter that avoids the bridge rectification and directly converts low AC input voltage to high DC output voltage is presented. In this converter AC is converted to DC directly i.e. from low AC voltage to high DC voltage in single stage conversion. With electronic circuits now capable of operating at microwatt levels, it is possible for them to be powered using non- traditional sources. This has led to energy harvesting, eliminating batteries in systems where battery use is inconvenient, impractical, expensive or dangerous. It can also be used for data transmission and energy harvesting can power smart wireless sensor nodes, to monitor and optimize complex industrial processes, remote field installations. Key to energy harvesting is a power converter that can operate using ultra-low-voltage inputs. The converter topology used here is the Buck-Boost Converter. The buck boost converter is used rather than boost converter alone is because of its negative gain which conditions the negative half cycle of the supply. The simulation is done in MATLAB/SIMULINK 2009b.

KEYWORDS: Buck-Boost converter, power conversion, energy harvesting, microgenerators, discontinuous conduction mode.

I. INTRODUCTION

Power requirement for electronic devices has reduced because of semiconductor devices which lead to the development of devices like wireless, sensors, medical implants etc. In this era of environmental problems like global warming, self powered devices play an important role. Usually self powered devices harvest the ambient energy using microgenerators and having without any continuous power supply. Conventional AC-DC converters for energy harvesting consist of a full bridge diode rectifier stage and a DC-DC converter[1]. However the diode-bridge would cause considerable voltage drop, making the low-voltage rectification impossible. Much primitive structures have transformers in the booster stage to eliminate diode voltage drops but that also creates noises. Modern topologies uses bidirectional switches and split capacitors, but due to operating frequency in low range the value of the capacitors have to be large enough to suppress the voltage ripple below the desired level. Conduction losses and parasitic capacitances losses contribute 31%- 37% of total losses. Many types of microgenerators used for harvesting different forms of ambient energies [2]. The types of generators are electromagnetic, electrostatic and piezoelectric. Compared with all types of microgenerators electromagnetic microgenerators have the highest energy density. The power level of conventional microgenerators is very low (few micro watts to tens of milliwatts). Practically, an electromagnetic micro generator is a spring-mass-damper based resonance system shown in figure 1. In this, the small amplitude mechanical vibrations are amplified into larger amplitude translation movements. The function of the power converter is important than the maximum energy conversion. The output voltage of electromagnetic microgenerator is AC but electronic loads require DC voltage for further operation [4]. Due to the practical size limitations the output of electromagnetic micro generator is very low (few 100mV), where the electronic loads require higher DC voltage (3.3V).

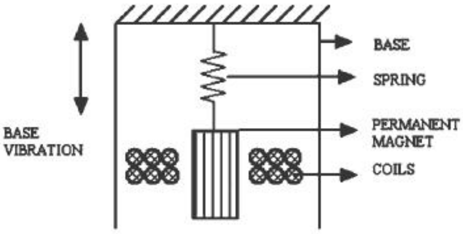


Figure 1: Spring-mass-damper based resonance system

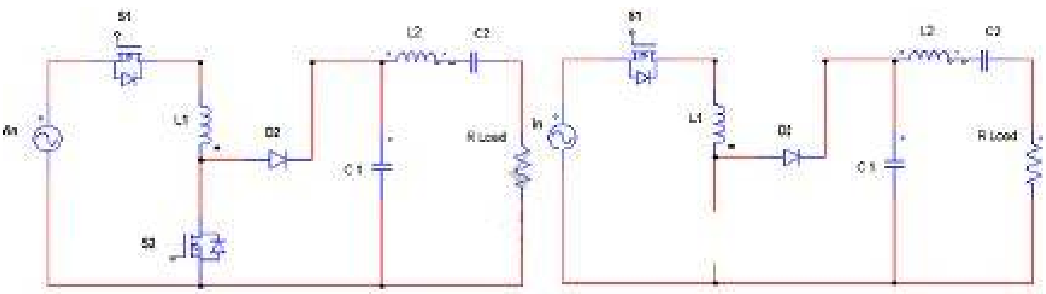
Why we go for Buck-Boost topology rather than Boost topology alone is because this converter has the ability to set-up the input voltage with a reverse polarity, so it is an appropriate candidate to condition the negative voltage cycle [2]. Buck and Boost also shares the general capacitor and inductor hence reduction in no. of components could be achieved. Buck- Boost structures with linear regulators are in use but these were changed when switching converters came in to take part in. Switching converters are particularly useful in sub milliwatt applications because the generated energy will be in the milliwatt operating range. Also linear voltage regulators can't synthesize optimum load impedances.

II. NOVEL STEP UP CONVERTER

In this converter model, bridge rectification is avoided and the microgenerator power is processed by single stage boost type power converter. In latest topologies bidirectional switches and split capacitors are used. In this converter the output DC is split into two series connected capacitors and each capacitor charged for only one half cycle the microgenerator output voltage. The time phase of the resonance-based microgenerators output voltages are normally milliseconds, huge voltage drops will occur in the capacitors during the half cycles when the capacitors are not charged by the converter. In practical, large capacitors will required to achieve the permissible voltage ripple at DC bus output. This is not applicable for microgenerators because of practical size limitations.

There are six modes of operation for the converter and the operating modes are as follows.

Mode I: This mode starts when S_2 is turned ON at t_0 , the inductor current is zero. The turn on of S_2 is achieved through zero current switching (ZCS) to reduce switching loss. Inductor L is charged by the input voltage as both S_1 and S_2 are conducting. Both diodes are reverse biased. The load is charged by the energy stored in the output filter capacitor C.



(a) (b)

Figure 2: (a) Mode I, (b) Mode II

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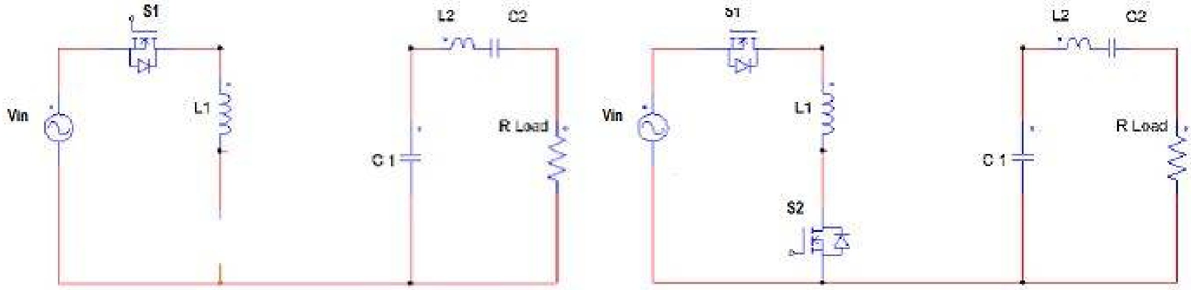
Mode II: S_2 is switched OFF at t_1 where $t_1 - t_0 = d_1T_S$, d_1 is the duty cycle of the boost operation, and T_S is the switching period. The energy accumulated in the inductor during Mode I is transferred to the load. The inductor current reduces linearly. During this mode, switching loss take place during the turn on of diode D_2.

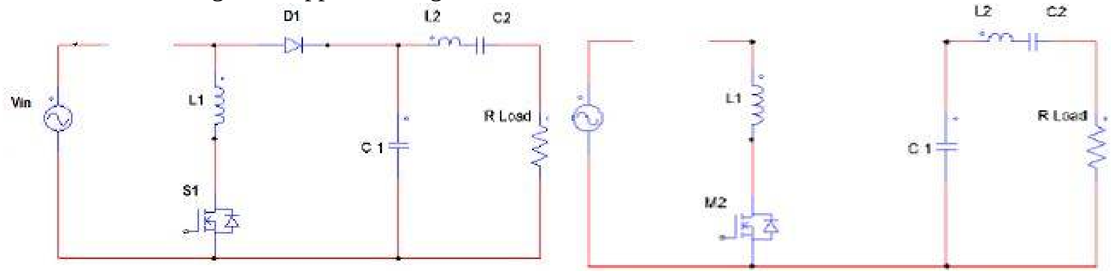
Mode III: D_2 is automatically turned OFF when the inductor current becomes zero at t_2 ($t_2 - t_1 = d_2T_S$). This prevents the reverse recovery loss of diode. The load is again powered by the accumulated energy in the capacitor. The converter would go back to Mode I as soon as S_2 is switched ON, if the input voltage is still in positive cycle.



(a) (b) Figure 3: (a) Mode III, (b) Mode IV

Mode IV: In the negative input cycle, Mode IV starts as soon as S_1 is turned ON at t_0 ZCS condition can also be achieved by making sure the converter operation in DCM. The energy is transferred to the inductor L again, while the output filter capacitor C supplies the load.

Mode V: At t_1, S_1 is turned OFF, where $t_1 - t_0 = d_1T_S$, d_1 is the duty cycle of the buck-boost operation. The energy accumulated in the inductor during Mode IV is transferred to the load. The inductor current decline linearly. During this mode, switching loss happens during the turn on of the diode D_1.



(a) (b) Figure 4: (a) Mode V, (b) Mode VI

Mode VI: When the inductor current diminish to zero at t_2 ($t_2 - t_1 = d_2T_S$), D_1 is turned OFF at zero current. The load is constantly powered by the charge accumulated in the output capacitor. The converter would return to Mode IV as soon as S_1 is switched ON, if the input voltage is still negative.

The system model was designed using the simple equations of buck-boost converter. To ensure better performance both converters are operated in DCM. We know that throughout the boost converter operation, the input current i and the boost inductor current i_{L1} are equal, but during the buck–boost converter operation, the input current i and the current in buck–boost inductor i_{L2} are not equal. This is due to; in the buck–boost converter the input current turns into zero at thepoint of switch turn OFF period (T_{OFF}). Hence, in a switching cycle, the energy moved to the output by a buck–boost converter is similar to the energy stored in the inductor, where, in the boost converter, the energy moved to the output is more than the energy stored in the inductor. Hence, for the identical duty cycles, input voltages and inductor values, the whole powers delivered by the two converters in excess of an input voltage cycle are not equal. Hence we use a common inductor L. Usually the output of microgenerator will be few mVs.

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Lets design the system with an AC input of 400 mV,100 Hz to supply an electronic load of 4V. For a buck boost converter,

$$\frac{V_O}{V_g} = \frac{D}{1-D} \quad \text{...} \quad (1)$$

Therefore, duty ratio D=0.909

Output current, $I_0 = \frac{V_0}{R}$ = 20 m A .... (2)

Assuming lossless system, $V_0 I_0 = V_g I_g$, source current I_g =0.2 A

On the boundary the CCM-DCM conduction, the minimum parameter values are

$$I_{0min} = \frac{V_0 (1-D)^2 T_S}{2L} \quad \text{...} \quad (3)$$

And Inductor L= 16.56 µH

Let the voltage ripple be 5%, $\frac{DT_S}{RC} = \frac{\Delta V_0}{V_0}$ .... (4)

And Capacitor C= 18µF

Table 1: Simulation Parameters

INPUT VOLTAGE	400 mV,100 Hz
INPUT CURRENT	0.18 mA
SWITCHING FREQUENCY	50 kHz
OUTPUT VOLTAGE	3.3 V
OUTPUT CURRENT	16.5 mA
LOAD RESISTANCE	200 Ω
INDUCTANCE	24 µH
CAPACITOR	44.5 µF

III. SIMULATION AND RESULTS

The simulation was carried out in MATLAB/SIMULINK 2009b.The simulink diagram is shown in figure 5.

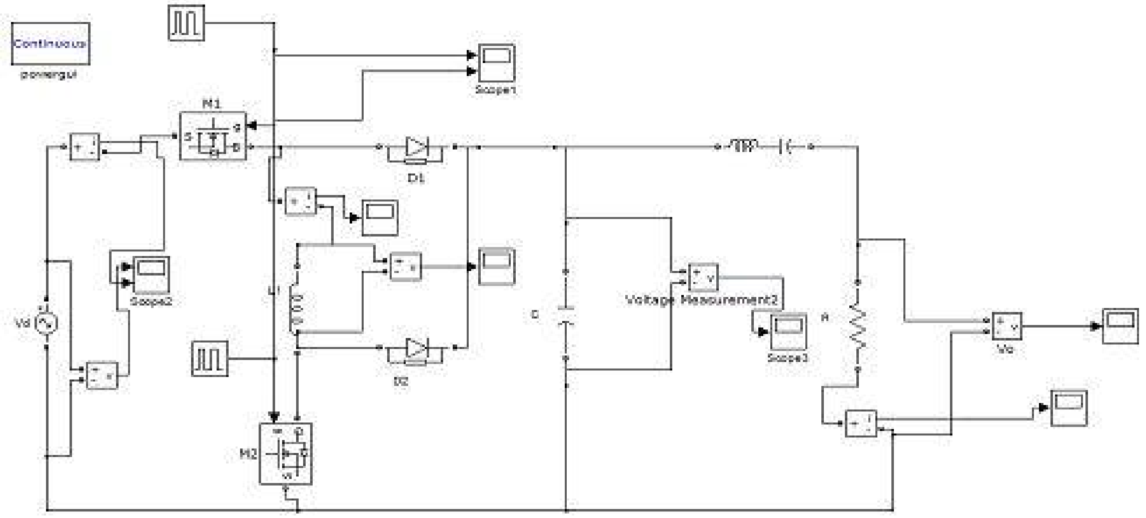

Figure 5: Simulink model of the novel step up converter

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The minimum values obtained from design of the system are not used for simulation, instead values are found on trial and error method. The parameters used for simulation are shown in table 1.

For an input supply of 400 mV AC we obtained an output of 3.9 V DC, which is needed for an electronic load. The various waveforms obtained from the simulation model are shown in figures below. The switching frequency was selected to be 50 kHz. The gate pulses and voltage across switches S_1 and S_2 are shown in figure 6 & figure 7 respectively.

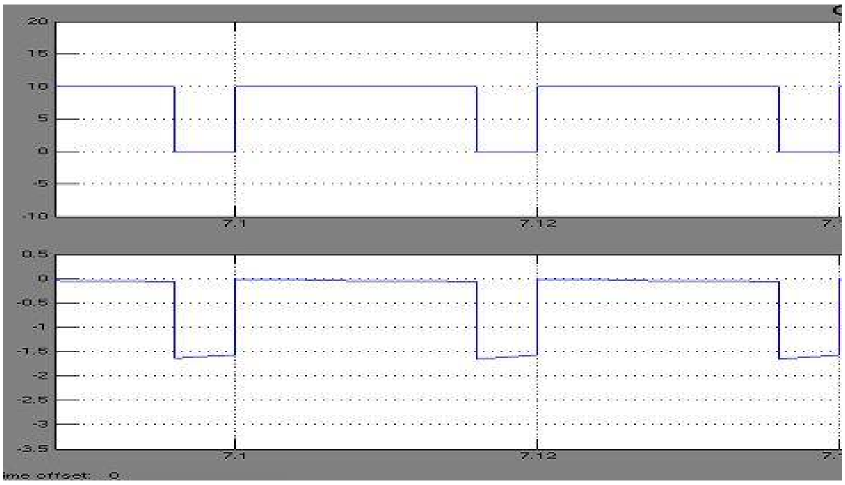

Figure 6: Gate pulse and voltage across switch S_1

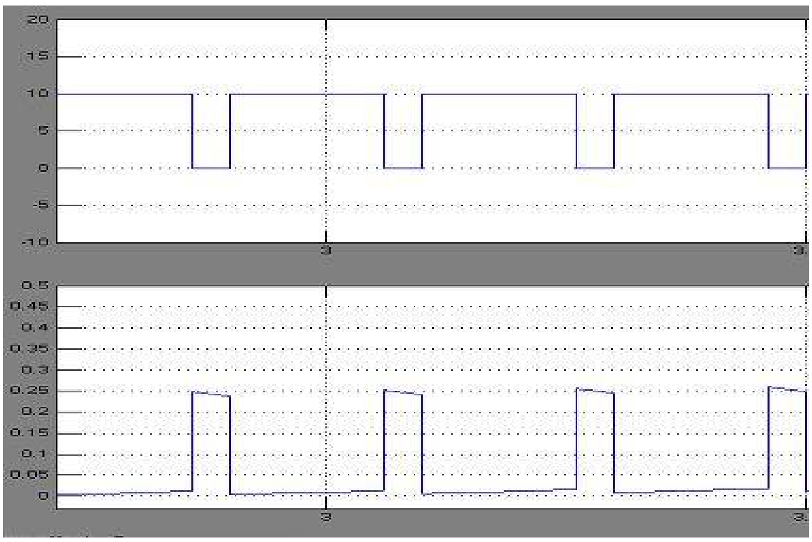

Figure 7: Gate pulse and voltage across switch S_2

A lower AC voltage say 400 mV is given as input supply. The output obtained for a resistive load of 200Ω is shown in figure 8, 4V is obtained as output. An output current of 20 mA was designed but on simulation it was obtained to be 16.5mA is shown in figure 9.

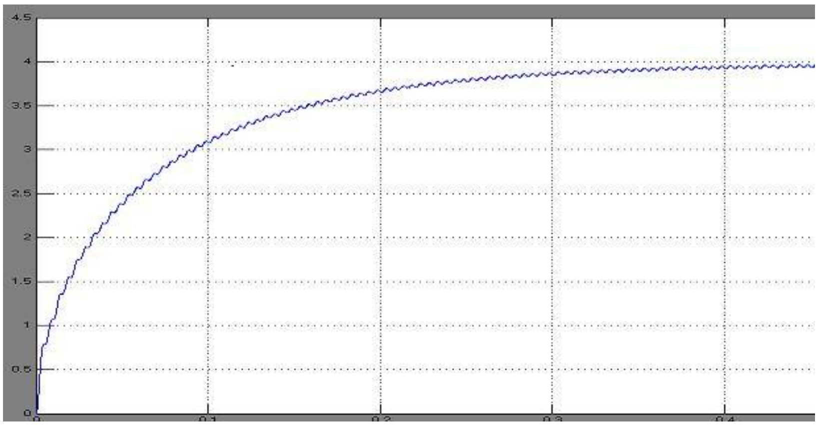

Figure 8: Output voltage across the load

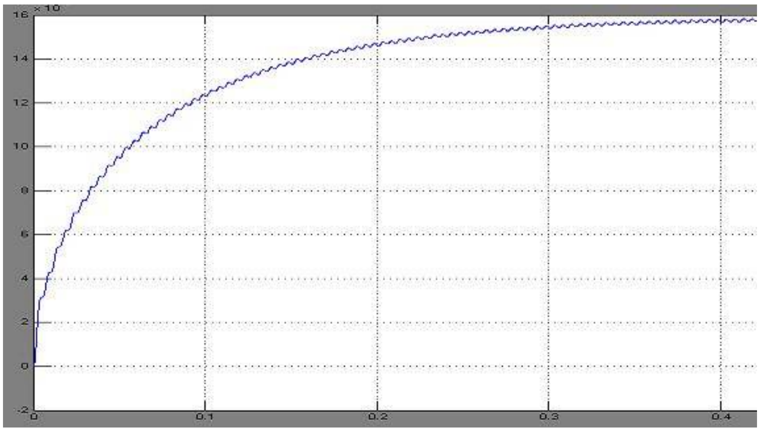

Figure 9: Output current across the load

The source current is obtained to be 0.18 mA instead of 0.2 mA as designed as shown in figure 10.

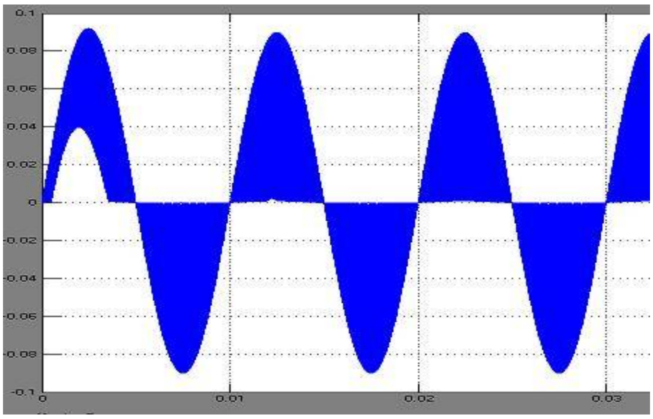

Figure 10: Source current

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The current across diode and inductor is also taken and is shown in figure 11 & figure 12 respectively.

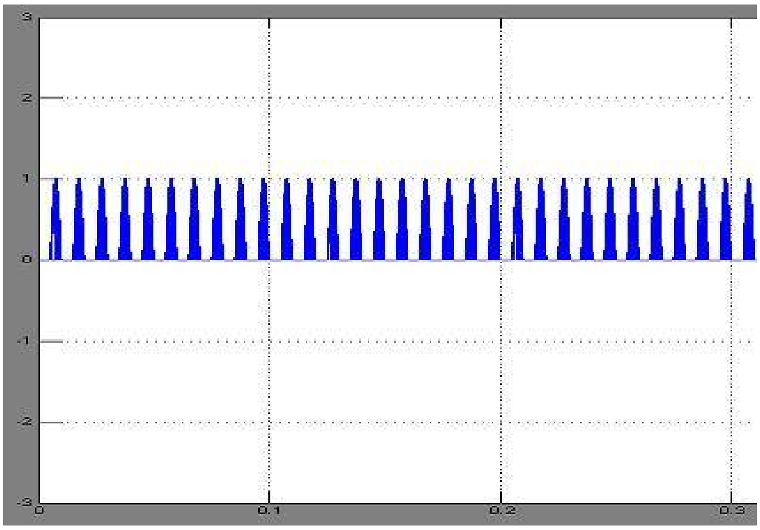

Figure 11: Diode current

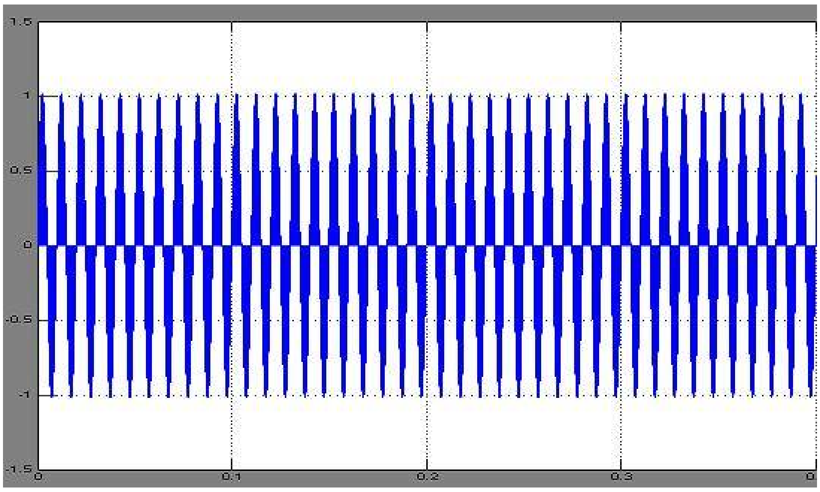

Figure 12: Inductor current

IV.CONCLUSION

The topology is a combination of a boost converter and a buck-boost converter to condition the positive input cycles, respectively. Not more than one inductor and one filter capacitor are required in this topology. In comparison to state-of-art bridge free rectifiers, this study employs the lowest amount of passive energy storage components, and achieves the maximum conversion efficiency. The topology successfully boosts the 400 mV, 100Hz AC to 4V DC, this potential can drive an LED or the same can be used for battery charging, provided current gain is optimum. Further expansion can be brought about by installing an active feedback circuit and using instrumentation amplifier at the booster stage. The instrumentation amplifier has to be provided with an input supply as V_{CC} for driving it this will incur the use of a backup. But providing an active feedback circuitry with minimal losses makes the circuit completely self reliable and we can operate the given circuit with no

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backup supply that is why the paper is titled as Self Powered Buck-Boost Converter. Since Infrared Data Transmission also uses the same converters at the receiver stage by widening the output range, the industrial application of this converter can also be widened.

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