Design of Single Input Dual Output Converter for Battery Charging Applications of EV

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***Abstract*—This study presents the integration of a buck converter (SLBC) and a super-lift to create a DC-DC multi-port converter. The proposed single-input dual-output (SIDO) converter generates a step-down voltage by the buck converter and a step-up voltage by the Luoconverter, both at the same time, with the advantages of conventional positive output voltage super-lift. This construction maintains a minimal output voltage ripple by not using electromagnetic components to provide a dual output. On the other hand, the recently launched SLBC offers a broad variety of output voltages with a straightforward construction and suitable control mechanism. Furthermore, a comparative analysis with other comparable setups is conducted in order to highlight the benefits of the suggested SIDO converter. Additionally, the findings of simulations and experiments show a significant decrease in conduction losses in comparison to previous SIDO converters in the identical circumstances. A 150W prototype is tested in the lab and many simulations using MATLAB software are used to verify the functioning correctness of the proposed Converter.**

***Index Terms*—DC-DC Converter,Single-Input Dual-Output Converter(SIDO),High Voltage gain.**

I. Introduction

DC-DC converters play a pivotal role in modern electronics by efficiently converting one voltage level to another, enabling the operation of a vast array of electronic devices.These converters are essential components in various applications, including portable electronics, renewable energy systems, electric vehicles, telecommunications, and industrial automation.

DC-DC converters are electronic circuits or devices that convert a direct current (DC) input voltage to a different DC output voltage level. They are indispensable in situations where the desired output voltage differs from the available input voltage, facilitating power conversion with minimal loss and maximum efficiency. By altering voltage levels, DC-DC converters enable the efficient transfer of power between different components of electronic systems, ensuring optimal performance and functionality.

In 1920s, the DC to DC conversion technique was established at first. A simple voltage DC to DC conversion is a voltage divider (rheostat). However, this method only transfers the output voltage smaller than the input voltage with poor efficiency. In 1950s,the power semiconductor devices (SCR and transistor) have been introduced and it has marketed in 1957s (for commercial purpose). In 1960s, the DC choppers have designed with help of the power semiconductor devices like (transistor). The DC-DC converter or DC chopper which converts the fixed D.C voltage magnitude into variable D.C voltage magnitude. For high power application, the multi-quadrant chopper is developed. After 1960s, the DC-DC converter was developing rapidly for needing low voltage DC power source in telecommunication technology. DC-DC converters have evolved significantly over the years to meet the increasing demands of various applications, The various types of Dc-Dc converters are: Linear Regulators (1950s-1960s), Switched Mode Power Supplies (SMPS) (1970s), Isolated DC-DC Converters (1980s), Multi-Phase and Resonant Converters (1990s-2000s), Digital Control and Advanced Topologies (2010s-Present).

Buck Converter: The buck converter reduces the input voltage to a lower output voltage. It operates by intermittently switching a semiconductor switch (usually a MOSFET) to control the energy transfer from the input to the output. This converter may work in discontinuous mode if the frequency (f) is small, conduction duty (k) is small, inductance (L) is small, and load current is high.

Super-Lift Converter: Super lift converters represent an advanced class of DC-DC converters designed to achieve extremely high step-up voltage ratios efficiently. These con-

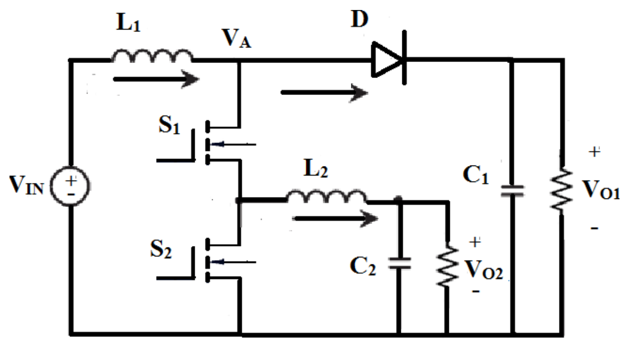

Fig. 1. Structure of SIDO Converter

verters are particularly useful in applications where the required output voltage is significantly higher than the input voltage, such as renewable energy systems, electric vehicles, and high-voltage power supplies.The distinguishing feature of super lift converters is their ability to achieve voltage boosting capabilities beyond what traditional converters can achieve. They achieve this through innovative topologies and control strategies that minimize power losses and maximize efficiency. One notable example of a super lift converter is the Super Lift Luo Converter. It combines the benefits of the Luo converter, known for its high step-up capabilities, with additional features to achieve even greater voltage lift. By integrating various control techniques and advanced components, super lift converters can efficiently convert input voltages to much higher output voltages, making them ideal for demanding applications.Voltage-lift (VL) technique has been successfully applied in DC/DC converter's design. However, the output voltage of all VL converters increases in arithmetic progression stage by stage. Super-lift (SL) technique is more powerful than VL technique. The output voltage of all SL converters increases in geometric progression stage-by-stage.All super-lift converters are outstanding contributions in DC/DC conversion technology,and invented by Professor Luo and Dr. Ye in 2000–2003.

By integrating buck converter functionality, the proposed converter aims to provide enhanced flexibility and performance in various applications, including renewable energy systems, electric vehicles, and power supplies. The design methodology, control strategy, and simulation results are presented to validate the effectiveness and feasibility of the proposed converter topology.The results show promising efficiency, voltage regulation, and transient response, indicating the potential of the proposed topology for future power electronics applications.

II. Designing of the Converter

Fig.1 Shows the structure of proposed Converter The proposed structure of SIDO Converter includes the components like Inductors,Capacitors,Switching transistors,Diode,Control Circuitry,Feedback components,Filtering components,Buck converter components,Luo Topology.

Inductors stores and release the energy for a smooth output voltages,Coupled inductors are a crucial component in the SLLC, as they facilitate the high voltage gain characteristic of the Luo converter, Capacitors are used to store and transfer energy in the SLLC, working in conjunction with the inductors to achieve voltage conversion,A switching transistor, such as a MOSFET, is employed to control the energy flow in the converter. It regulates the duty cycle to adjust the output voltage and ensure efficient operation, A diode is often included to provide a path for current flow in the circuit and to prevent reverse current when the transistor is off, Control circuitry, which may include a microcontroller or dedicated ICs, is utilized to regulate the operation of the con- verter, adjust the duty cycle,and ensure stable output voltage, Feedback Components, such as voltage sensors or feedback loops,monitor the output voltage and provide feedback to the control circuitry to maintain desired voltage levels, Filtering Components such as Inductors and capacitors may also be used for filtering purposes to reduce ripple in the output voltage and improve overall performance and Specific components related to the Buck converter integration, such as additional control circuitry or feedback mechanisms tailored to the Buck converter operation, are also included.

These components work together to achieve the desired voltage conversion and performance characteristics of the Super Lift Luo Converter with integration of the Buck converter structure.

III. WORKING OF SIDO

The Working of proposed Converter involves Four main different Modes of Operation such as:

In a single-input dual-output converter integrating these Buck and super lift Luo converters, the control circuitry ensures that both converters operate harmoniously to provide the desired output voltages. The buck converter regulates one output voltage, while the super lift Luo converter regulates the other. The control strategy may involve synchronizing the switching frequencies of both converters and implementing appropriate feedback loops to regulate the output voltages accurately.

Mode 1($0 \le t < t_1$)): S1 is on during this time. Reduced L1 current is used to supply step-down load RL2 and charge L2. The interval comes to an end at ((D1-D2)/2)Ts. Addi- tionally, the voltage of S1 reached zero during the preceding switching interval due to the resonance path connecting L1, L2, and Co2.

$$V_{o2} = V_{in} - V_{L1} - V_{L2} \quad (1)$$

$$i_{L1} = i_{in} - i_{D1} \quad (2)$$

$$i_{L2} = i_{L1} + i_{C1}3 \quad (3)$$

Mode 2 ($t_1 \le t < t_2$) is as follows: S2 is activated and D2 is inversely biased during this time. In this case, the power shift to RL2 causes a drop in L2's current. L1 is additionally charged via Vin. This operation mode has a time interval of D2 Ts.

$$V_{o2} = -V_{L2} \tag{4}$$

$$i_{L2} = i_{C_{o2}} + \frac{V_{o2}}{R_{L2}} \tag{5}$$

$$V_{C1} = V_{L1} = V_{in} \tag{6}$$

Mode 3($t_2 \leq t < t_3$) is as follows: This Mode and Mode 1 are comparable. S2 is on during this time. In order to deliver step-down load RL2 and charge L2, L1 current is reduced.The interval comes to an end at ((D1-D2)/2)Ts.

Mode 4 ($t_3 \leq t < T_s$)) is as follows: Both S1 and S2 are off during this time. To supply both RL1 and RL2, respectively, the current of L1 and L2 is reduced.

$$V_{o1} = V_{C1} + V_{in} - V_{L1} \tag{7}$$

$$V_{C1} = V_{in} \tag{8}$$

$$V_{o2} = -V_{L2} \tag{9}$$

$$i_{L1} = i_{C1} = i_{C_{o1}} + \frac{V_{o1}}{R_{L2}} \tag{10}$$

Each mode of operation may utilize different control strategies and operating conditions to ensure efficient and reliable performance of the single input dual output converter. Protection modes are necessary in a single input dual output converter that combines a buck converter and a super lift Luo converter in order to guarantee the system's stability and safety. Typical protective strategies include the following:

Overvoltage Protection (OVP): This mode protects the system from output voltages that are too high. In order to avoid damaging downstream components, it might be necessary to turn off the converters or activate voltage clamping mechanisms.

Undervoltage Protection (UVP): This feature keeps the output voltages from falling below a level that is safe for operation. It can control the converter's operation or initiate shutdown mechanisms to keep the output voltage within allowable bounds.

Overcurrent Protection (OCP): OCP stops too much current from passing through the output circuits and converters. Current sensing devices may be used to identify overcurrent situations and initiate safety precautions like lowering the duty cycle or turning the converters off.

Short-Circuit Protection: This mode guards against damage to converters and other components by identifying short circuits in the output circuits and initiating preventive procedures. To guard against high currents, it can entail rapidly turning off the converters or restricting output current.

Temperature Protection: In order to prevent overheating and component failure, temperature protection monitors the temperature of vital components, such as power

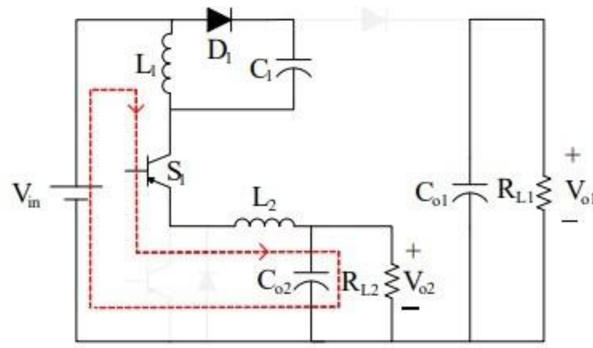

Fig. 2. Mode 1

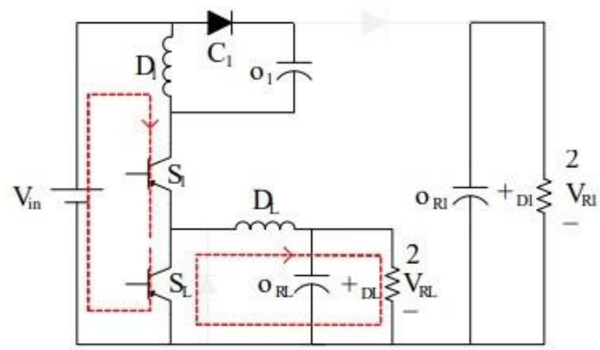

Fig. 3. Mode 2

semiconductors, and either activates cooling devices or lowers power output.By using these protective modes, the single input dual output converter may operate safely and dependably under a range of load situations and operating conditions.

It can control the converter's operation or initiate shutdown mechanisms to keep the output voltage within allowable bounds.

IV. CALCULATIONS

Voltage Gain Calculation: Voltage gains are computed under the assumptions of perfect components and minimal voltage ripples in the inductors. As a result, the voltage gain of the suggested SLBC is given in this part. It is based on the voltage-second balancing of the inducers and is calculated from the converter's operating modes in the preceding section. For the step-up output of the SLBC converter, the voltage gain can be computed as follows.

$$V_{in} \times (D_2 T_s) = (V_{o1} - 2V_{in}) \times (1 - D_2)\, T_s \tag{11}$$

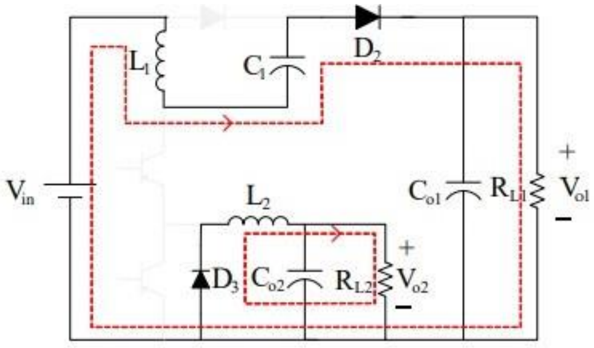

Fig. 4. Mode 4

$$\frac{V_{o1}}{V_{in}} = \frac{2 - D_2}{1 - D_2} \quad (12)$$

Furthermore, the voltage gain for step-down output is calculated as:

$$V_{o2} = (D_2 - D_1) + (D_1 - D_2)\frac{2 - D_2}{1 - D_2} \times V_{in} \quad (13)$$

$$\frac{V_{o2}}{V_{in}} = \frac{D_1 - D_2}{1 - D_2} \quad (14)$$

Efficiency Calculation: The proposed converter efficiency is calculated by

$$\eta = \frac{P_o}{P_{in}} = \frac{P_o}{P_o + P_{\text{loss}}} \quad (15)$$

V. SIMULATION

The following elements must be included in a simulation model of a super lift Luo converter integrated with a buck converter:

Switches: MOSFETs or IGBTs to control the switching operation of both converters.

Inductors: Inductors are essential components in both converters to store and transfer energy.

Capacitors: Capacitors for energy storage and filtering in both converters, smoothing out the output voltage.

Diodes: Freewheeling diodes to provide a path for inductor current during the off state of switches.

Control Circuitry: Implement control circuits for both converters, which may include PWM controllers, feedback loops, and control algorithms to regulate voltage and current.

Voltage and Current Sensors: Sensors to measure input and output voltages and currents for feedback control.

Load: A resistive or reactive load to represent the output of the converters and simulate different operating conditions.

Gate Drivers: Drivers to interface between the control circuitry and the switching devices, ensuring proper switching operation.

Voltage Sources: Provide DC input voltage sources to the converters to simulate input power.

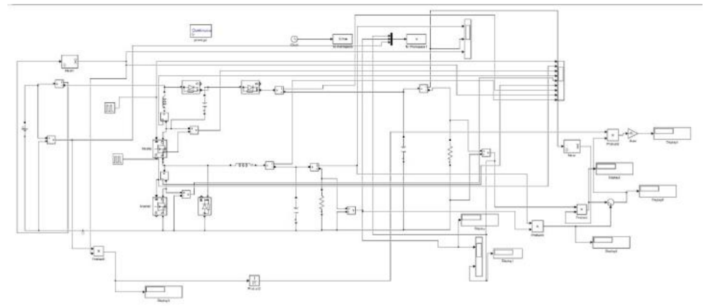

Fig. 5. Simulation Diagram

Simulation Software: Choose and set up the simulation software (e.g., MATLAB/Simulink, LTspice, PSpice) with appropriate models for the components and converters.

Parameter Values: Determine and assign appropriate parameter values for components such as inductance, capacitance, resistance, and switching frequencies based on the desired operating conditions and converter specifications.

Interconnection: Connect the components according to the circuit topology of the super lift Luo converter integrated with the buck converter, ensuring proper signal paths and feedback loops.

By assembling these components and configuring them within the simulation software, you can create a comprehensive simulation model to analyze the behavior and performance of the integrated converter system under various conditions. PSCAD/EMTDC/MATLAB software is used to simulate the proposed SIDO in order to verify the operation validation.

Key Waveforms:

Key waveforms refer to the essential graphical representations of electrical parameters within a circuit or system. These waveforms provide valuable insight into the behavior, operation, and performance of the circuit or system. Key waveforms help engineers and technicians understand how signals and voltages change over time, allowing them to analyze and troubleshoot electronic devices effectively.

In the context of power converters like the Super Lift Luo Converter with integration of a buck converter, key waveforms typically include input voltage, inductor current, switch voltage, output voltage, diode voltage, and capacitor voltage waveforms. Each waveform reveals specific aspects of the converter's operation, aiding in design optimization, performance evaluation, and fault diagnosis.

The load currents (i_{L1}, i_{L2}) and switch voltages and currents are the same. This validates the waveforms were theoretical.

VI. SIMULATION RESULTS

The simulation results for f_s = 30kHz are displayed in Fig.(7a),(8a), where D_1 and D_2 have two different values.

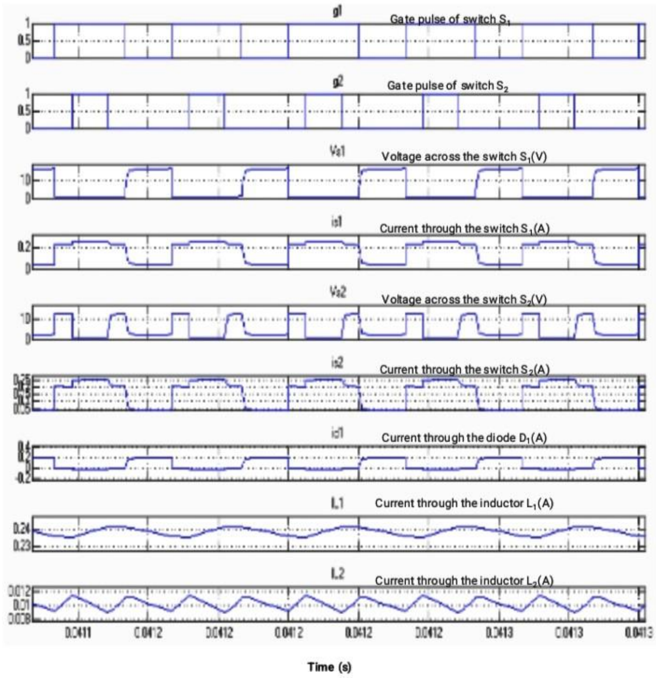

Fig. 6. key waveforms from simulation

This image shows how output voltage values and voltage gain formulae agree. This method is used to calculate voltage gains for different duty cycles. As illustrated in Fig.(7a) , the step-up and step-down voltage gains for D_1 = 60% and D_2 = 30%, respectively, are 2.43 and 0.43. Furthermore, since D_1 = 90% and D_2 = 80%, as illustrated in Fig.(8b) Step-up and step-down voltage gains are 6 and 0.5, respectively. Therefore, equations and , respectively, are validated by the output voltage values that were acquired from simulation.

Figure 7(a),8(b), makes it clear that there are fluctuations in the waveforms before reaching steadystate conditions. Indeed, the output voltages for $D_1 + D_2 \le 1$ exhibit overshootThe simulation results with two difference values for $eq1$ are displayed in Fig. for f_s = 30kHz.

But under $D_1 + D_2 \ge 1$, these fractions are erased by overlap in the switch operation, leading to an increase in setting time. As such, there is a close link between the values of D_1 and D_2 and the desired control of output voltages. Therefore, the choice of how to strike a balance between the aforementioned parameters rests with the designer.

The step-down voltage gain and D_1 value have the opposite relationship when D_2 is considered to be fixed. Because of the constant input current, there are also very few ripples observed in the output voltages.

Simulation Results of output voltages for proposed SIDO
Vo1=step-up voltage
Vo2=step-down voltage

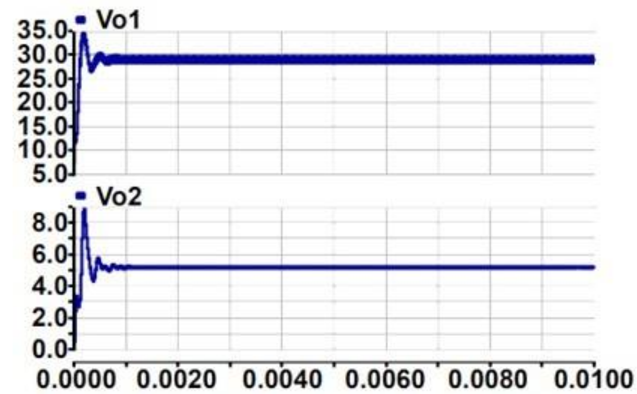

Fig. 7. (a) D_2 = 30% and D_1 = 60%

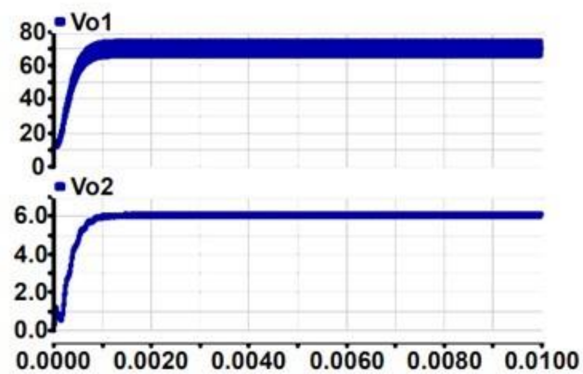

Fig. 8. (b) D_2 = 80% and D_1 = 90%.

VII. EXTENSION OF PROPOSED DESIGN

In this section, to achieve higher voltage gains, and to charge batteries the proposed SLBC is extended by adding two batteries. Thus, The step-up voltage gain reaches to $\frac{2-D_2}{1-D2}^{2}$. Fig.9 shows the structure of the extended SLBC. The additional elements in this structure are one nickel metal hydride battery and lithium ion battery Other values are obtained. Accordingly, Fig. 10 illustrates the output voltages in different duty cycles when D_2 = 30% and D_1 = 60%.

Compared to the proposed SLBC, the extended structure has a significant increase in step-up output voltage level and by this extension two batteries can charge at a time by decreasing switching losses,lower the ripple and increase in output voltage and efficiency.

A BMS(Battery Management System) is essential for monitoring the battery's state of charge, voltage, and temperature. It ensures safe charging and discharging, prolonging battery life and preventing overcharging or deep discharging.

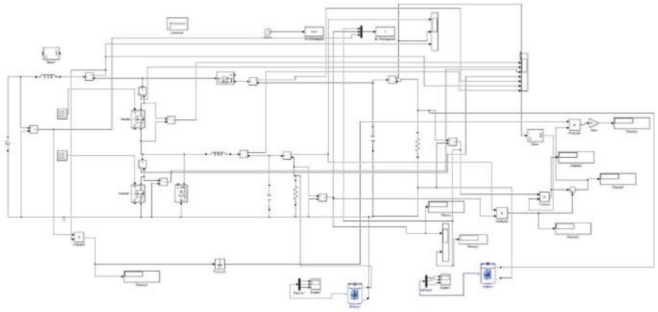

Fig. 9. Simulation model with batteries

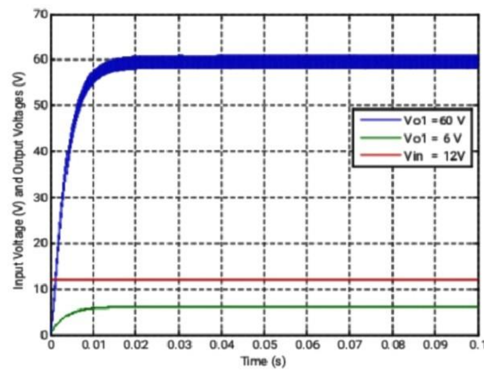

Fig. 10. Extended Simultion model Results

Battery charging applications in electric vehicles continue to evolve with advancements in technology, infrastructure deployment, and regulatory support, driving widespread adoption of electric transportation and reducing greenhouse gas emissions from the transportation sector.

Overall, connecting batteries to a single input dual output converter provides flexibility and efficiency in powering multiple loads from a single power source, making it suitable for various battery-powered applications, including portable electronics, renewable energy systems, and automotive applications.

VIII. CONCLUSION

A buck converter based on series-connected switches and a super-lift Luo-converter comprise the multi-output structure known as the planned SLBC. The key characteristics are minimal conduction losses without the need for electromagnetic devices, a broad voltage range generation capability, enhanced voltage gain, and a straightforward switching control technique. Simulation and experimental measurement results confirm that the theoretical analysis is true. As a result, outputs for step-up and step-down can be delivered simultaneously. Additionally, by increasing output power, the efficiency of SLBC may be changed from around 98% to 93%. The suggested configuration can be used to a SIMO converter with various output voltage levels. Lastly, it should be highlighted that EVs can take advantage of the new capabilities our converter has to offer thanks to the previously described design and specification of the suggested converter.

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