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Voltage Gain Enhancement Using Ky Converter

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Abstract: *The KY Converter, Which is a step up converter, The name given to this converter is first letter of the authors, K.I. Hwu, Y. T. Yau. This converter always operate in CCM, and the output current is non-pulsating, and low output voltage ripple and higher voltage boosting capability. In this paper, different modes of KY Converters are studied. The simulation is carried out to study the perfomance of the combinations of KY Converter in MATLAB/SIMULINK. Simulation result are studied. The result help to find the most suitable converter for the Micro-source applications.*
Keywords: *KY Converter, One Plus D Converter, Inductor coupled KY Boost Converter, Step up Converter combining KY and buck-boost Converter*

I. Introduction

The over usage of fuel energy cause the global warming, environmental pollution and rise in price of the petroleum and diesel. The studies reveals that the demand of fuel energy rises with 8-10 percent per annum. This can be avoid by using non-renewable energy.

In such condition micro-source are obtaining more importance. The micro-source are either DC Source or High frequency AC Source. These categories of source are mainly used for renewable energy applications. Mainly for solar cell modules, fuel cell stacks wind turbines and reciprocating engines. If the output of the micro-source is DC, the magnitude of output is very low. So there arise the needs of a high voltage boosting converter output voltage. Different boosting converters are available now such as boost , buck-boost, CUK and SEPIC converter. And KY Converter like. Among these KY converter is most acceptable one.KY converter is a DC to DC voltage boosting converter [1].

Which is always operate in CCM and and the output current is non- pulsating. The output voltage has less ripples. For many applications the output voltage gain ripples and gain is need to taken in to consideration. Regarding the traditional non-isolated voltage-boosting converters [2], [3], such as the traditional boost converter and buck-boost converter, their voltage gains are not high enough for some circuits. So KY converter can use instead of all other boost converters.

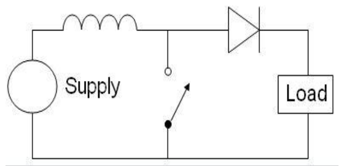
The KY Converter and the combinations of other converters with KY Converter will have more voltage gain and less ripple. The example is that One plus D KY Converter is the basic form of KY Converter. Which has less ripples when compared with the boost converter. But the KY Converter has less voltage gain. In that situation we can use the combinations of KY converter with other boost converter such as Step-Up Converter Constructed by KY and Buck-Boost Converters. In the micro-source applications we can use the Converter constructed by KY and buck-boost converter. Because we can obtain more voltage gain with less output voltage and output current ripples. So it will be more advantageous than the normal KY Converter.

II. Dc-Dc Boost Converters

The available converters for boosting the voltage are boost converter, KY Converter and the Converter constructed by KY and buck-boost converter are studied and found out the most acceptable one for the micro-source application.

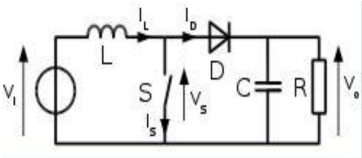
2.1 Boost Converter

A Boost converter is switch mode DC to DC converter in which the output voltage is greater than the input voltage. The principle behind the boost Converter is the tendency of an inductor to resist changes in current by increating and destroying a magnetic field.



Boost converter

When switch S is ON : The diode will be open circuited since the diode is at higher voltage compared to the side which is shorted to ground through the switch. During this state the inductor charges and the inductor current increases. The inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive.



Boost Converter schematic

When the switch is opened: The current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current towards the load. Thus the polarity will be reversed. So two sources will be in series causing a higher voltage to charge the capacitor through the diode D.
For the ON state,

IL,ON = (1/L) * Vin *D * TS+ IL,ON

For the OFF State,

I’’’L,OFF = (1/L) * (Vin –VOUT) *(1-D) * TS+ I’’L,OFF

Using these equations we get,

(1/L) * Vin *D * TS = - (1/L) * (Vin –VOUT) *(1-D) * TS

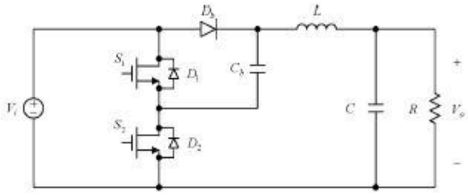
Vin *D = (Vin –VOUT) *(1-D)

VOUT/VIN = 1/ 1-D

Modes of operation of Boost converter are,
The boost converter can be operated in two modes:
a) Continuous conduction mode in which the current through inductor never goes to zero
b) Discontinuous conduction mode in which the current through inductor goes to zero

2.2 KY Converter

KY converter is a step up converter. The behavior of KY converter can be considered as synchronous rectification. In the case of synchronous rectification, the diode is replaced by a MOSFET switch to develop the efficiency and to reduce the conduction losses. But this can be achieved only in the case of light loads. The feature of KY converter, which makes it different from other converters, is that it always operates in. Also the output voltage ripple is very low since the output current is not pulsating. Above all, its behavior is similar to that of the buck converter with synchronous-rectification (SR), and hence, this converter possesses good load transient response. However, its ratio of the output voltage to the input voltage is one plus D, where D is the duty cycle of the pulse width-modulation (PWM) control signal for the main switch.



KY Converter

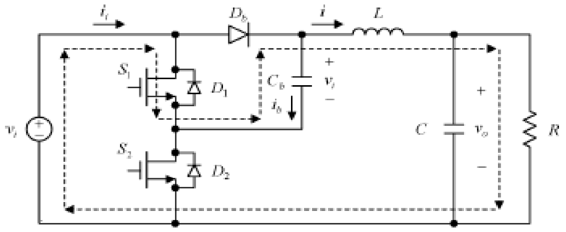
Working:

Mode 1: In Fig., as soon as S1 is turned on and S2 is turned off, the voltage across L is the input voltage vi plus the voltage vi across Cb minus the output voltage vo , there by causing L to be magnetized . Also, the current flowing through C is equal to the current i flowing through L minus the current flowing through R. Besides, in this mode, Cb is discharged.
And hence, the corresponding differential equations are,

$$L\left(\frac{dI}{dt}\right) = 2Vi - V0$$

$$C(dV0/dt) = i - V0/R$$

Ii= I



Mode 1 operation of KY Converter

Mode 2: In Fig., as soon as S1 is turned off and S2 is turned on, the voltage across L is the input voltage vi minus the output voltage vo , thereby causing L to be demagnetized. Also, the current flowing through the C is equal to the current i flows through L minus the current flowing through R. Besides, in this mode, Cb is abruptly charged to vi within a very short time, which is much less than Ts . And hence, the corresponding differential equations are,

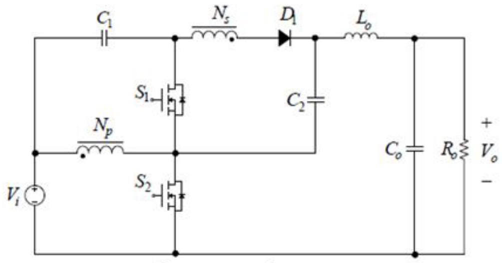
$$L\left(\frac{di}{dt}\right) = Vi - V0$$

$$C(dV0/dt) = i - V0/R$$

$$ii=i+ib$$

2.3 Step-Up Converter Constructed by KY and Buck-Boost Converter

This converter contains two MOSFET switches S1 and S2, one coupled inductor composed of the primary winding with Np turns and the secondary winding with Ns no. of turns, and one energy-transferring capacitor C1, and one charge pump capacitor C2,also one diode D1, one output inductor Lo, and one output capacitor Co. In addition, the input voltage is represented by Vi, the output voltage is signified by Vo, and the output resistor is represented by Ro.



Step up converter combining KY and buck-boost

Before taking up this section, there are some assumptions to be made as follows.

(1) The coupled inductor is modeled as an ideal transformer except that one magnetizing inductor Lm is connected in parallel with the primary winding and one leakage inductor Ll1 is connected in series with the primary winding. Therefore, the coupling coefficient k is defined as Lm /(Lm + Ll1) .

(2) The converter operates in the positive current mode. That is, the currents flowing through the magnetizing inductor Lm and the output inductor Lo are always positive.

(3) Dead times between two MOSFET switches are omitted.

(4) The MOSFET switches and the diodes are assumed to be ideal components.

(5) The values of all the capacitors are large enough such that the voltages across them are kept constant at some values.

(6) The magnitude of the switching ripple is negligible. Therefore, the small ripple approximation will be adopted herein in analysis.

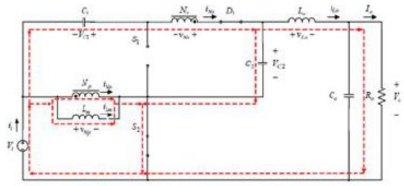
These following analysis contains the explanation of the power flow path for each mode, along with the corresponding equations and voltage gain. Inherently, there are two operating modes in the proposed converter.

Mode 1: During this interval, as shown in Fig. 3, S1 is turned off, but S2 is turned on. Therefore, the input voltage Vi is imposed on Np, thus causing Lm to be magnetized and the voltage across Ns to be induced, equal to Vi Ns / Np . In addition, D1 becomes forward-biased C2 is charged to Vi +VC1 +Vi Ns / Np , and the voltage across Lo, vLo, is a negative value, equal to VC2 Vo , thus making Lo demagnetized. As a consequence, the input voltage Vi, together with the voltage across C1, VC1, plus the induced voltage on Ns, vNs, plus the voltage across Lo, vLo, provides the energy to the load.

Also, the associated equations are shown below:

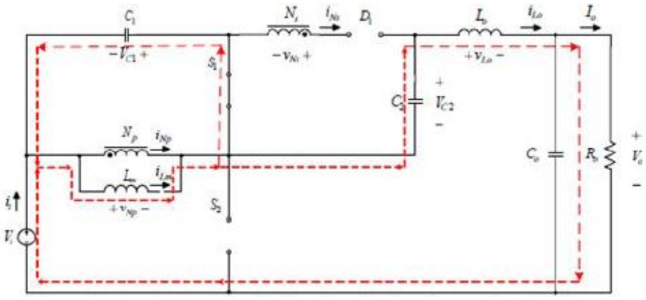
VNP =Vi

VL0= VC2-V0



Mode 1 operation

Mode 2: During this interval, as shown in Fig., S1 is turned on, but S2 is turned off. Therefore, the voltage VC1 is imposed on Np, thereby causing the magnetizing inductor Lm to be demagnetized, and the voltage across Ns to be induced, equal to VC1 Ns / N p . In addition, D1 becomes reversebiased,the voltage on Lo is a positive value, equal to Vi +VC1 +VC2 Vo , thus causing Lo to be magnetized. As a result, the input voltage Vi, together with the voltage across Lm, vNp, plus the voltage across C2, VC2, provides the energy to Lo and the load.



Mode 2 Operation

The voltage gain can be expressed to be,

$$\left(\frac{V0}{Vi}\right) = \frac{2-D}{1-D} + n$$

0<D<1

III. Design Considerations

For the inductor design

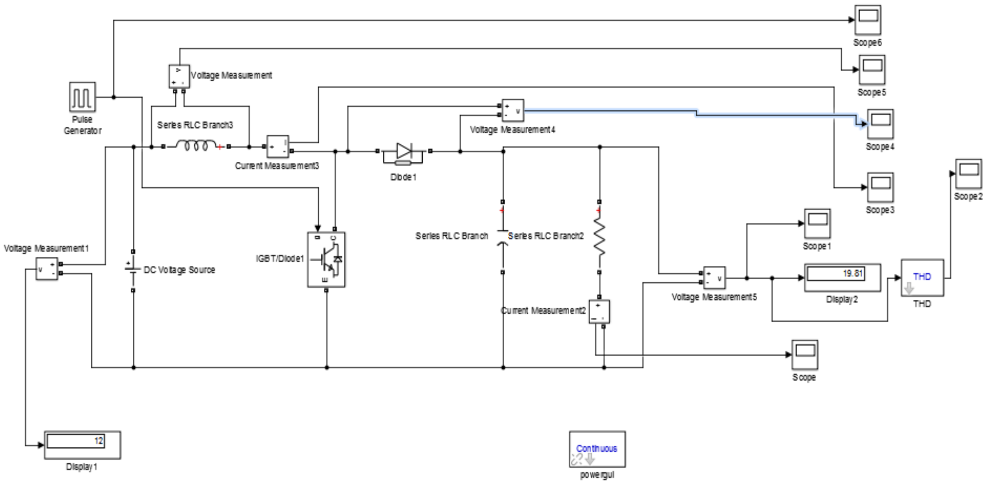
$$V(t) = L\left(\frac{di}{dt}\right)$$

Where v is the voltage over the inductor, L is the value of the inductor in Henrys, and di/dt is the change in current over time in the inductor. Operating frequency, f = 195 KHz.
For the capacitor design,

$$C=(I_0D)/(f\Delta V_0)$$

For the Boost Converter the component specification are,

Components	Specifications
inductor	5e-5
capacitor	5.7e-5
Resistor	100 Ohm



Simulation dia. for the Boost Converter

For the case of KY Converter prior to taking up this section, there are some specifications given as follows:
1) Rated input voltage *Vi* is set to 12 V.
2) Rated output voltages *Vo* are set to 24V,18 V and 72V or the Boost converter, KY converter and the step up converter constructed with KY and buck-boost converter respectively.
3) Switching frequency *fs* is set to 100 kHz.
4) The duty ratio for the switch is set to 0.5
5) Rated output powers *Po*-rated are 50 W, 50W and 60 W for the Boost Converter KY converter and thestep up converter constructed with KY and the buck-boost converter, respectively.

For the KY converter to be considered, there are some assumptions used to obtain the value of *Cb* as follows: *1) Cb* is abruptly charged to *Vi* in mode 2; 2) percentage ε of decreased variation in voltage on *Cb* during the discharge period is set to 0.1% in mode 1; 3) input voltage is an infinite bus, i.e., the input voltage is always kept constant and possesses infinite capacitance that is much larger than the value of *Cb* ;

$$Ee = 1/2Cb\{(2Vi)^2 - [(2-\varepsilon)Vi]^2\}$$
$$= 1/2(4\varepsilon - \varepsilon^2)CbVi^2$$

Also, in mode 1, the energy *Es* is sent to the load, and can be represented as,

$$Es = (P0\text{-rated}D)/\eta fs$$

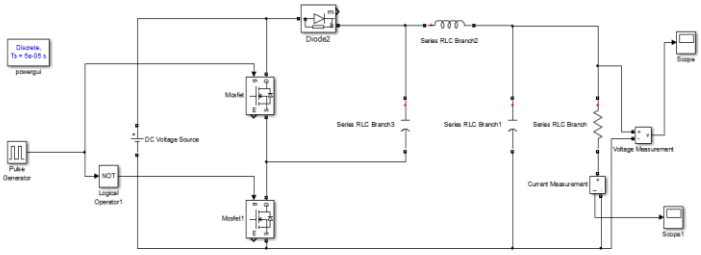
According to energy conservation, *Ee* is equal to *Es* , and hence, value of *Cb* can be expressed as

$$Cb = (2Po\text{-rated}D)/(4\varepsilon - \varepsilon^2)V i^2 \eta f_s.$$

C_b here selected as 1.7e-3 and C0 as 1F.
From the industrial view point, the output inductor is generally designed to have no negative current when output current is above 20%~40% of rated output current . Therefore, in this paper, boundary between positive current and negative current is assumed to be 40% of the rated output current. The value of L is 18µF.

For the KY Converter the component specification are,

Components	Specifications
C_b	1.7e-3 F
L	1.8e-5 H
C_0	1F
R_0	100 Ohm



Simulation for KY Converter

For the case of step up converter constructed by KY and buck-boost Converter,
The *Magnetizing inductor design:* To make sure that *Lm* always operates in the positive region, the required equation is as follows.

$$L_m \geq V_i D T_s / \Delta i_{Lm,min}$$

where *ILm*,*min* is the minimum dc current in *Lm*. And finally, the value of *Lm* is set at 148.7μH.
Output inductor design: From the industrial of viewpoint, output inductor is generally designed to have no negative current when the output current is above 20%~30% of the rated output current. Eventually, the value of L_o is set at 188μH.
Energy-transferring capacitor design: Assuming the peak-to-peak value of the capacitor voltage during the charge period, Δ*vC*1 , is set to 1% of *VC*1 or less, that is, Δv_{C1} is smaller than 120mV, the value of *C*1 can be obtained as follows:

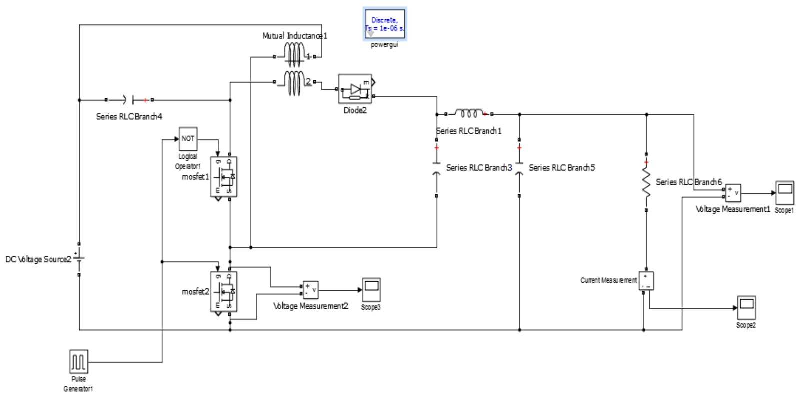
$$C_1 \geq (i_{c1} \Delta t) / \Delta V_{c1}$$

Charge pump capacitor design: Assuming the variation in capacitor voltage during the discharge period, Δv_{C2} , is set to 0.1% of *VC*2 or less, that is, Δ*vC*2 is smaller than 60mV, the value of *C*2 can be obtained as follows:

$$C_2 \geq i_{c2}\, \Delta t / \Delta V_{C2}$$

For the KY Converter the component specification are,

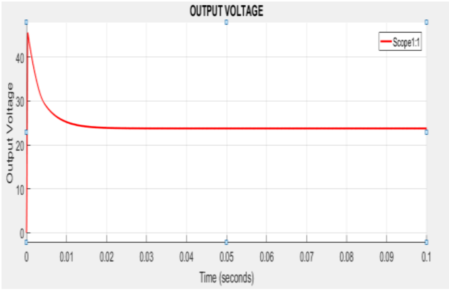
Components	Specifications
C_1	470e-6 F
Coupled inductor	*Lm*=148.7Mh *L*1=1.3μH,L_2=4e-4, *k*=0.997
L_0	188e-6 H
C_0	220e-6 F



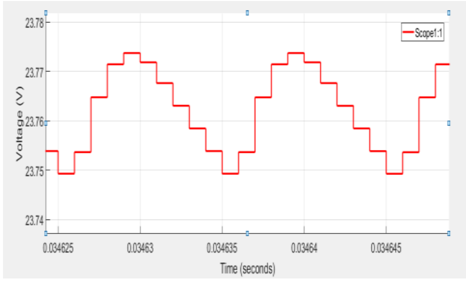
Simulation Diagram for the step up converter constructed with KY and buck-boost converter

IV. Simulated Results

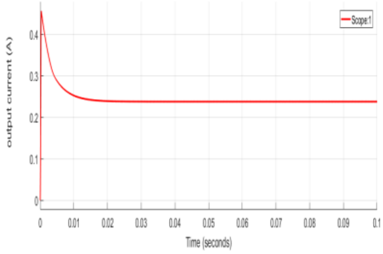
The available converters i.e. boost converter and ky converter and the step-up converter constructed by combining ky and the buck-boost converters are studied under the same condition with the same duty ratio and frequency under the same load. The boost converters are very simple circuits and we obtain the maximum output voltage. But the output voltage ripples are very high and output current is pulsating when compared with the others.



Output Voltage for
boost converter

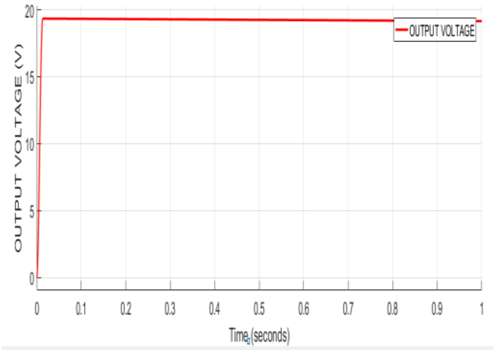


Output Voltage ripple
for boost converter

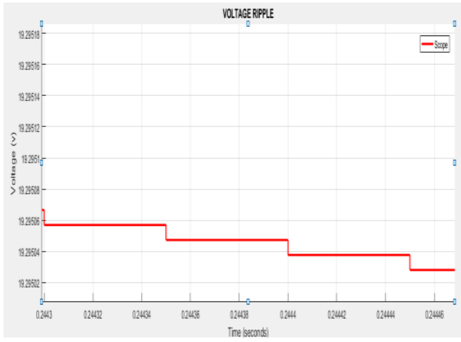


Output Current for boost converter

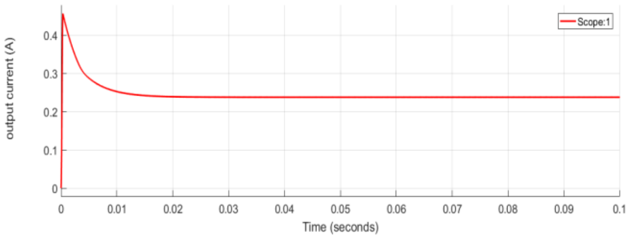
The applications of the power supply using the low voltage battery, analog circuits, such as RF amplifier, audio amplifier, etc., sometimes need high voltage to obtain enough output power and voltage amplitude. This is achieved by boosting the low voltage to the required high voltage. For such applications, the output voltage ripple must be taken in to account seriously.



Output voltage for KY Converter

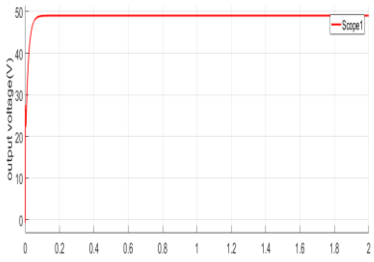


Output voltage ripple for KY Converter

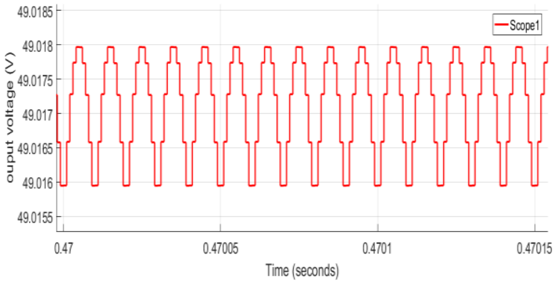


Output Current for KY Converter

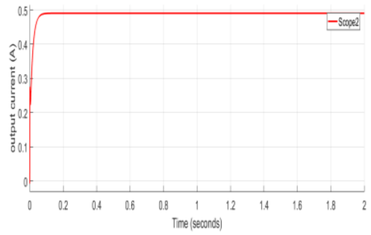
Regarding the conventional non isolated voltage-boosting converter such as the boost converter, their output currents are pulsating, thereby causing the corresponding output voltage ripples to tend to be large.



Output Voltage for step up converter constructed with KY and buck-boost converter



Output Voltage ripple



Output Current

In the case of the KY Converter,the above problems are solved, the output voltage ripples for converter are very small and the output current is non-pulsating. But the voltage gain is not that much suitable for high power applications. Because the voltage gain is small when compared with other higher converters. So we need to consider the step up converter constructed by KY Converter and buck-boost converter. In the case this converter voltage gain is high. And the output voltage ripples are very small and the output current is nonpulsating.So the KY Converter constructed with buck-boost converters used for high voltage industrial applications.

Comparative study for various DC-DC Converter topologies,

	BOOST	1+D	[(2-D)/(1-D)] +n
NO. OF SWITCHES	1	2	2
Input Voltage	12	12	12
Output current			
Output voltage ripple	0.025	2.3e-4	2e-3
Voltage Ripple percentage	0.1054	5.22e-5	5.025e-3
Output current	0.25	0.25	0.48
Duty Ratio	0.5	0.5	0.5

V. Conclusion

From the study of the various DC-DC converters high step-up converter is presented is very useful when compared with the other conventional boost Converter and the KY Converter. By combining the coupled inductor with the turns ratio, and the switched capacitor, the corresponding voltage gain is higher than that of the existing step-up converter combining KY and buck-boost converters. Furthermore, the converter has no floating output, and has one output inductor so the output current is non-pulsating. Moreover, the structure of the proposed converter is quite simple and very suitable for industrial applications.

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