Brushless DC Motor Drive Using an Isolated-Luo Converter for Power factor correction

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Abstract - *A brushless DC (BLDC) motor has several application in medical, industrial, aeronautical field. A configuration of Luo converter with high frequency isolation for feeding brushless DC (BLDC) motor drive with power quality improvements at AC mains is presented. A low frequency switching of the voltage source inverter (VSI) is used for reducing the switching losses associated with the six solid-state switches of VSI (Voltage Source Inverter). This is obtained by electronic commutation of BLDC motor and adjusting the DC bus voltage of the VSI for speed control. The isolated- Luo converter is designed in discontinuous inductor current mode (DICM) for voltage control and power factor correction is achieved inherently at the AC mains using a single voltage sensor. Performance of drive is evaluated for improved power quality at AC mains for varying speeds and supply voltages. The simulation of the circuit is done in PSIM and results are obtained.*

Key Words: BLDC (Brushless DC), Discontinuous Inductor Current Mode (DICM), Voltage Source Inverter (VSI),

1. INTRODUCTION

Using of Permanent Magnet in electrical machines have so many benefits and advantages than Electromagnetic excitation machines these are zero excitation losses result in high efficiency, simple construction, low cost maintenance and high torque or high output power. In early 19th century permanent magnet excitation system was used for first time in electrical machines [1]. The performance of this machine was very poor due to low quality of hard magnetic material make this less usable. After the invention of alnico invigorated the use of permanent magnet excitation system increases. Rare earth permanent magnets increases the power density and dynamic performance of the machine [1]. The high power to weight ratio, high torque, good dynamic control for variable speed applications, absence of brushes and commutator make Brushless dc (BLDC) motor, good choice for high performance applications. Due to the absence of brushes and commutator the mechanical wear of the moving parts can be avoided. Moreover, better heat dissipation property and ability to operate at high speeds make them superior to the conventional dc machine [2].
Conventionally, a combination of diode bridge rectifier (DBR) and DC bus capacitor is used for feeding the BLDC motor. However, such combination draws highly distorted current from the supply system, which is rich in harmonics and results in very high total harmonic distortion (THD) of supply current at very low power factor [1]. Hence power factor correction (PFC) converters are used for meeting these recommended guidelines of IEC61000-3-2. A PFC converters are generally designed for their operation in continuous or discontinuous conduction mode. The current in inductors or the voltage across capacitors remains continuous or becomes discontinuous in these modes of operation, respectively. A continuous inductor current mode (CICM) requires sensing of supply voltage (vs),DC link voltage (V_{dc}) and input current (i_{in}) for the voltage control with PFC operation [6]. This offers reduced stress on the solid-state switch of PFC converter but at the cost of high number of sensors. However, a PFC converter operating in discontinuous inductor current mode (DICM) requires only single voltage sensor for voltage control and inherent PFC is achieved at AC mains. But, the stress on PFC converter increases in this mode of operation and, therefore suitable for low and medium power applications [18]. The Luo converter is widely used in DC-DC conversion as it exhibits good voltage regulation over a wide range of voltage fluctuations and possess high light load efficiency. This paper explores a new configuration of an isolated-Luo converter for feeding BLDC motor drive with sensor reduction and power factor correction

2. BLDC MOTOR DRIVE FED BY AN ISOLATED-LUO CONVERTER

Fig. 1 shows proposed PFC based isolated-Luo converter fed BLDC motor drive. A single-phase DBR followed by an isolated-Luo converter is used for control of DC bus voltage with power quality improvements at AC mains. The proposed isolated-Luo converter is designed to operate in DICM, i.e. the magnetizing inductance (Lm) of the high frequency transformer operates in discontinuous current conduction.

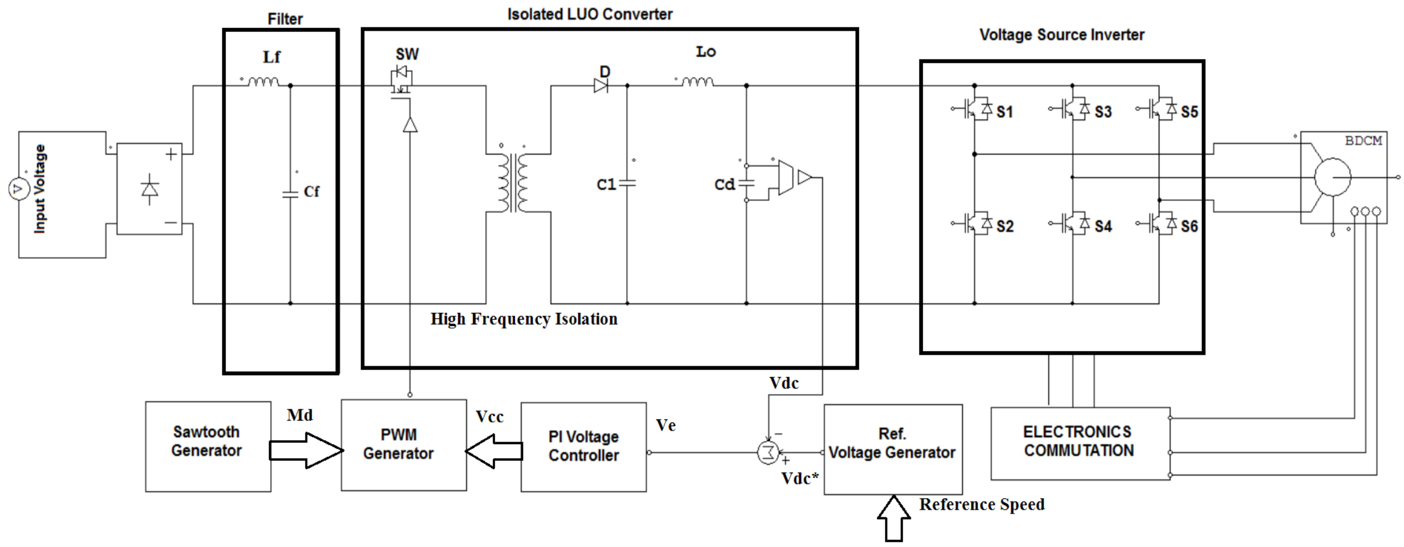


Fig-1: Isolated Luo Converter fed BLDC Motor

The BLDC motor is electronically commutated, which in-turn reduces the switching losses in it. Moreover, the complete operation of the drive is realized using a single DC-bus voltage sensor for reducing the cost of overall drive system. An improved power quality of the proposed drive is evaluated at various speeds and various supply voltages.

3. OPERATION OF PROPOSED PFC CONVERTER

Three modes of operation of proposed PFC based isolated-Luo converter in DICM are shown in Figs. 2(a)-(c). Moreover, Fig. 3 shows associated waveforms in a switching period.

Mode 1: As shown in Fig. 2(a), when switch S_w is turned-on, the current in primary winding of high frequency transformer (HFT) i.e. I_{HFTp} increases. The output inductor (L_o) and intermediate capacitor (C_1) discharge and DC link capacitor (C_d) charges in as shown in Fig. 3.

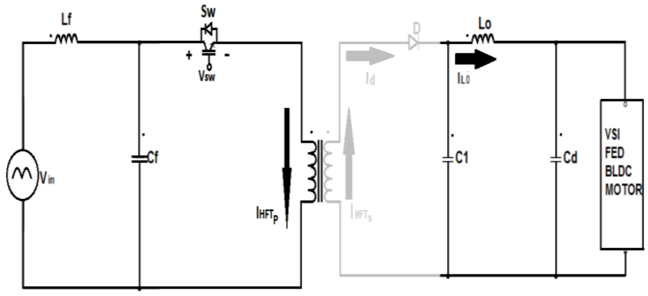


Fig- 2(a) Mode 1

Mode: 2 when switch S_w is turned-off, the current starts flowing in secondary side of HFT (i_{HFTs}) as shown in Fig. 2(b). The output inductor (L_o) and intermediate capacitor (C_1) charge and DC link capacitor discharges via diode (D) as shown in Fig. 3.

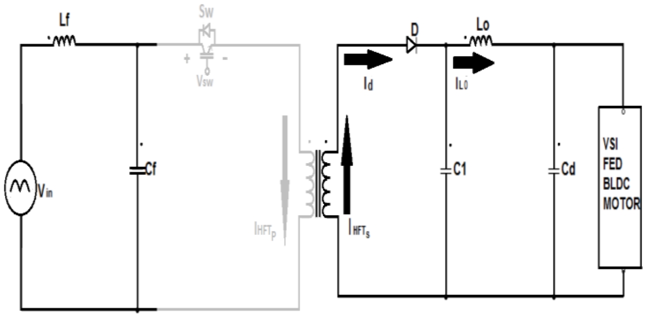


Fig-2(b) Mode 2

. **Mode: 3** As shown in Fig. 2(c), no energy is left in the HFT i.e. current (i_{HFTp} and i_{HFTs}) becomes zero and enters DICM. The current in output inductor (L_o) and DC link voltage (V_{dc}) increase and voltage across intermediate capacitor (V_{C1}) decreases as shown in Fig. 3

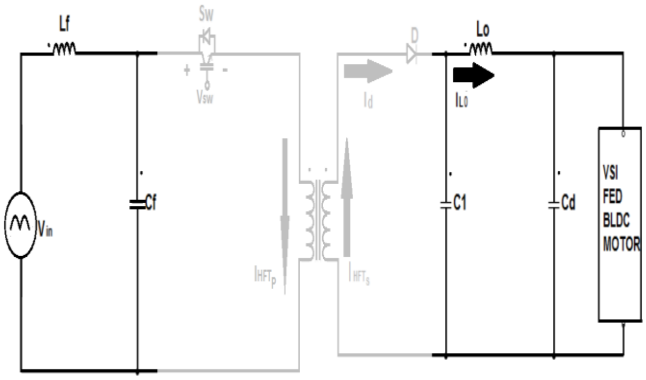


Fig-2(c) Mode 3

Fig. 3 shows associated waveforms in a switching period.

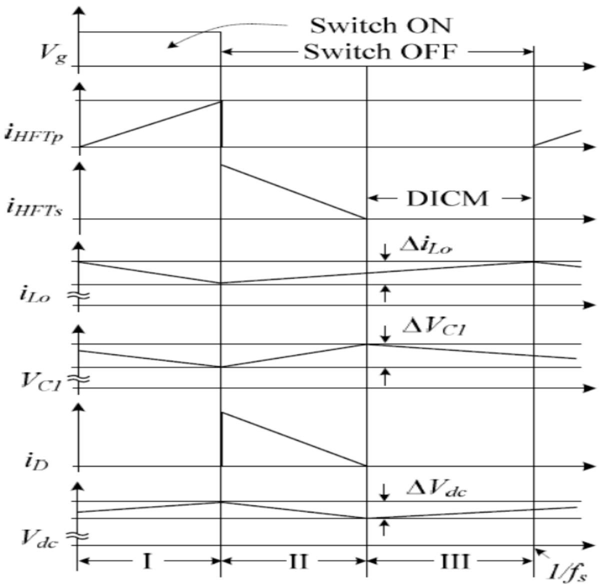


Fig-(3) Main waveform

4. DESIGN OF PROPOSED PFC CONVERTER

For a BLDC motor of 188 W, a front-end converter of 250 W (Po) is designed. The DC link Voltage is to be controlled from 50V (V_{dcmin}) to 130V (V_{dcmax}).
The input Voltage V_s is given as

$$V_s = V_m \sin 2\pi f t = 220\sqrt{2} \sin 314t \cdots\cdots\cdots\cdots. \quad (1)$$

Where V_m is a peak input voltage (311V), f is the line frequency i.e. 50 Hz. The average value of rectified voltage is as (3).

$$V_{in} = \frac{2\ V_m}{\pi} = \frac{2*311}{\pi} = 198V \cdots\cdots\cdots\cdots\cdots\cdots.. \quad (2)$$

The expression relating the input and output voltage, V_{dc} of an isolated-Luo converter is as

$$V_{dc} = \left(\frac{N_2}{N_1}\right) * \frac{d}{1-d} * V_{in} \cdots\cdots\cdots\cdots\cdots\cdots\cdots.. \quad (3)$$

Where d represents the duty ratio and N2/N1 is the turns ratio of HFT which is taken as 0.5. Now using (3), the duty ratio for the designed value of DC link voltage of 80 V (V_{des}) is calculated as 0.4468 (d_d). The critical value of magnetizing inductance (L_{mc}) to operate at the boundary conduction is expressed as (6).

$$L_{mc} = \frac{R_L * (1-d_d)^2}{2 * d_d * f * \left(\frac{N_2}{N_1}\right)^2} \cdots\cdots\cdots\cdots\cdots\cdots\cdots. \quad (4)$$

Where RL is the emulated load resistance and fs represents the switching frequency (which is taken as 45 kHz). Now, using (4), the critical value of magnetizing inductance (L_{mc}) is calculated as 779.3 mH. Therefore, the value of magnetizing inductance of HFT (L_m) is selected less than Lmc as 300 mH for its operation in DICM .The intermediate capacitor (C_1) is designed as.

$$C_1 = \frac{V_C d_d}{2R_L \ \ f \Delta V_s} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots. \quad (5)$$

Where VC is voltage across intermediate capacitor (i.e.$0.5V_{in}+V_o$) and ΔVC is the permitted capacitor ripple voltage. Using (5), the intermediate capacitor is calculated as 387.8 nF and is selected as 330 nF for $\Delta V_C = 0.5V_C$.
The expression for output inductors (L_o) is given as

$$L_0 = \frac{d_d\ I_{L0}}{16 f^2\ c_1\ \Delta I_{L0}} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots. \quad (6)$$

Where I_{Lo} is the output side inductors current as Po/V_{des}. Hence, using (6) the output side inductors are calculated for a ripple current of 2% as 2.089 mH and are selected as 2 mH. The DC link capacitor (C_d) is calculated as.

$$C_d = \frac{I_{0min}}{2\Delta V_{dcmin}\ \omega\ l} \cdots\cdots\cdots\cdots\cdots\cdots. \quad (7)$$

Where I_{omin} is given as P_{omin}/V_{dcmin} (P_{omin} is power at output DC voltage of 50 V i.e. 96 W)
$\omega_L = 2\pi f L$, where f_L represents the line frequency and ΔVdcmin is allowed DC link voltage ripple as 3% of V_{dc}.
Using (7), the DC bus capacitor is calculated as 2038 μF and it is selected as 2200 μF. A filter capacitance (C_f) is selected such that this value is lower than a maximum capacitive value of filter (C_{max}) and is given as

Table-1: Simulation Parameter

PARAMETERS	VALUES
Supply Voltage	230 v
Switch	IGBT
Inductor L_f	4mH
Inductor L_0	2mH
Capacitor C_d	2200µF
Capacitor C_f	330nf
Capacitor C_1	330nF

5. SIMULATION MODELS AND RESULTS

The simulation model of proposed system is shown in fig 4

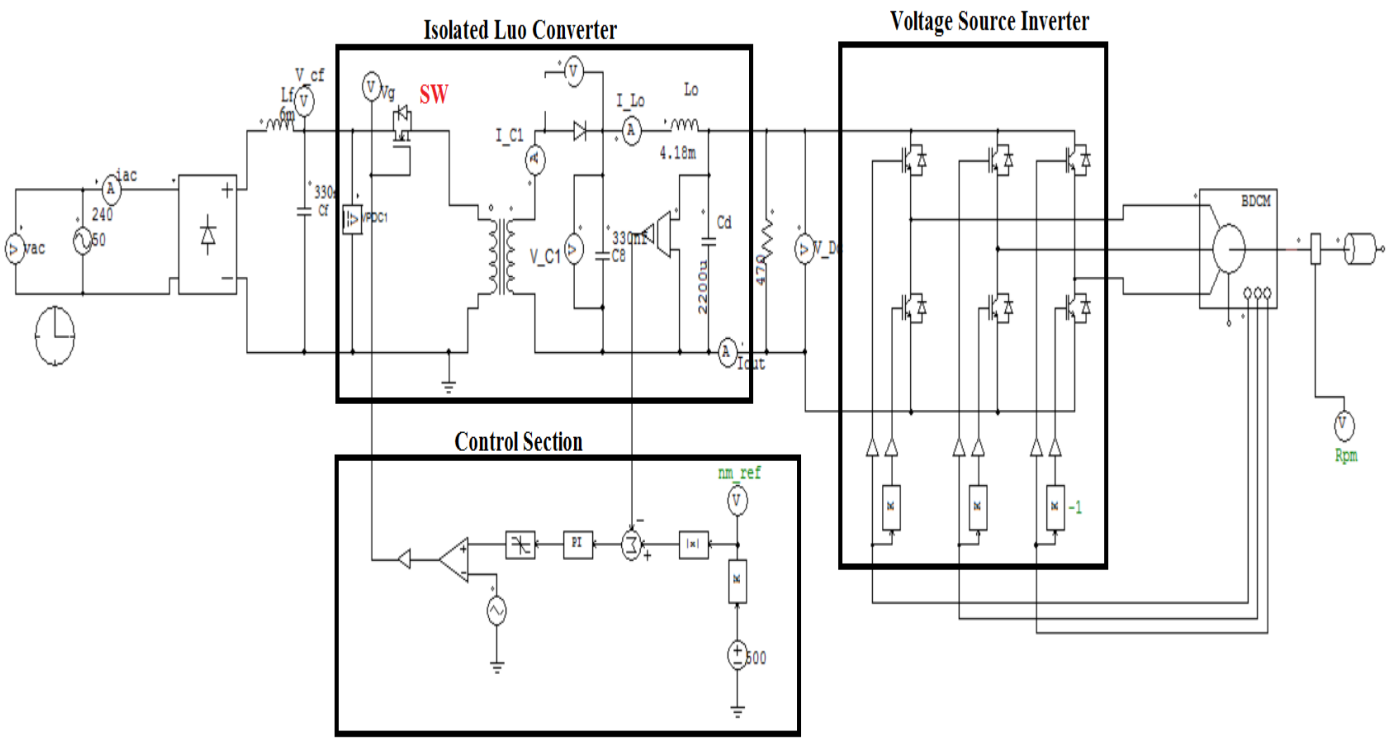


Fig-4 Simulation model

Here the supply voltage is given as 230V. The Simulation parameters are given in table 5. Here PI control is employed for closed loop. IGBT is used as switch. A high frequency transformer is used for isolation. The ratio of isolation transformer is taken as 1:2. A full bridge rectifier is used for converting Ac in Dc. Isolated luo converter is Dc to Dc converter which is used to drive BLDC .

The simulation Result for bldc motor with speed 800 rpm and Torque 0.2 Nm is shown below.

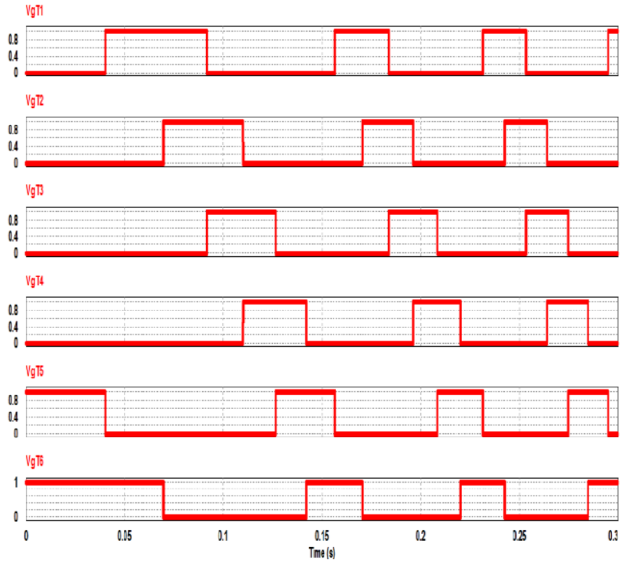


Fig-5: Switching Pulses for VSI

The six solid state switchs (IGBT) are used for Drive BLDC motor. The signal to IGBT are sensed from Hal sensor from motor. The switching Pulses for voltage source

Inverter is above. Two IGBTs are trigger at a time and remaining are off during that time

Below shown is the waveform of input current and

voltage. The power factor is obtained as 0.998.The voltage waveform across Capacitor C_1 and C_d is shown in figure 8 and figure 9**.**

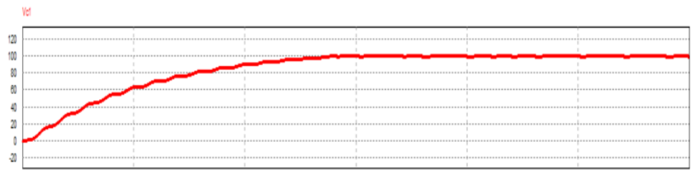


Fig-8: Voltage across C_1

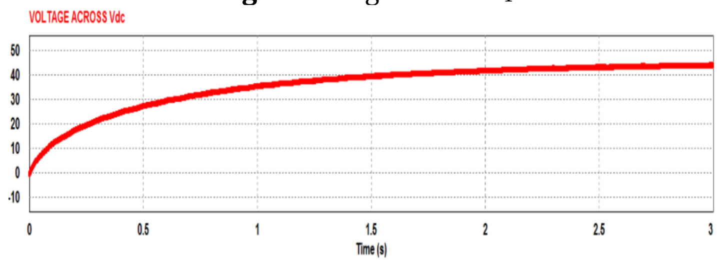
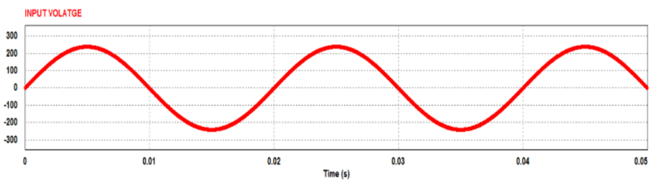


Fig-9: Voltage across Capacitor

The voltage across C_1 and C_d is obtained as 100V and 45V. The capacitor C_1 and C_d are used for buck operation the voltage across C_1 and C_d is obtained as 100V and 45V. The capacitor C_1 and C_d are used for buck operation



The Speed is obtained as 1000 rpm and Torque is obtained as 0.13Nm.The obtained waveform is shown in figure 10 and figure 11.

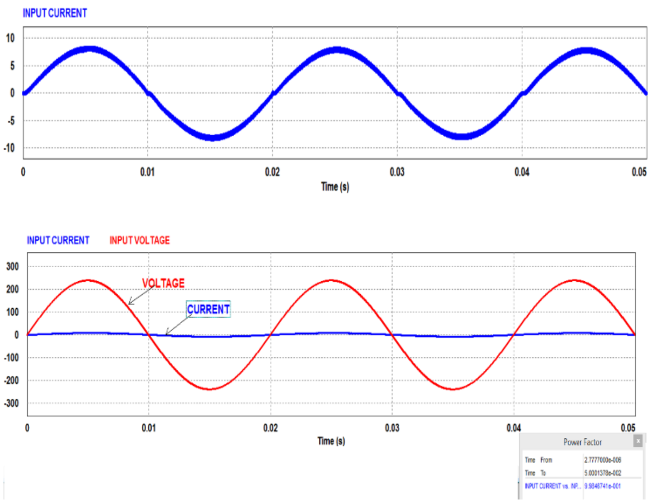


Fig-6 Input current and voltage

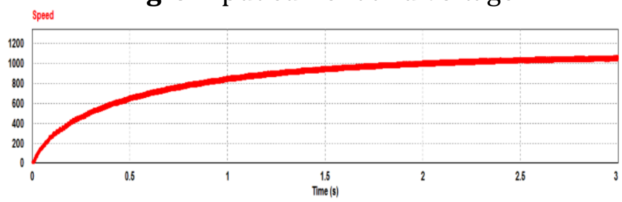


Fig-10 Speed of Motor

Figure 11 shows the Torque of the Motor.

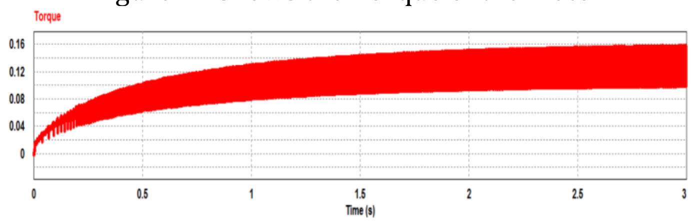


Fig-11 Torque of bldc motor

5. CONCLUSIONS

A new configuration of an isolated-Luo converter has been proposed in this work for feeding the BLDC motor drive. The operation of proposed drive has been realized using a single voltage sensor. An approach of variable DC link voltage has been used for adjusting the speed of a BLDC motor. Moreover, switching losses in six solid-state switches of VSI has been reduced by electronically commutating BLDC motor such that the VSI operates in low frequency switching. An inherent power factor correction has been achieved due to the design of PFC converter in DICM.

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