LED Driver with Three-Phase Series Resonant Converter with Reduced Source Ripple Current

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***Abstract* –LEDs are the present day light sources which require suitable driver for maintaining the appropriate current in it for proper operation. If such kind of systems are powered from PV panels, the possibility of ripples in the source current are more based on the converter being used. This paper proposes a power controller to reduce the ripples in the source current with an ability of driving the LED. In the proposed circuit, a 3-phase full bridge series resonant inverter followed by a rectifier feeds the LED load. For regulating the current in the LED a small power converter is used additionally. Pulse Width Modulation (PWM) is used for dimming operation of the light source. Soft switching is used for high efficiency. The proposed converter is studied using MATLAB simulation. This configuration is also suitable for handling large power.**

***Key Words**: 3-phase Full-Bridge inverter, series resonance, LED.*

I. INTRODUCTION

Light emitting diode (LEDs) are the contemporary development in the lighting industry. The advantages of LEDs include environment friendly, fast response, long life, Energy efficient, small size, very good color exhibition[1], etc. Applications of Lighting emitting diode include, street lighting, decorative lighting, traffic lighting, domestic lighting and so on [2]. Constant current driver is required for LED operation. For any variations in supply voltage LED driver must regulate the current through the LED lamp. For this, converters of high efficiency are required.

In general, LED is considered as a power semiconductor device which uses a fixed DC and are fed from high efficient devices such as SMPS etc..,[3]. There are several converter topologies for driving LEDs. Out of all the topologies buck boost converter topology is preferred in many applications for the constant power operation [4]. To reduce the voltage stress in LED drivers buck converters are preferred in many circuits [5]. At the same time the ripples in the source current has to be reduced to improve the system efficiency [6]. Further, a different method is discussed to reduce ripples from the source current when solar power is used as the input [7]. Although the voltage stress and ripples in the source current are reduced, it is always important to improve the efficiency by reducing the switching losses in circuit. Hence, soft switching LED driver is important. For this the circuit has to give ZVS or ZCS operation in the resonant converter circuit [7]. LED drivers built on resonant technique use half-bridge or full-bridge configurations. Full-bridge topologies are having higher power capability. An LED driver having multi strings is proposed in [9] based on full-bridge resonant converter. For LED driver application, a Zero Current Switching (ZCS) based switched capacitor converter is presented in [10].

In this paper, LED driver based on 3-phase full-bridge inverter is presented. This driver is having low source current ripple. Center-tapped transformer based rectifier is used to regulate the output voltage across the LED lamp. PWM based dimming is implemented in this topology. Also the presented topology is tested for the ZVS operation in the converter so that the soft switching operation of the LED is assured.

This paper is organized as follows: The proposed circuit and its principle of operation along with its expected waveforms are discussed in section II. The design considerations and calculations are presented in Section III. Results and Discussions are described in Section IV followed by the conclusions in section V.

II. OPERATING PRINCIPLE OF THE PROPOSED LED DRIVER

Fig. 1 shows the proposed topology of the LED Driver. It is composed of a 3-phase full-bridge inverter followed by a 3-phase diode bridge rectifier. An auxiliary converter with center tapped rectifier for regulation of output voltage. 3-phase full-bridge inverter consists of switches(S_1 to S_6), 3-phase diode bridge rectifier consists of diodes(D_1 to D_6), center-tapped rectifier consists of diodes D_7 and D_8. 3-phase full-bridge rectifier and center-tapped rectifier are connected in parallel. A Series resonant branch is connected in each phase with resonant inductors L_{r1},L_{r2} and L_{r3}, and resonant capacitors C_{r1},C_{r2} and C_{r3} as shown in figure1. V_{01} is the output voltage of 3-phase bridge rectifier, V_{02} is the output voltage of center-tapped rectifier. C_1 and C_2 are the filter capacitors. V_{01} and V_{02} are connected in series and sum of the two voltages is applied to LED lamp. Majority of the power is supplied by V_{01}. When there are any changes in supply voltage V_{DC}, output voltage is regulated by using V_{02}. Ripple in the lamp current is filtered using filter inductor L_f at output.

The 3-phse full-bridge inverter switches are operated in 180^0 conduction mode with a duty cycle of 50% and at a constant frequency. A small time period of dead band is provided to avoid short circuit of supply. Operating waveforms are shown in Fig.2. V_{AB} is the line voltage of the inverter at inverter terminals A and B. I_r is the line current of inverter flowing through series branch of resonant elements, it is of sinusoidal nature because the fundamental component of current is allowed by series resonant elements. The resultant voltage V_{o1} +V_{o2} is shown in Fig.2. It is applied to LED lamp through filter inductor L_f .The output voltage V_o across the LED lamp and current I_o

through the lamp is shown in Fig.2. To incorporate the variation of illumination, a series switch is connected with LED load which is operating at a frequency of 50HZ. Diode D_9 is a free-wheeling.

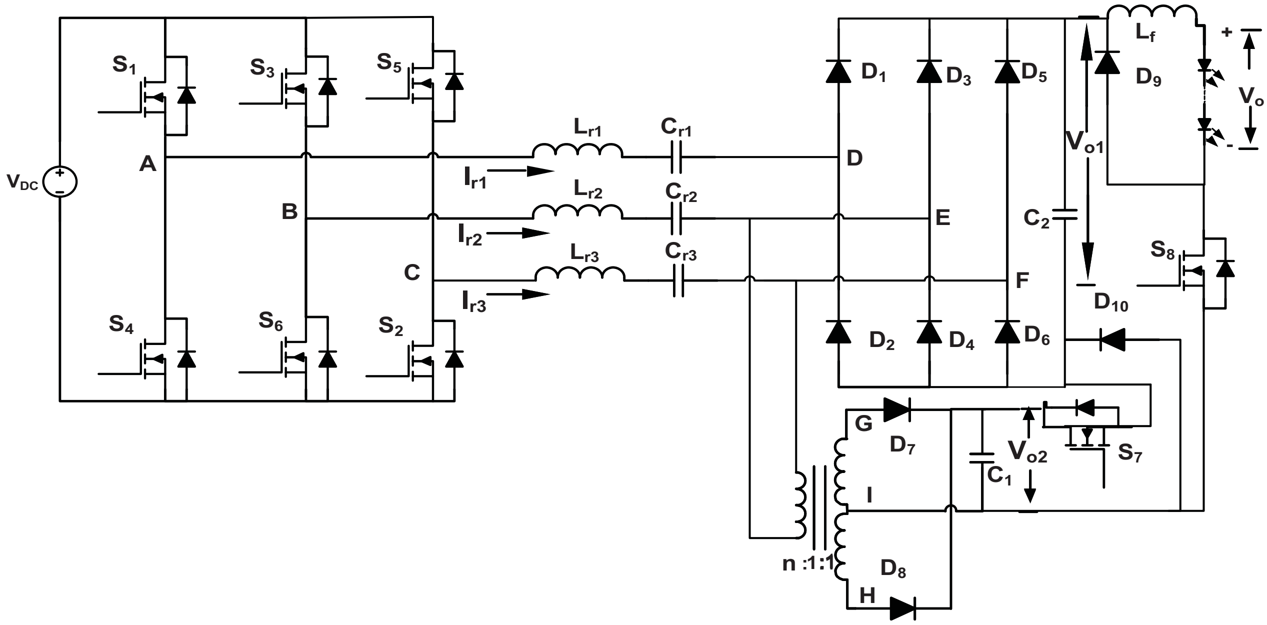


Fig.1. Proposed LED Driver

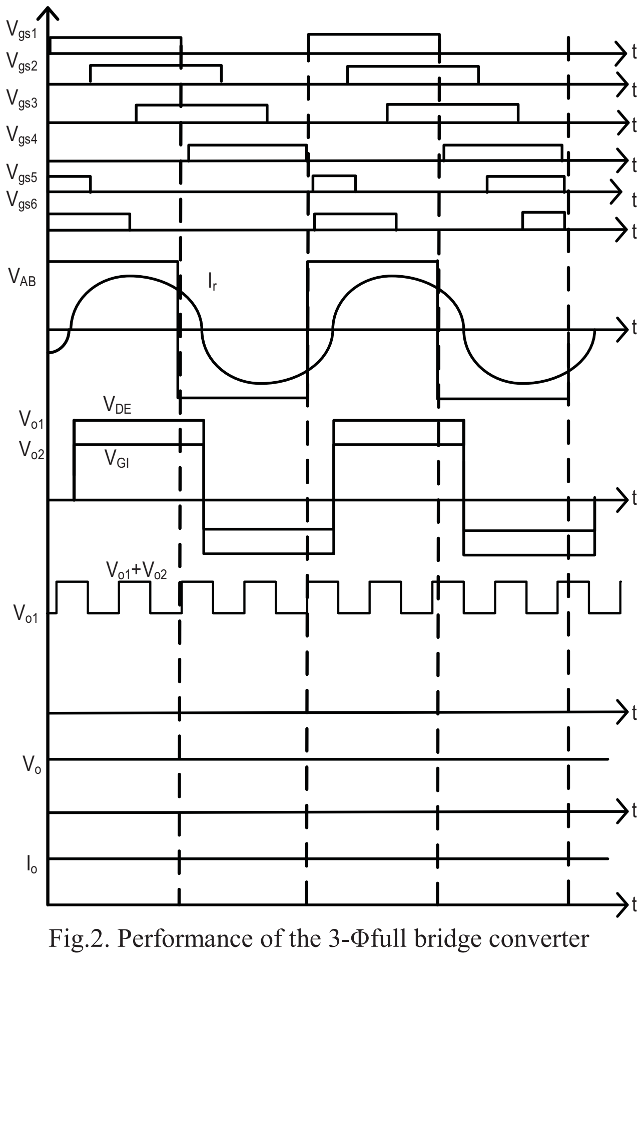


Fig.2. Performance of the 3-Φfull bridge converter

III. DESIGN OF THE PROPOSED CONVERTER

The following assumptions were made for the proposed driver model:

i) LED driver is functioning under steady state conditions.

ii) A forward DC Voltage in series with the forward resistance is considered as the LED model. Hence a constant voltage appears across LED.

In the this configuration, voltage V_{A1} is the per phase fundamental component of inverter output voltage. V_{D1} is the fundamental component of voltage at the rectifier input. Static gain of the converter is calculated by using voltage division principle. To do so the per phase equivalent circuit is considered, as in Fig.3.

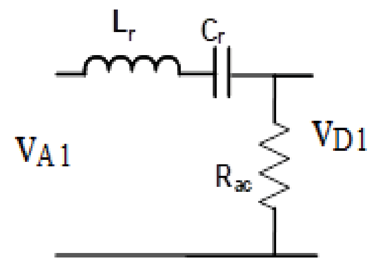


Fig.3. Per phase AC equivalent circuit

$$\frac{V_{A1}}{V_{D1}} = \frac{R_{ac}}{R_{ac}+j(X_{Lr}-X_{Cr})} \tag{1}$$

$$R_{ac} = \frac{6R_{LED}}{\pi^2} \quad (2)$$

$$Q = \frac{\omega_o L_r}{R_{LED}} = \frac{1}{\omega_o C_r R_{LED}} \quad (3)$$

$$\omega_o = 2\pi f_o = \frac{1}{\sqrt{L_r C_r}} \quad (4)$$

$$X_{Lr} = 2\pi f L_r \quad (5)$$

$$X_{Cr} = \frac{1}{2\pi f C_r} \quad (6)$$

From the above equations, we get

$$V_o = \frac{R_{ac}}{\sqrt{(X_{Lr} - X_{Cr})^2 + R_{ac}{}^2}} V_{DC} \quad (7)$$

The design parameters are tabulated in Table1.

Table.1: Design Parameters

Parameter	Value
Input voltage V_{in}	48 ± 5% V
Switching frequency	100kHz
Resonant frequency	90kHZ
Resonant inductor L_r	70.55 µH
Resonant capacitor C_r	44.32nF
Capacitor C_1	20µF
Capacitor C_2	20µF
Inductor L_f	1 mH
Output voltage V_O	40.7V
Output current I_O	1.66A
Output power P_O	67.562W
LED ratings	Forward Resistance=1.76Ω in series with DC voltage of 2.32 V.
PWM dimming frequency	50Hz

In this paper, one string of LEDs is formed with 14 series LEDs. The forward voltage of one string is 32.48V in series with a forward resistance of 24.7Ω. Five such strings are connected in parallel as load.

IV. RESULTS AND DISCUSSIONS

The proposed configuration is simulated using MATLAB. The output voltage and the output current waveforms for the 3-Φ inverter are as in Fig.4. The input voltage is 48V.

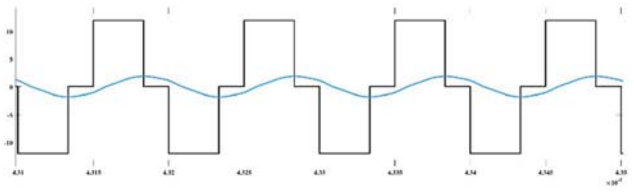
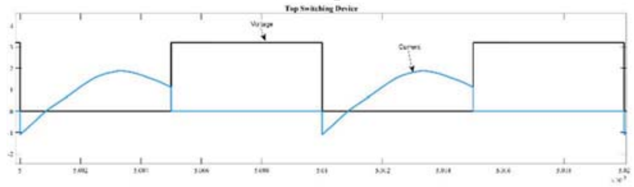


Fig.4. Inverter voltage and the current

As the switching frequency is above the resonant frequency, ZVS operation of the switching devices can be achieved. ZVS operation of the 3-Φ inverter can be observed from device voltage and current waveforms. Top and bottom switches of one leg are considered and the voltage and current are waveforms are shown in Fig.5.

(a) Top switch



(b) Bottom Switch

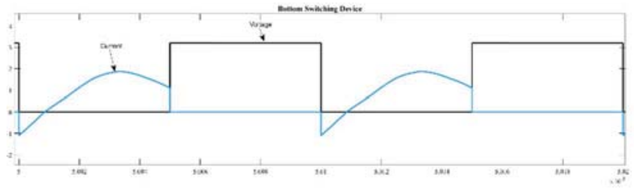


Fig. 5. Waveforms for ZVS operation

Fig.5 shows the turn-on and turn-off transitions of voltage and current of switches. The voltage shown is 15V/div and the current is 2A/div. As it is showing perfect ZVS, the high efficiency with low switching losses can be ensured from this circuit.

The voltage across C_1, C_2 are as shown in Fig.6.

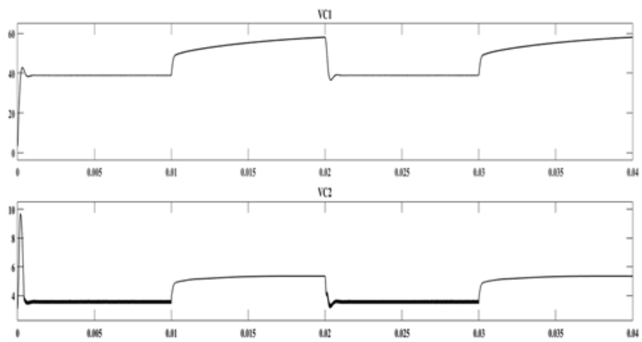


Fig.6. Voltages across the capacitor C_1,C_2

The voltage across C1 , C2 are 38.9V and 3.7V respectively during the dimming switch ON condition. During OFF condition, voltages are 58V and 5.2 V respectively. Accordingly the output voltage i.e the voltage across LED is 40.6V during ON and 32.48V during OFF condition as shown in Fig.7. The output current is 1.67A during ON and 0A during OFF condition. The output voltage and the output current are as shown in Fig.7.

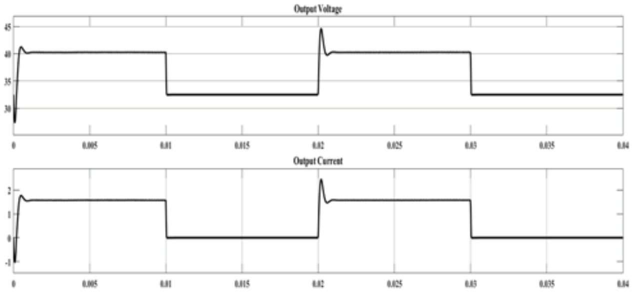


Fig.7. Output voltage and output current of LED

The voltage across LED(load) is 32.48V during OFF condition and 40.6V during ON condition. During OFF condition the voltage across the LED has to be equal to zero. But here the voltage across the LED is 32.48V due to forward drop of LEDs which is represented as a voltage source in the simulation.

The source current waveform as shown in Fig.8.

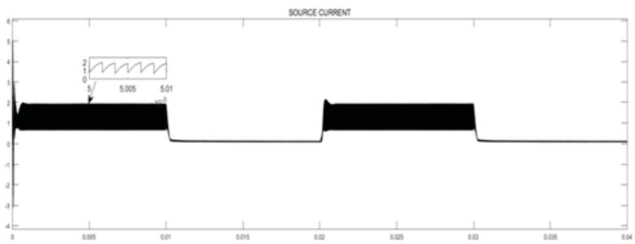


Fig.8. Source current waveform

As the voltage is changing from 32.48V to 40.6V during OFF-ON conditions respectively, the transient in the output voltage is more which may cause damage to the LED load. To reduce the transient behavior in the output voltage , another technique is proposed in this paper. This is done by switching ON all top switches at one time and bottom switches at one time. After implementing this technique, voltages across C_1 and C_2 are as shown in Fig.9.

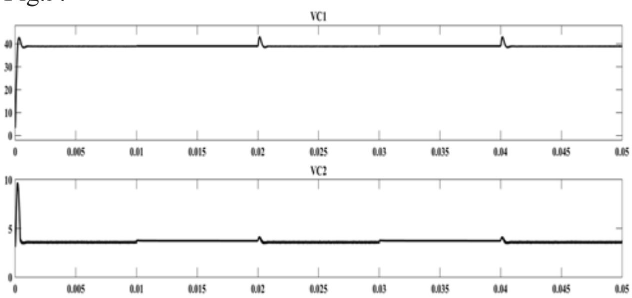


Fig.9. C_1,C_2 Voltages after modification of pulses

From Fig.9., it can be observed that the voltage is constant during ON-OFF conditions. The output current and voltages at LED are as shown in Fig.10.

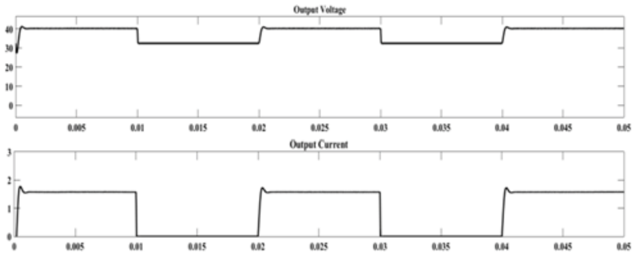


Fig.10. Output waveforms of LED

From Fig.10, it can be observed that during transient condition the variation in the output current and voltage are very low. This kind of output voltage is very much useful in case of LED driver circuits. The current waveform of the source current with 3-Φ inverter is as shown in Fig.11.

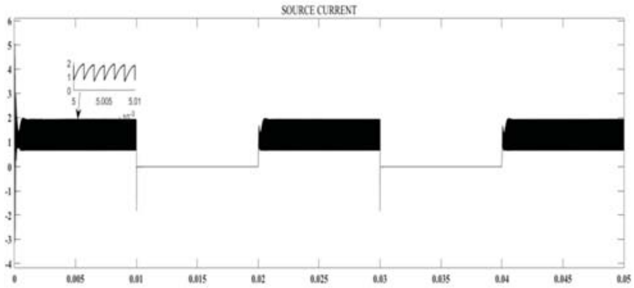


Fig.11. Source current with 3-phase circuit

In the source current waveform it can be observed that at the instant of switching OFF condition a current spike present. This is because of the circulating current that is present due to switching OFF of all the switches at a time. To compare the performance further in terms of the source current ripples, the circuit is compared by replacing the 3-phase inverter and converter with single phase inverter and converter. The source current waveform with the single phase circuit is as shown in Fig.12. The peak to peak ripple current with single phase operation is 4A whereas for three phase operation it is 1A.

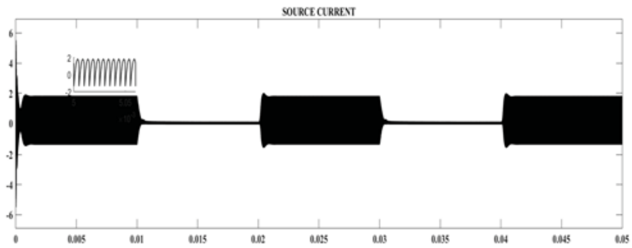
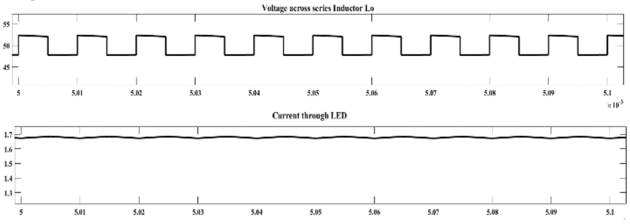


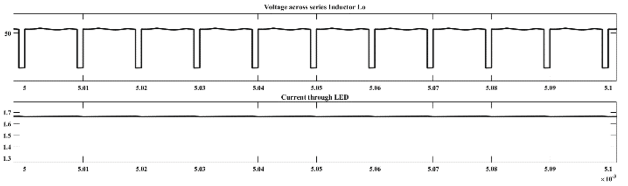
Fig.12. Source current with 1-phase circuit

Further, in this paper the LED driver is tested by varying the input DC voltage ±5% by maintaining the output voltage and output current as constant at 40.6V and 1.67A. When the DC input voltage is increased by 5%, the duty cycle of the switch S_7 is decreased so that the output current is retained at constant value. Similarly when the DC input voltage is decreased by 5%, the duty ratio of the switch S_7 is increased so as to keep the current through LED at constant value. This discussion is verified through the simulation and analyzed by taking all three different conditions and the results obtained are shown in Fig.13.

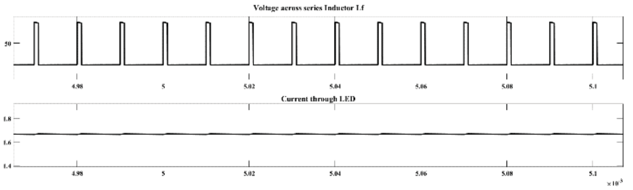
To show the variation of the duty ratio, the voltage across the series Inductor, L_f is considered and as shown in Fig.13



(a) Input voltage= 48V



(b) Input voltage= 48 - 5%V



(c) Input voltage= 48 + 5%

Fig.13. Variation of the voltage across L_f and LED current

From the above waveforms, it is found that with the variation of the DC input voltage the output current of the LED are maintained as constant by varying the duty cycle at switch S_7. It is also observed that with the variation in the duty cycle of S_7 there is no change in ZVS condition. Further, efficiency of the drive is estimated by varying the duty cycle of the dimming switch connected in series with the LED. The variation of the % duty cycle w.r.t % efficiency of the LED driver is as in Fig.14.

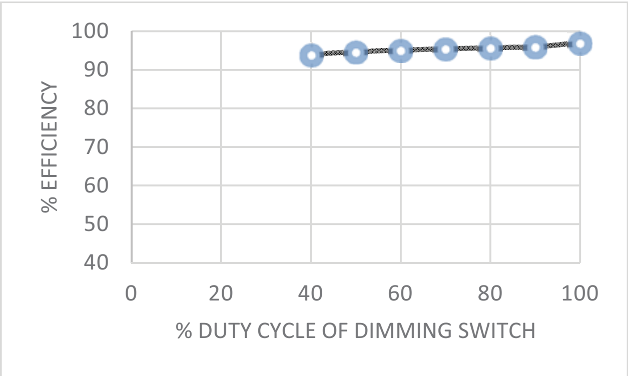


Fig.14. Variation of efficiency w.r.t illumination of LED

The efficiency at full illumination is 97.08%. The output power is controlled by an auxiliary converter handling small power and main converter ZVS situations are not effected. It offers high efficiency when compared with the 1-Φ inverter circuit. Since the ripple in the source current is reduced, the efficiency of the proposed system is increased. Hence this configuration can be used for solar power based street light applications.

V. CONCLUSIONS

The proposed configuration is an LED driver with an objective to handle relatively large power and also with reduced source current ripple. This type of configuration is helpful when powered from PV panels. The three phase series resonant inverter reduces the source current ripple compared to the same when powered from single phase series resonant inverter. The designed LED driver is meant for an output power of 67.5 W. The three phase inverter handles most of the power and an auxiliary converter regulates the load current for any supply voltage variations. This handles small power. Hence overall efficiency is mainly governed by the three phase inverter. The switching losses are reduced by using the Soft switching operation in this inverter. The source ripple current with proposed configuration is 1Ap-p and the same with single phase inverter is 4Ap-p. At half (50%) illumination of LED the efficiency is 94.16% and at full illumination of LED the efficiency is 97.08%.

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