Self-Oscillating Fly-back Converter for Mobile Batteries Charging Applications

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Abstract: *The self-oscillating flyback converter is a popular circuit for cost-sensitive applications due to its simplicity and low component count. This paper presents self-oscillating fly-back converter for mobile batteries charging applications. The converter is designed to step-down the high voltage input to an acceptable level from 220 VAC to 7VDC. By adding indictor and capacitor the power factor and input currant increased, and became 500mA, where the old input currant was 250mA, Diode was connected between Emitter and collector, so the output voltage was improved, and has less ripple, in addition to the soft switching was obtained, simulation model is developed by using MULTISIM software. The operation principle of this converter is described using some operating waveforms based on simulation results and a detailed circuit operation analysis. Analytical results are verified by laboratory experiment. With an input of 220 VAC, 500mA and an output of 7V DC, the efficiency of circuit was75%.*

Index Terms: *Mobile battery charger, DC-DC converter, fly back converter, self-oscillating fly-back converter*

I. Introduction

In recent years, contactless power supplies have been widely employed in the battery chargers of many handheld electronic products, because of convenience and reliability. The self-oscillating flyback converter is a cost-effective solution for power supplies. In order to reduce the volume of electronic products.

Self-oscillating converter is suitable for battery chargers, electronic ballasts, DC–DC converters, and other applications with similar demands, due to simplicity, reliability, low cost, and power-handing capability[1].

Self-oscillating converters become popular for cost-sensitive applications owing to their simplicity, low component count, reliability and low cost. Since the control circuit is implemented with very few discrete components, the overall cost of the circuit is lower than IC based solutions. use especially in battery-charger applications[2],[3].

The self-oscillating flyback converter is a robust, low component count circuit that has been widely used in low power off-line applications. It is also referred to as ringing choke converter (RCC) since the regenerative signal for oscillation comes from ringing of transformer choke. The merits of the RCC can be attributed to blocking oscillation, automatically limiting input power when the output is overloaded. Moreover, the oscillation may naturally cease if the output is short-circuited. Even though the flyback converter operating with pulse width modulation (PWM) also exhibits merits, when voltage-mode control is employed it presents the trouble of right-half-plane zero while its choke current is continuous [4],[5].

In this paper, a different approach is proposed for the self-oscillating DC-DC converter as shown in fig.3,It consist of Transistor Q, Capacitor C, Diode D, Transformer T, Resistance R.

There are three types of conduction mode, continuous conduction mode (CCM), discontinuous conduction mode (DCM) and boundary conduction mode (BCM)[6]. Self-oscillating flyback converter, shown in fig. 3, was made up using only discrete components. It operates at the boundary of continuous/discontinuous conduction mode (CCM/DCM) and uses peak current mode control. Therefore, the circuit operates with a variable switching frequency. The control circuit was developed with a single transistor Q. Using transistor(SA331) in flyback converters provides many advantages: an easier layout, fewer components needed for regulation and driving, and cost and volume reductions[7].

Battery charging is one of the important technologies for almost electronic equipment. Power flows through the battery charger to the lithium-ion (Li-Ion) batteries. A good battery charger can extend the battery life but a poor one may do harm to both of the power grid and batteries. Moreover, the charging time and lifetime of the rechargeable battery depend strongly on the properties of the charger circuit[8]. A very basic battery charger may be formed by transformer, diode rectifiers and variac. For the very good battery charger

with high stability, high efficiency and low harmonic, more complex techniques need to be applied such as power factor correction, pulse width modulation, varies of feedback control, etc [9].

The ideal charging source for Li-Ion is a constant-current, constant-voltage, or (CC-CV). A constant current is applied to the cell until the cell voltage reaches the final battery voltage (4.2V ±50mV) for most Li-Ion cells, but a few manufacturers' cells reach full charge at 4.1V. At this point, the charger switches from constant-current to constant-voltage, and the charge current gradually drops. The gradual drop in charge current is due to the internal cell resistance. Charge is terminated when the current falls below a specified minimum value, I_{min}. It should be noted that approximately 65% of the total charge is delivered to the battery during the constant current mode, and the final 35% during the constant voltage mode. Secondary charge termination is usually handled with a timer or if the cell temperature exceeds a maximum value, TCO (absolute temperature cutoff). It should be emphasized that Li-Ion batteries are extremely sensitive to overcharge! Even slight overcharging can result in a dangerous explosion or severely decrease battery life. For this reason, it is critical that the final charge voltage be controlled to within about ±50mV of the nominal 4.2V value[11], [12]. Fig. 1 shows the charging characteristics for lithium battery.
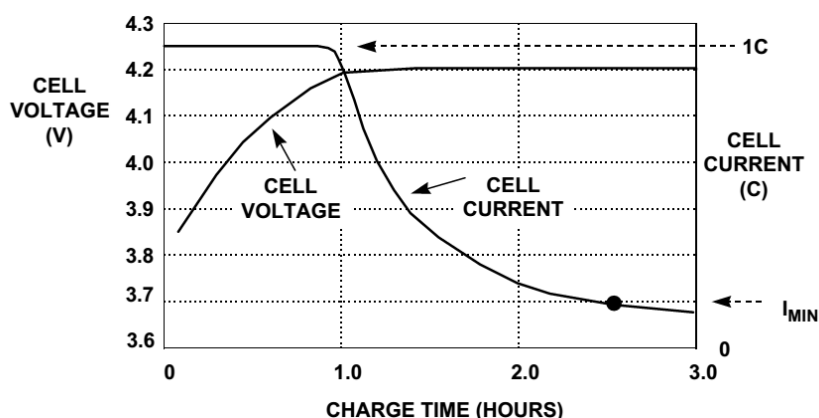

Fig. 1 Charging characteristics for lithium battery[13]

Each battery cell has its own composition and therefore charging curve/characteristics. The battery charger should be knowledgeable enough to comply with such battery specific requirements. Another challenging aspect in the design of a battery charger is to automatically handle large variety of batteries with different configuration and capacity. Battery charging is the most substantial issue in battery management systems. Basically A charger performs three functions: 1) delivering charge to the battery; 2) optimizing the charge rate; and 3) terminating the charge. The charge can be delivered to the battery through different charging schemes, depending on the battery chemistry[14],[15].So This paper presents self-oscillating fly-back converter for mobile batteries charging applications.

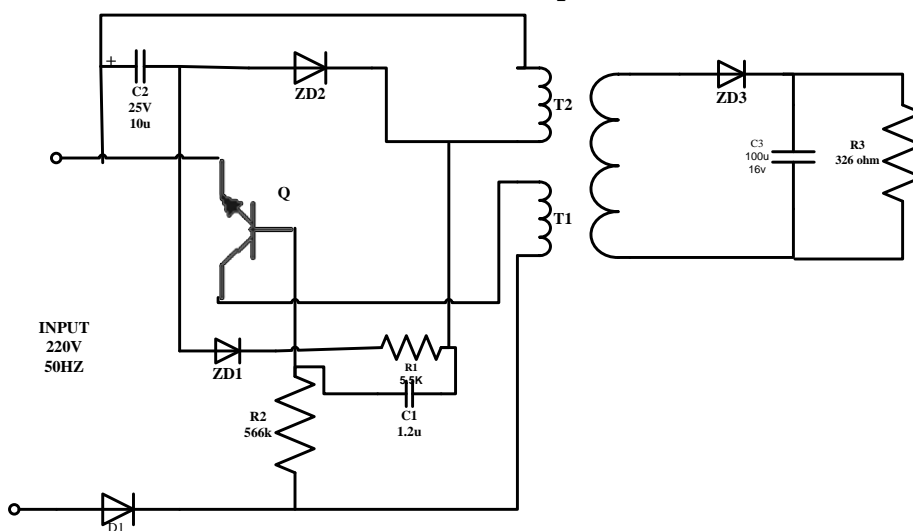## II.   Circuit Description

Fig. 2 Self-Oscillating Flyback Converter for mobile battery-charging

A self-oscillating flyback converter for mobile battery- charging is proposed in Fig. 2. When the input 220V, 50HZ, at emitter terminal of transistor and D_1. C_2 begin to charge. Currant in one direction pass by ZD_1. In this case R_1 create enough voltage to make Q switch on. One output signal control in the diode output ZD_2 and it control in the transformer input. When a part of negative currant pass by diode D_1 through resistance R_2, C_1. R_2 makes volte in base of Q. Q behaves as switch and oscillator. This control in transistor input instead of AC 220V and frequency 50HZ, the input is in pulses in one direction and has less amplitude. The transformer input is pulses has a max value less than the max 220V and frequency less 50 HZ. The transformer output became in one direction, one diode is enough for DC completed circuit signal.

The capacitor C_3 is used for smoothing and R_3 for recharge C_3 and limit of the increase in voltage.

2.1 Theory of operation

The operation intervals divided into two intervals. Each of these circuit intervals have been referred here as modes of circuit operation. The complete operation of the power supply circuit is explained with the help of functionally equivalent circuits in these different intervals.

Interval 1

In Fig, 3-A, when the switch is opened the current flow in capacitor c_2 and the charging start. when switch 'S' is on, the primary winding of the transformer gets connected to the input supply with its dotted end connected to the positive side. At this time the diode 'D' connected in series with the secondary winding gets reverse biased due to the induced voltage in the secondary (dotted end potential being higher). Thus with the turning on of switch 'S', primary winding is able to carry current but current in the secondary winding is blocked due to the reverse biased diode. The flux established in the transformer core and linking the windings is entirely due to the primary winding current. This mode of circuit has been described here as Mode-1 of circuit operation. Fig. 3(a) shows (in bold line) the current carrying part of the circuit and shows the circuit that is functionally equivalent to the fly-back circuit during mode-1. In the equivalent circuit shown, the conducting switch or diode is taken as a shorted switch and the device that is not conducting is taken as an open switch. This representation of switch is in line with our assumption where the switches and diodes are assumed to have ideal nature, having zero voltage drop during conduction and zero leakage current during off state.
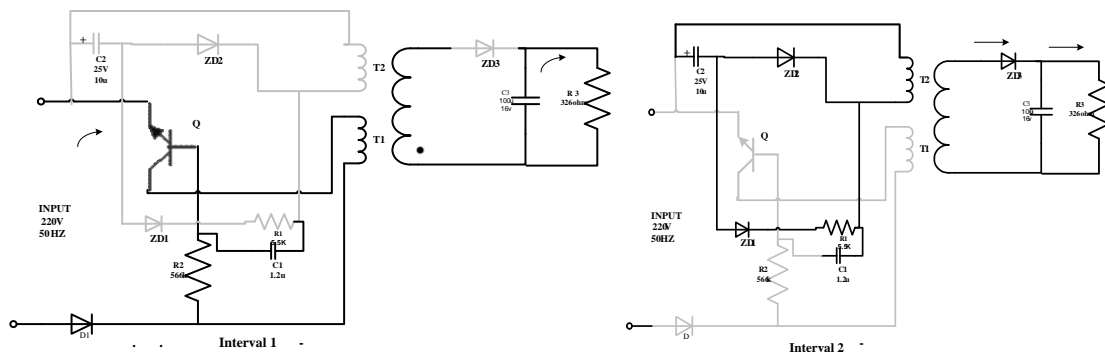

Fig. 3 Equivalent circuit Self-oscillating flyback DC-DC converter

Interval 2

In fig, 4-B, when the switch is closed the current flow in diode D_1 and the resistor R_2 control the charging and discharging of the capacitor C_1 thus to control transistor Q operation. Mode-2 of circuit operation starts when switch 'S' is turned off after conducting for some time. The primary winding current path is broken and according to laws of magnetic induction, the voltage polarities across the windings reverse. Reversal of voltage polarities makes the diode in the secondary circuit forward biased. Fig. 3(b) shows the current path (in bold line) during mode-2 of circuit operation while and shows the functional equivalent of the circuit during this mode. In mode-2, though primary winding current is interrupted due to turning off of the switch 'S', the secondary winding immediately starts conducting such that the net mmf produced by the windings do not change abruptly. (MMF is magneto motive force that is responsible for flux production in the core. MMF, in this case, is the algebraic sum of the ampere-turns of the two windings. Current entering the dotted ends of the windings may be assumed to produce positive MMF and accordingly current entering the opposite end will produce negative MMF) Continuity of MMF, in magnitude and direction, is automatically ensured as sudden change in MMF is not supported by a practical circuit for reasons briefly given below.

2.2 Transformer Design

In the structure of Transformer flyback converter, as shown in Fig. 4, the primary and secondary windings are wound in respective magnetic cores. Therefore, the electric energy is transferred from the primary side to the secondary side with the magnetic coupling, which avoids the occurrences of the spark and electric shock[16].
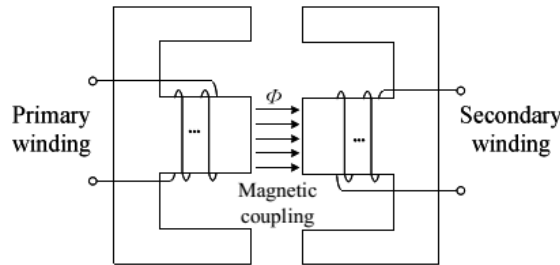

Fig. 4 structure of Transformer flyback converter[16]

structure of Transformer flyback converter, Primary Turns, Feedback, Secondary turns, Primary current, peak current, actual collector current shown in Eq. 5, Eq. 6, Eq7, Eq. 8, Eq. 9 and Eq. 10.

a) Primary Turns

$$N_P = \frac{V_{cc} t}{\Delta B \cdot A} \qquad (5)$$

Where: A Core area, V_{cc} Supply Voltage, Flux density swing Δ B

b) Feedback

$$N_{fb} = \frac{N_p V_{fb}}{V_{cc}} \qquad (6)$$

Where : V_{fb} feedback voltage

c) Secondary turns

The secondary voltage should be7.6 V because we want the output voltage to be 7 V and there is a 0.6 V diode loss.

$$N_S = \frac{N_p V_s}{V_{cc}} \qquad (7)$$

d) Primary current

$$I_{in} = \frac{W}{V_{cc}} \qquad (8)$$

Where : w input power

e) The peak current can be calculated as

$$I_{peak} = 4 \times I_{in} \qquad (9)$$

f) actual collector current

The actual collector current must exceed this calculated mean current by at least 50% to make sure that the diode D_1 remains in conduction during the complete fly-back period

$$I_P = 1.5 \times I_{peak} \qquad (10)$$

III.   Simulation Model of Self-Oscillating Flyback Converter

Fig.5 shows simulation of the circuit using MULTISIM software, Fig.6 shows the voltage waveforms, The circuit parameters are given in Table 1.
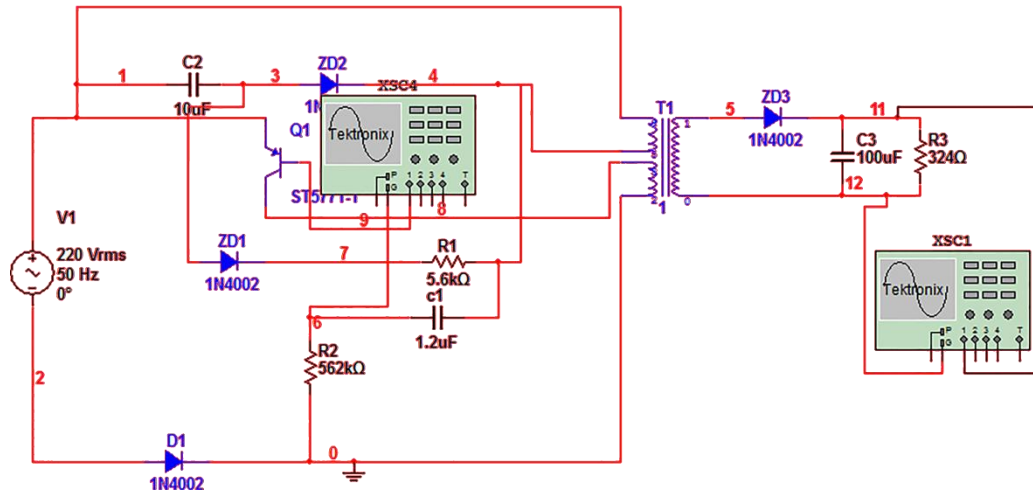
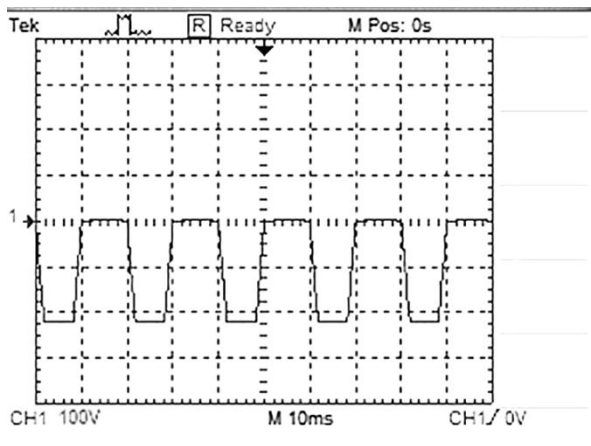**Fig.5.** Simulation model of self-oscillating flyback converter

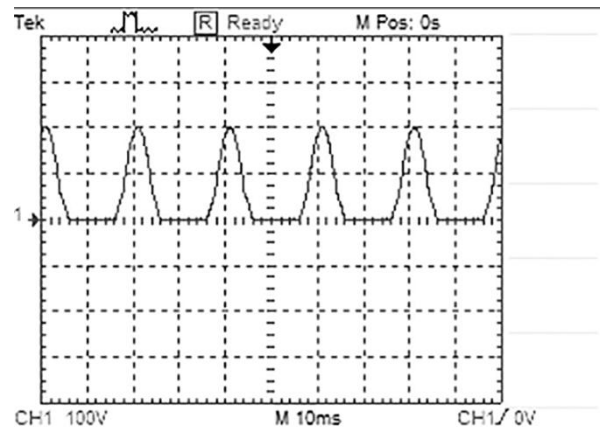**Fig.(6-a).** Voltage at the primary edge of the transformer

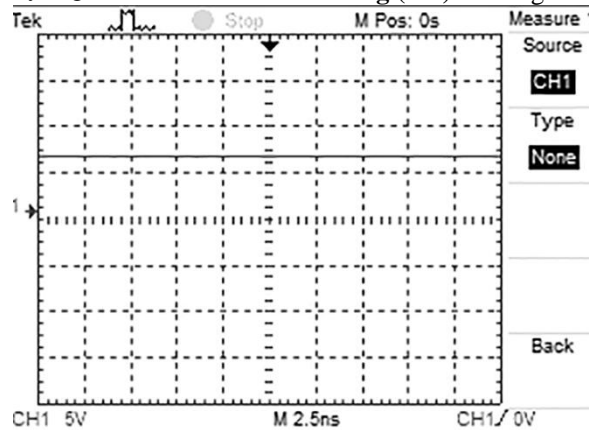**Fig.(6-b).** Voltage at the edge of the transistor base

Fig. (6-c) Output voltage of self-oscillating fly-back converter

Table1.   Circuit Parameters

Name	Quantity
1.2μF Capacitor	1
10μF Capacitor	1
100μF Capacitor	1
1N4007 Diode	4
2 pin Terminal Block	1
SA331,NPN Transistor	1
3.1 (W) x 3.1 (H) in Printed Circuit Board	1
326 Resistor	1
5.5K Resistor	1
566K Resistor	1

IV.   Experimental Setup

Table 2 shows experimental results of self-oscillating fly-back converter circuit , Fig. 7 shows The board layout for the proposed for self-oscillating flyback converter for mobile battery-charging, the experimental setup of self-oscillating flyback converter is shown in Fig. 8.

Table 2 Experimental results of self-oscillating fly-back converter circuit

Parameters	Values
AC input voltage	220V
DC output voltage	7V
Switching frequency	50Hz
Input current	500mA
Input power	55W
Transistor model	SA331
Power factor	0.5

−   layout for the proposed for self-oscillating flyback converter for mobile battery-charging
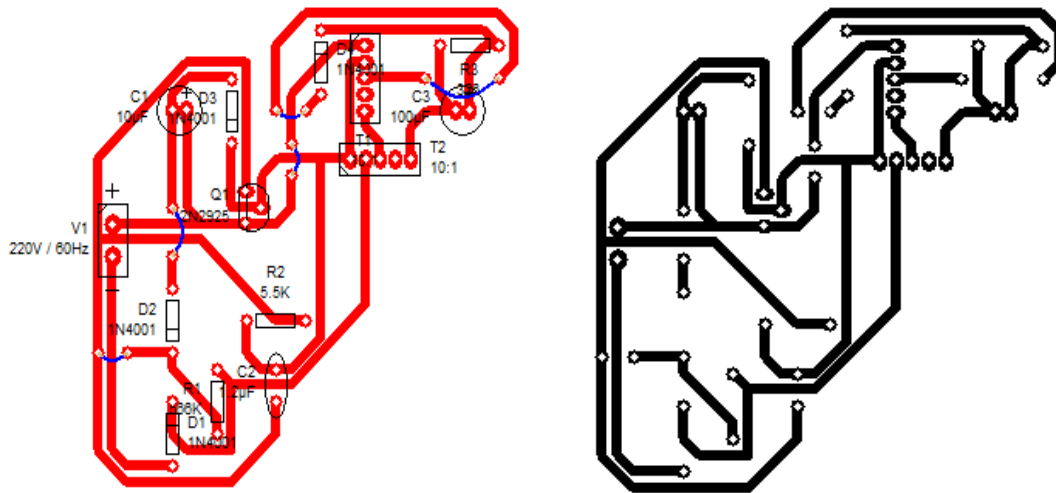

Fig. 7 The PCB layout for Self-Oscillating Flyback Converter for mobile battery-charging

Fig. 8 experimental setup for self-oscillating flyback converter for mobile battery-charging

Fig. 9 Shows Voltage at the primary edge of the transformer. Fig. 10 illustrates gate pulses patterns. Fig. 11. Shows input current waveforms, and Fig. 12 illustrates output voltage of fly-back converter.
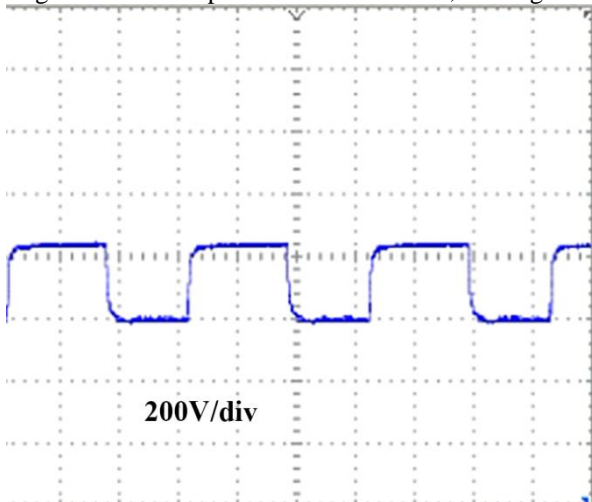

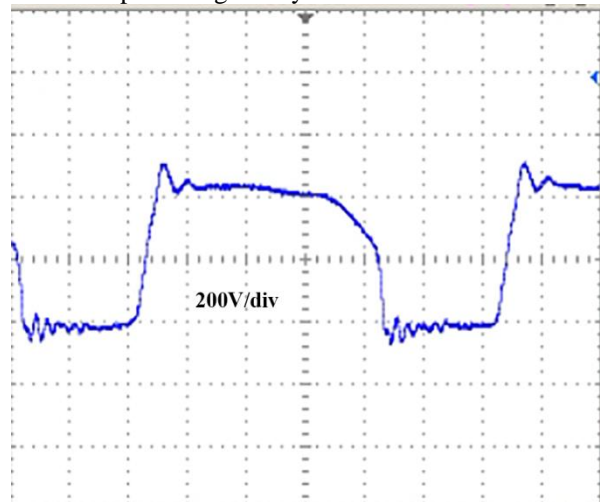**Fig. 9.** Voltage at the primary edge of the transformer
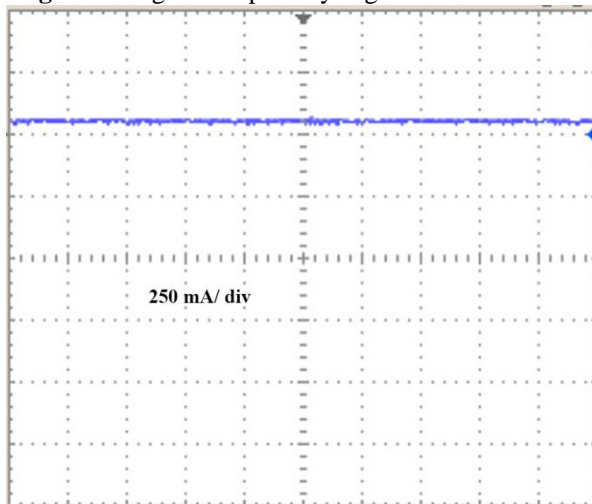

Fig. 10. Gate pulses patterns

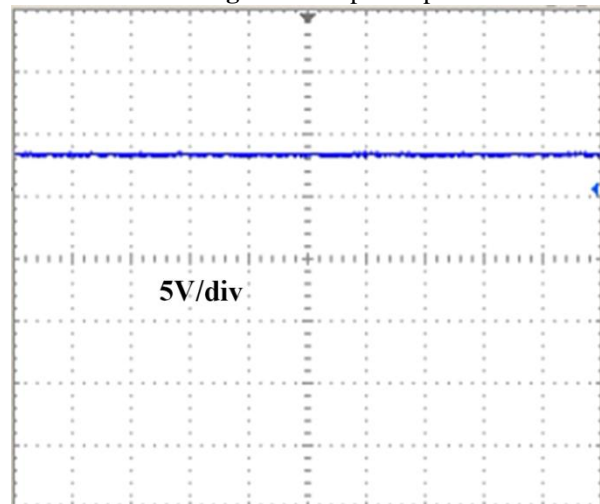**Fig. 11.** Input currant waveforms

Fig. 12. Output voltage of fly-back converter

4.1 Efficiency, Power Losses and Power factor for fly back converter circuit

Transformer losses can be divided into: core hysteresis losses, and winding losses. Transformer loss is sometimes limited directly by the need to achieve the required overall power supply efficiency[17].

The power losses of the winding are shown as follows in Eq(11)

$$p_w = I_1^2 r_1 + I_2^2 r_2 \qquad (11)$$

The power loss of the core is indicated as follows in Eq. (12).

$$p_c = K_1 F^{K2} B^{K3} \qquad (12)$$

Where, P_C: core loss, $K_1=0.32$, $K_2=1.61$, $K_3=2.68$, B=0.17T, F=50
Total power losses are shown as follows in Eq. (13).

$$p_{loss} = p_w + p_c \qquad (13)$$

Where: Pw= power losses the winding, Pc= power losses of the core
The efficiency is indicated as follows in Eq. (14) [18]

$$\eta = \frac{p_o}{p_i} = \frac{p_i - p_{loss}}{p_i} = \frac{p_o}{p_o + p_{loss}} \qquad (14)$$

Where: Po = Power Out (watts), Pi = Power input(watts), Ploss power losses (watts)
The Power factor is indicated as follows in Eq(15)

$$p_i = V_1 I_1 \cos\theta \qquad (15)$$

Where $\cos\theta = \dfrac{p_i}{V_1 I_1} = \dfrac{V_1 I_1^{\,2}}{V_1 I_1} = \dfrac{220 \times (0.5)^2}{220 \times 0.5} = 0.5$

Thus

$P_i = 220 \times 0.5 \times 0.5 = 55W$

$p_c = K_1 F^{K2} B^{K3} = 0.32 \times (50)^{1.61} \times (0.17)^{2.68} = 1.5W$

$p_{loss} = p_w + p_c = 12.37 + 1.5 = 13.87W$

$p_w = I_1^{\,2} r_1 + I_2^{\,2} r_2 = (0.5)^2 \times 0.1 + (15.7)^2 \times 0.05 = 12.37W$

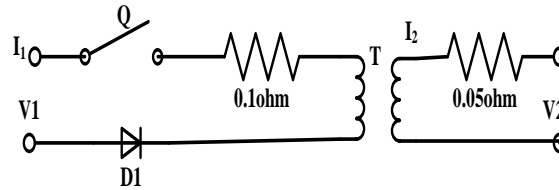where I_1, I_2, r_1, r_2, given in Fig. 13.

Fig. 13 Equivalent circuit for the transformer

Thus

$\eta = \dfrac{p_i - p_{loss}}{p_i} = \dfrac{(V_1 I_1 \cos\theta) - p_{loss}}{(V_1 I_1 \cos\theta)} = \dfrac{55 - 13.87}{55} = 0.7478 \times 100 = 74.78 \approx 75\%$

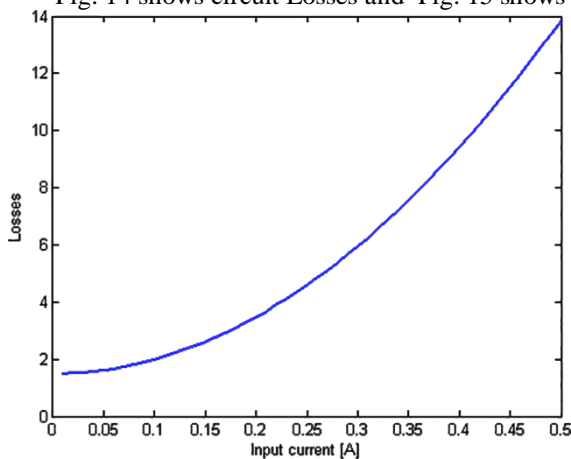Fig. 14 shows circuit Losses and Fig. 15 shows circuit Efficiency

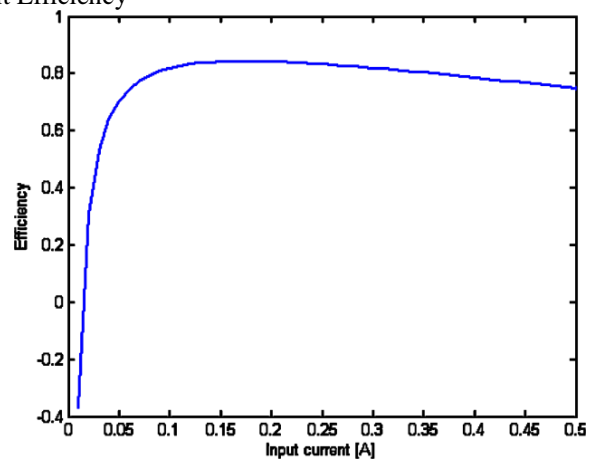**Fig. 14.** Circite power losses of fly-back converter

Fig. 15 Circite Efficincy of fly-back converter

4.2 Circuit Improvement

In Fig. 16, the circuit is improved by adding series inductor and parallel capacitor. This improves power factor and the input current increases from 250 mA to 500 mA. Also, diode D is added between emitter and collector of the transistor to enhance the output voltage.
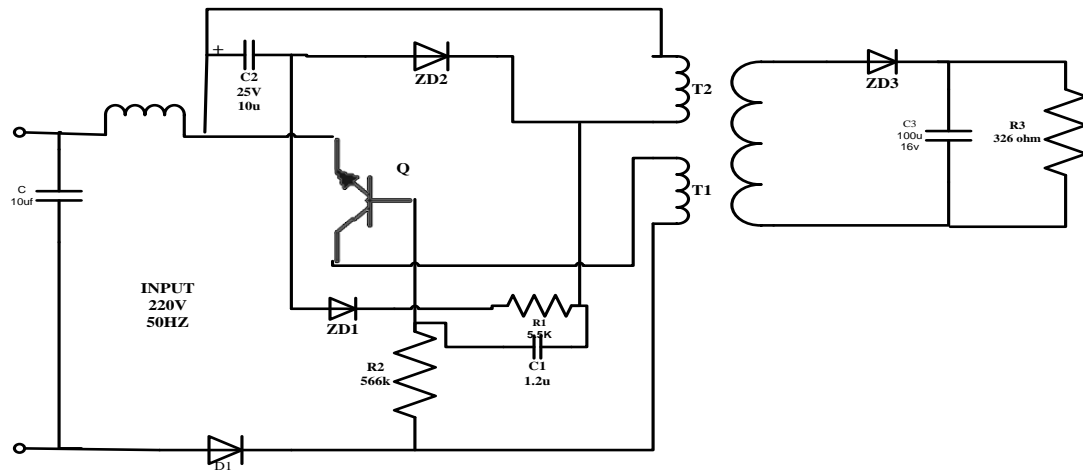
Fig. 16. Improving circuit for Self-Oscillating Flyback Converter for mobile battery-charging

V.   Conclusion:

In this paper self-oscillating fly-back converter has been proposed, this topology can achieve good performance because it has fewer components rather than conventional PWM ones. Also, it improves reliability and power-handing capability. It requires simple control solution and small filter. Analytical results are verified by laboratory experiment with an input of 220 VAC/500mA and an output of 7VDC. It is suitable for AC-DC converters for battery chargers. A simple converter charger is presented for regulation of the output voltage of the DC to DC flyback converters with constant frequency. A simple and efficient approach for controlling the output voltage of the isolated flyback converter is presented using sef-oscillated topology.

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