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Design of a Cell Charger for an iPad Using Full Bridge Rectifier and Flyback Converter

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***Abstract* - The aim of this paper is to design a 10W cell charger for an iPad" with restricted specifications. For this design, the most viable and appropriate configuration of the components to fulfill the given requirements is presented. First, parameters are calculated with hand calculation and then for analysis of the performance of the design circuit, results from Pspice are visualized. The performance analysis which covers the non-ideal effects on related waveforms of output voltage, current and power are discussed in details.**

***Index Terms* - Charger, Bridge, Flyback, Ripple, Harmonic**

I. INTRODUCTION

Nowadays, rechargeable battery has been broadly usable in various types of electronic devices, such as electrical vehicle, uninterrupted power supply, and portable devices. Therefore, battery charger plays a vital role in recharging batteries professionally and extending the battery life [1].

For developed countries, Power grids use AC power, whereas cell phones are charged using DC power . Therefore, AC-DC converters are required. The chargers rectify the AC signal and convert the signal to DC for the phone battery at the specified power rating [2].

Rectifier is a device that converts AC (Alternating Current) to DC (Direct Current). Rectifier can be classified into two groups i.e. Half Wave and Full Wave and also each of two groups can be divided into two types of Controlled Rectifier and Uncontrolled [3].

The use of rectifiers are easily noticeable when the distribution systems are connected with nonlinear loads and the consequence of nonlinear loads leads to harmonics which are generated in the network systems. For definition purpose, harmonics are any "Non-Linear" Current or Voltage in an electrical distribution system which are commonly produced by devices that rectifies AC Voltage into a DC Voltage. Harmonic frequencies in the power grid are a frequent cause of power quality problems". It is intrusive in this paper that harmonic components should be limited in use as much as permissible [4].

Isolated converter is required in the design of a cell phone charger. Fly-back converter is the simplest type of isolated DC-DC converters topology because there is no inductor at the output filter, only one semiconductor switch and only one magnetic component transformer or coupled inductor. Also, fly-back converters have Low cost because of less component requirement, Blocking voltage not occurred on the output diode, and transient response is fast because of output inductor absence . Therefore, Fly-back converter is chosen for this study [5].

II. METHODOLOGY

Firstly the calculations have been done manually for the parameters. Then, the formulated values have been simulated using Pspice and the results are visualized to obtain the best possible outputs.

Design Specification

The design of a 10W power adapter for the iPad has following specifications:

a) Input Supply: Single-phase 240Vrms at 50Hz.

b) Output voltage: 5.1 VDC, 5% (+ 2%) voltage ripple factor

c) Output current: 2.1A

d) The design Complies to IEC 61000-3-2 Standard: Electromagnetic Compatibility (EMC) limits for harmonic current emissions (equipment input current ⩽ 16 A per phase).

Design Calculations and Considerations

$$V_o = V_s \times \left(\frac{D}{1-D}\right) \times \left(\frac{N_2}{N_1}\right)$$

Where,

D is the duty cycle.

N_1 and N_2 are the numbers of turns used in each of the two windings.

$V_{s(peak)} = V_{s(rms)} \times \sqrt{2} = 240 \times \sqrt{2} = 339.411\ V$

Assuming: $\frac{N_2}{N_1} = \frac{1}{12}$

Then D=0.153
Let L_1=L_{min}=500 µH

Since $\frac{N_2}{N_1} = \sqrt{\frac{L_1}{L_2}}$

Then: L_2= 3.47 µH
The value for R_3 is calculated according to the following equation:

$$R_3 = \frac{V_O}{I_O} = \frac{5.1}{2.1} = 2.6\ \Omega$$

For S_{break} : V_1=0 V, V_2=5V, TD =0 , TR =1ns, TF =1ns,
Where,
V_1 is the initial value of the signal
V_2 is the pulsed value of the signal
TD is the delay time
TR is the rise time
TF is the fall time
PW is the pulse width
PER is the period
For the simulation, the switching frequency is approximately 50 kHz

$$PER = \frac{1}{f_s} = \frac{1}{50 \times 1000} = 20\ \mu\ sec$$

$$PW = \frac{D}{f_s} = \frac{0.153}{50 \times 1000} = 3.06\ \mu\ sec$$

The value of capacitor filter is calculated as follows

$$\frac{\Delta V_O}{V_O} = \frac{D}{R_3 \times f_s \times C} \rightarrow 0.05 = \frac{0.153}{2.6 \times 50 \times 1000 \times C}$$

Then, C=23.5µf

Circuit Diagram of The Buck Converter
The circuit diagram of proposed design is shown in figure 1 with all parameterized variables discussed above.

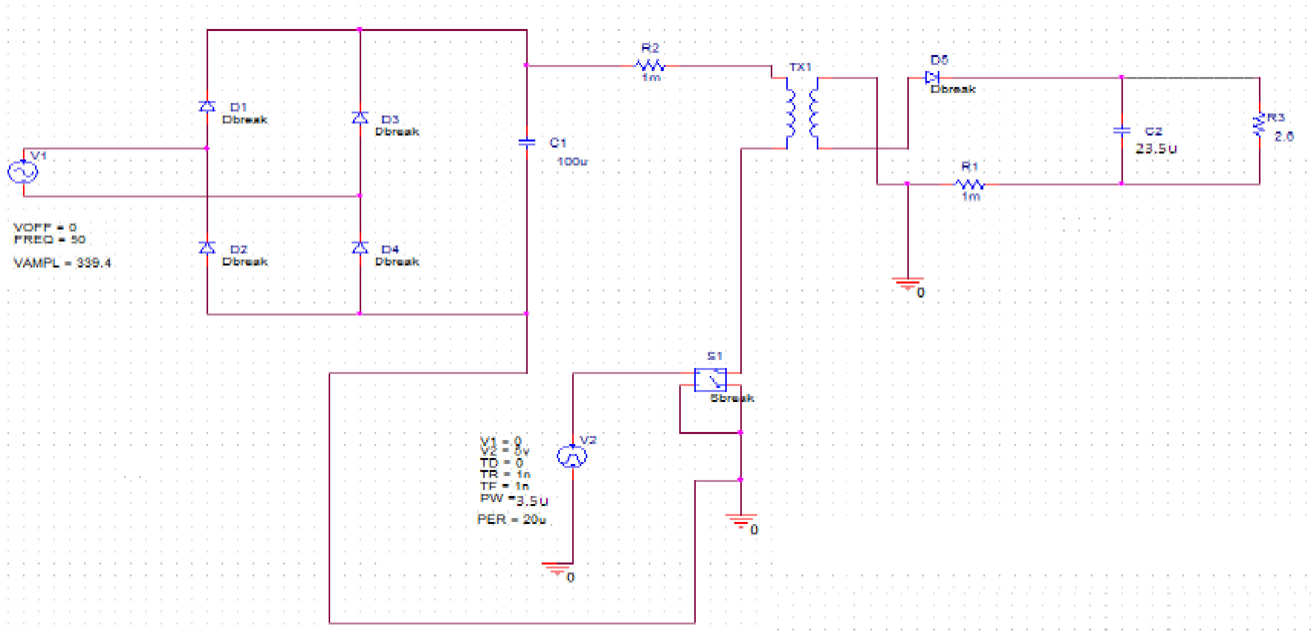

Figure 1: Simulated circuit of iPad cell charger

III. SIMULATION RESULTS AND DISCUSSION

As shown in Figure 2, the input voltage has the amplitude of 337.824V. The output voltage of rectifier, which is dc, has also been showed.

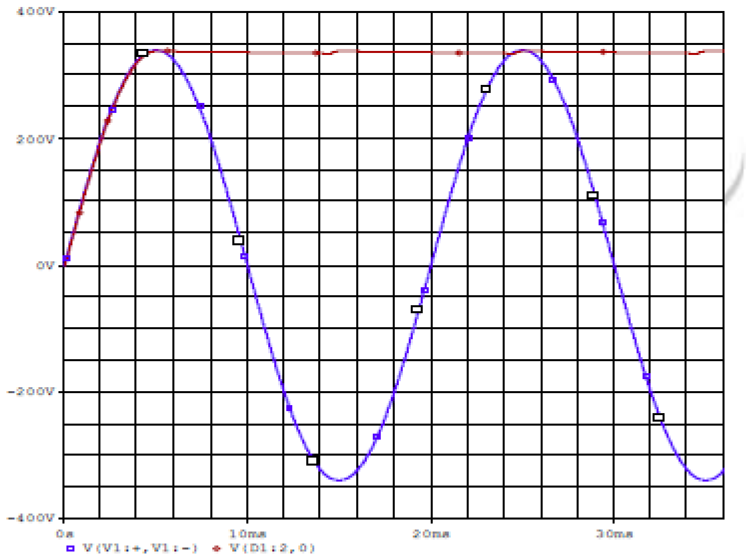

Figure 2: Input Voltage (blue) and Output Voltage (red) of Rectifier (C_1)

Figure 3 shows the input current of the circuit. It is seen that its value is nearly 10.60 A which is less than 16 A according to IEC 61000-3-2 Standard.

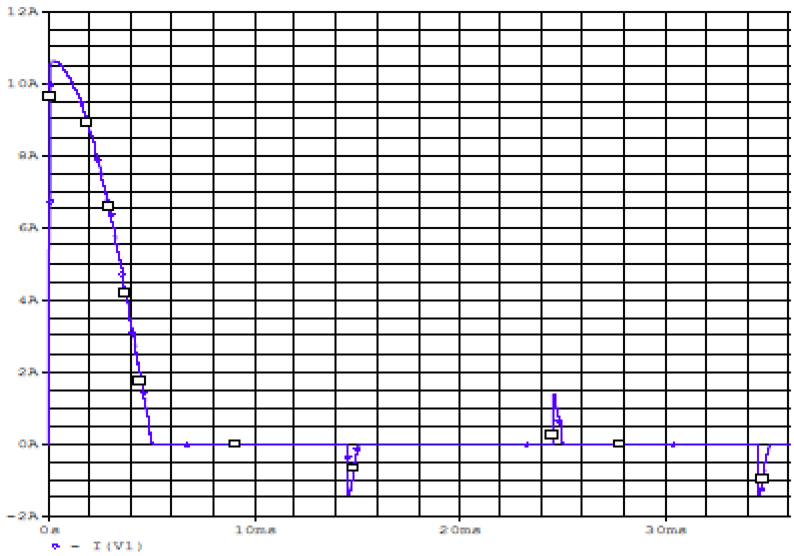

Figure 3: Input Current of the Circuit

Figure 4 illustrates the Fourier series of the input current. We have brought into use the Fourier series analysis concept to match the input current of harmonics. Figures 5, 6, 7 and 8 are showing the amplitudes of harmonics for fundamental, third, fifth and seventh harmonics respectively. By considering the figures the corresponding harmonic amplitudes for fundamental, third, fifth and seventh are 679.069 mA, 270.975 mA, 178.883 mA and 74.787 mA respectively. By comparing these values with table 1 which shows the maximum permissible harmonic current for class A equipment, it is clear that the results obtained comply IEC 61000- 3-2 Standard.

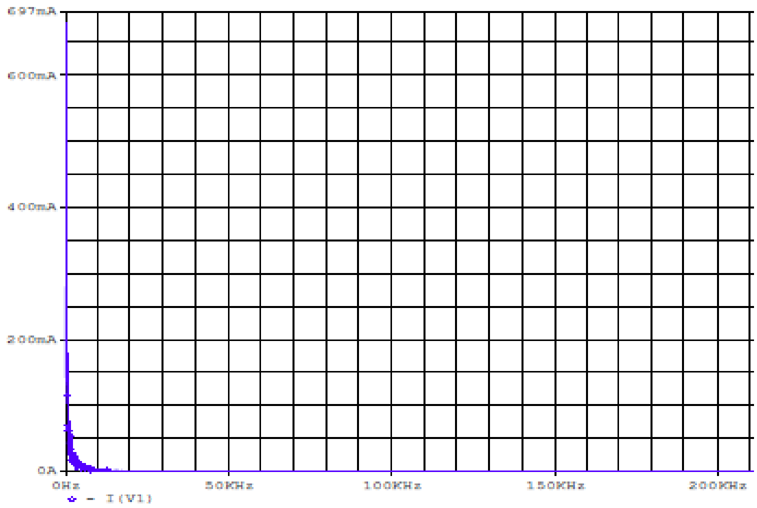

Figure 4: Fourier Series of the Input Current (mA)

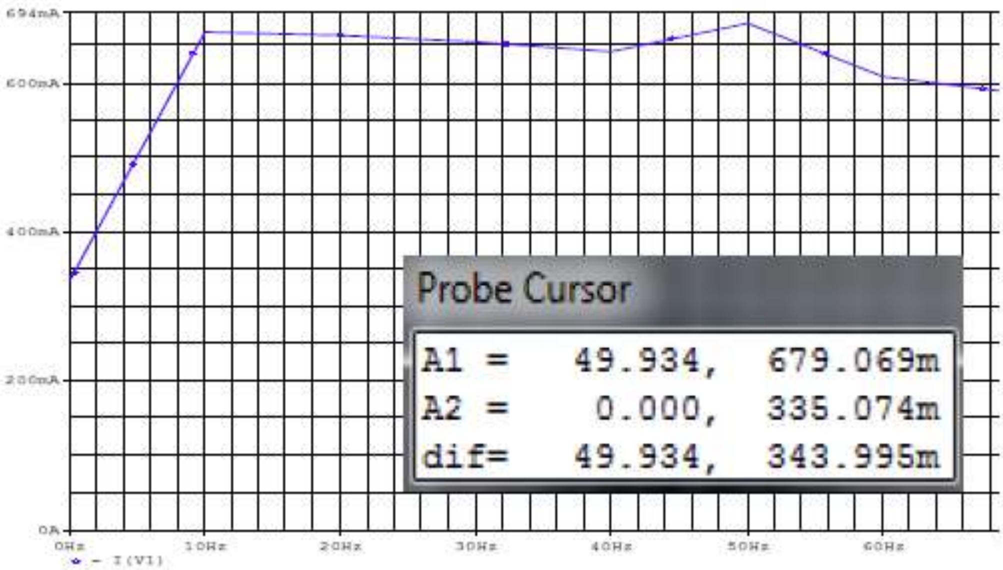

Figure 5: Fundamental Current (mA)

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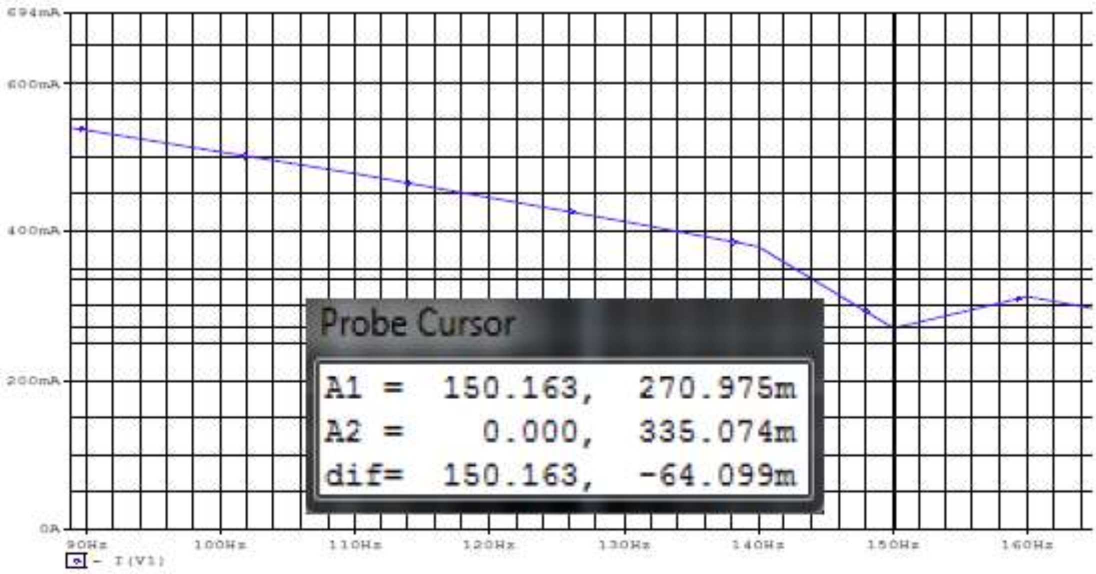

Figure 6: Third Current Harmonic (mA)

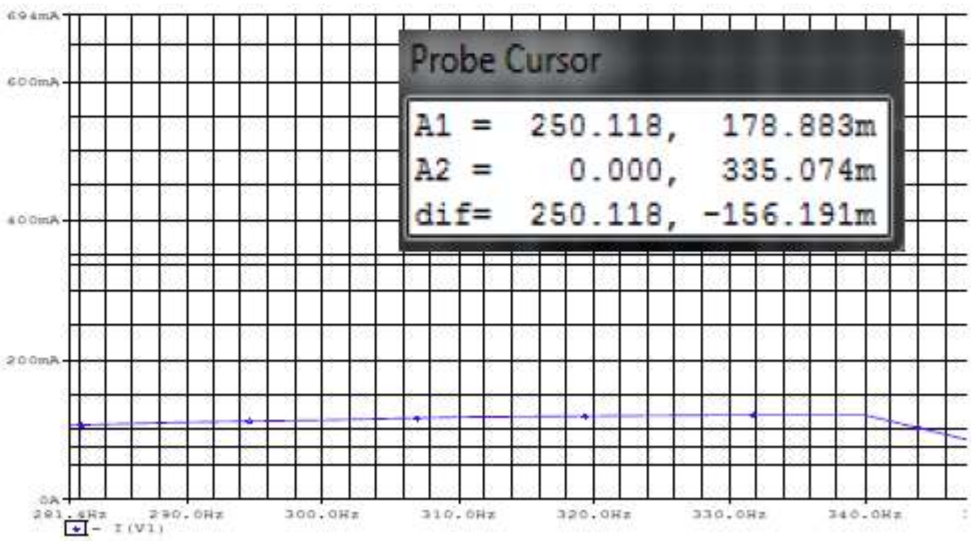

Figure 7: Fifth Current Harmonic (mA)

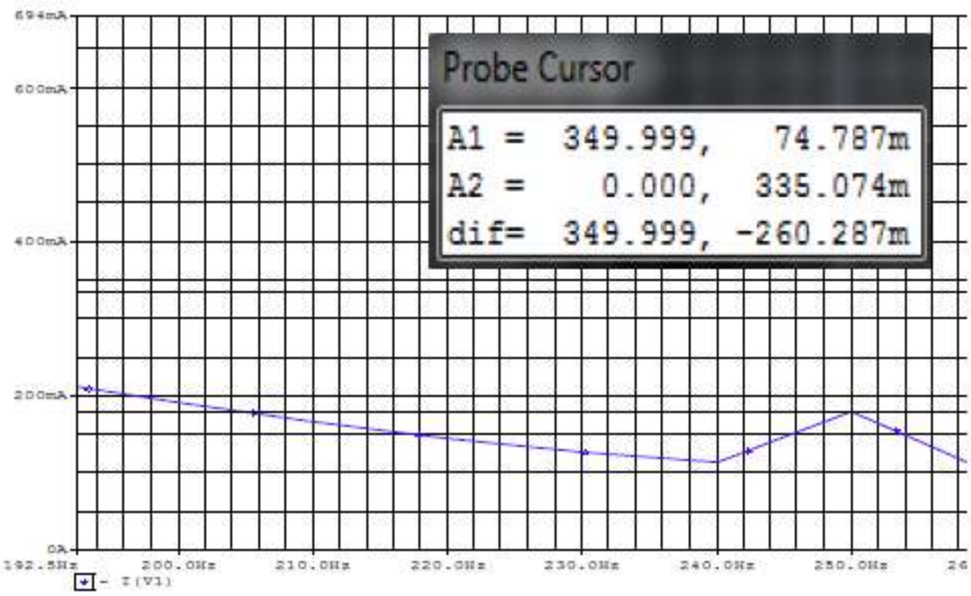

Figure 8: Seventh Current Harmonic (mA)

Harmonic order n	Maximum permissible harmonic current A
Odd harmonics	
3	2,30
5	1,14
7	0,77
9	0,40
11	0,33
13	0,21
$15 \le n \le 39$	$0{,}15\ \frac{15}{n}$
Even harmonics	
2	1,08
4	0,43
6	0,30
$8 \le n \le 40$	$0{,}23\ \frac{8}{n}$

Table 1: Limits for Class A Equipment

But one considerable issue is that the output voltage is $_o = 10.2\ V$. This value is more than required value for output of the circuit. the output voltage waveform is shown in figure 9.

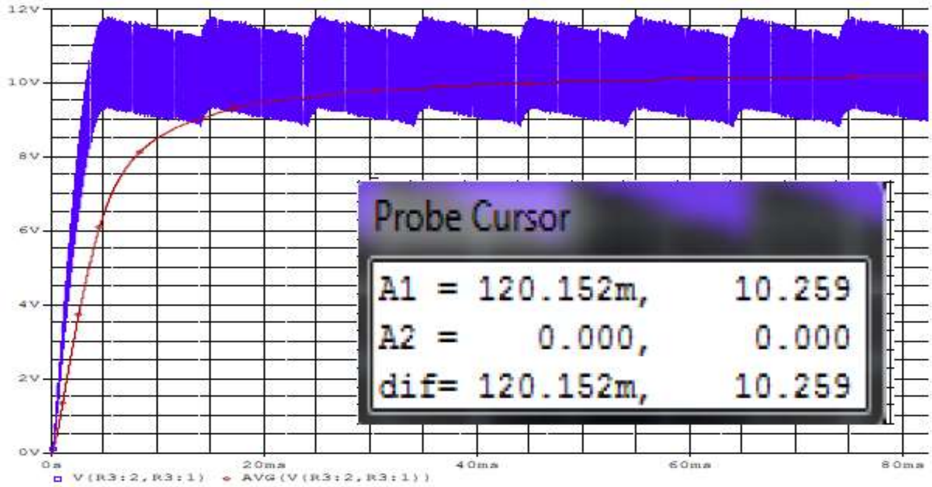

Figure 9: Output Voltage

So for obtaining the $V_o = 5.1V$, $W_2 = PW/2 = 1.55\mu s$, $D = 0.0775$, $c = 11.3\mu f$. Figures 10, 11 and 12 show voltage, current and power output waveforms respectively after using the new values for PW, D and C. Figure 10 shows that the output voltage of the adapter is 5.0662 V

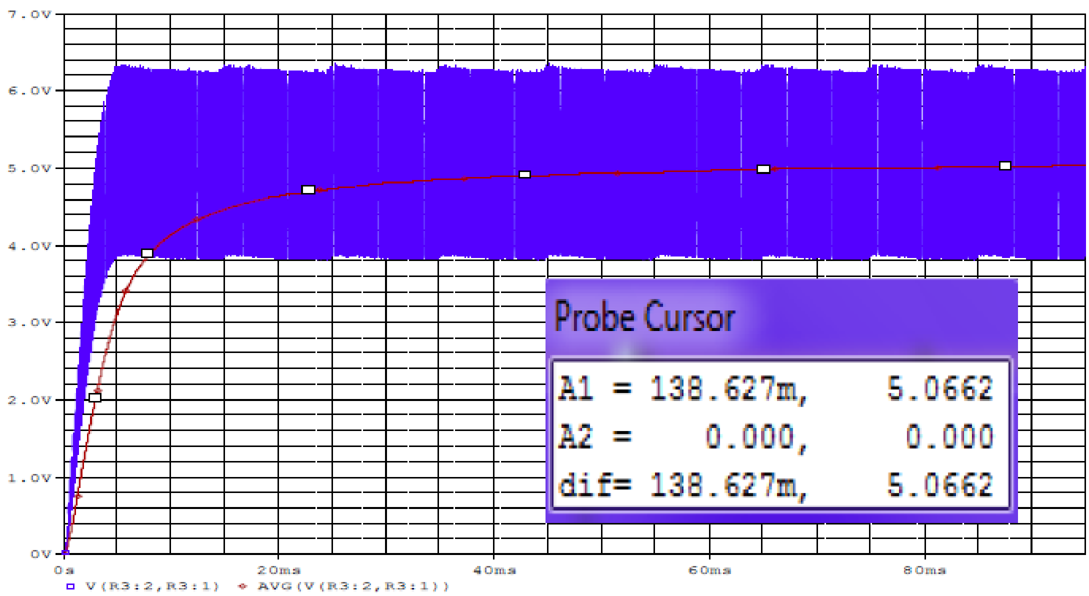

Figure 10: Output Voltage after using the new values for PW, D and C.

Figure 11 illustrates that the output current of the circuit is 1.95 A. The output value for power is 10.19 W as shown in figure12.

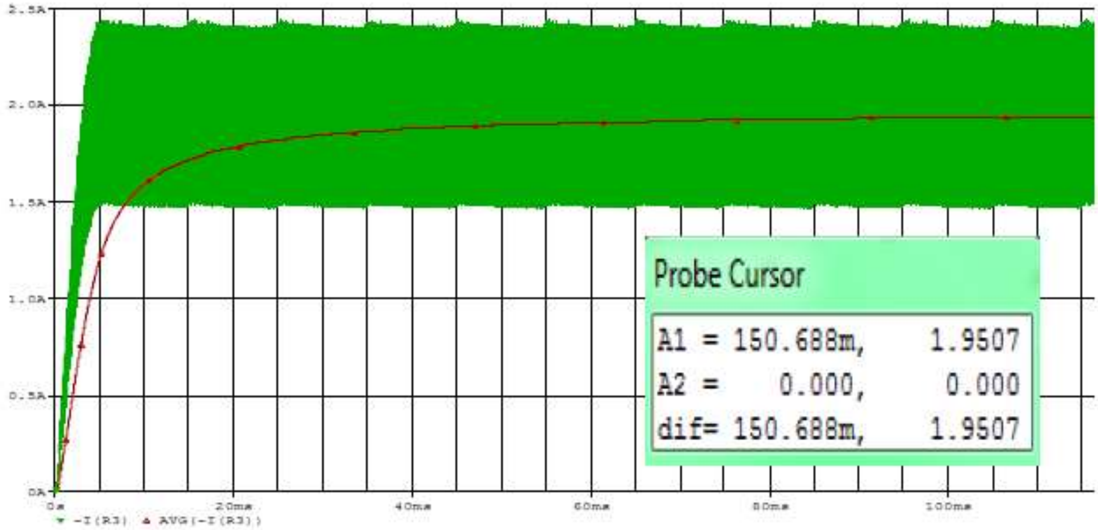

Figure 11: Output Current after using the new values for PW, D and C.

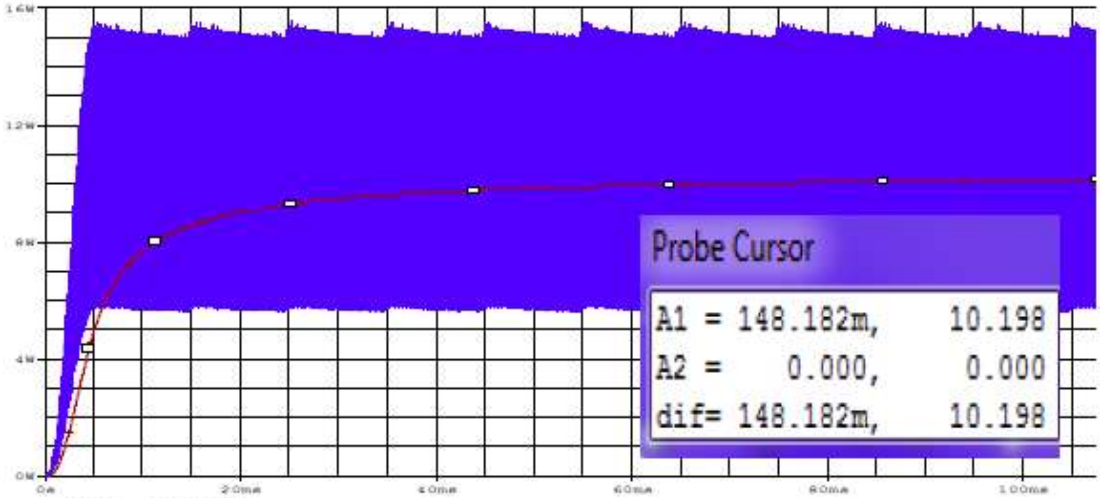

Figure 12: Output Power after using the new values for PW, D and C.

However, we can get: $V_o = 5.1V$ $I_o = 2.1A$ $P_o = 10W$ but the ripple is so high, so by adding a capacitor (C_2 = 100µf) at the output side we can achieve ripple = 4.7%. Figure 13 shows the simulated circuit of the cell charger with voltage ripple less than 5%.

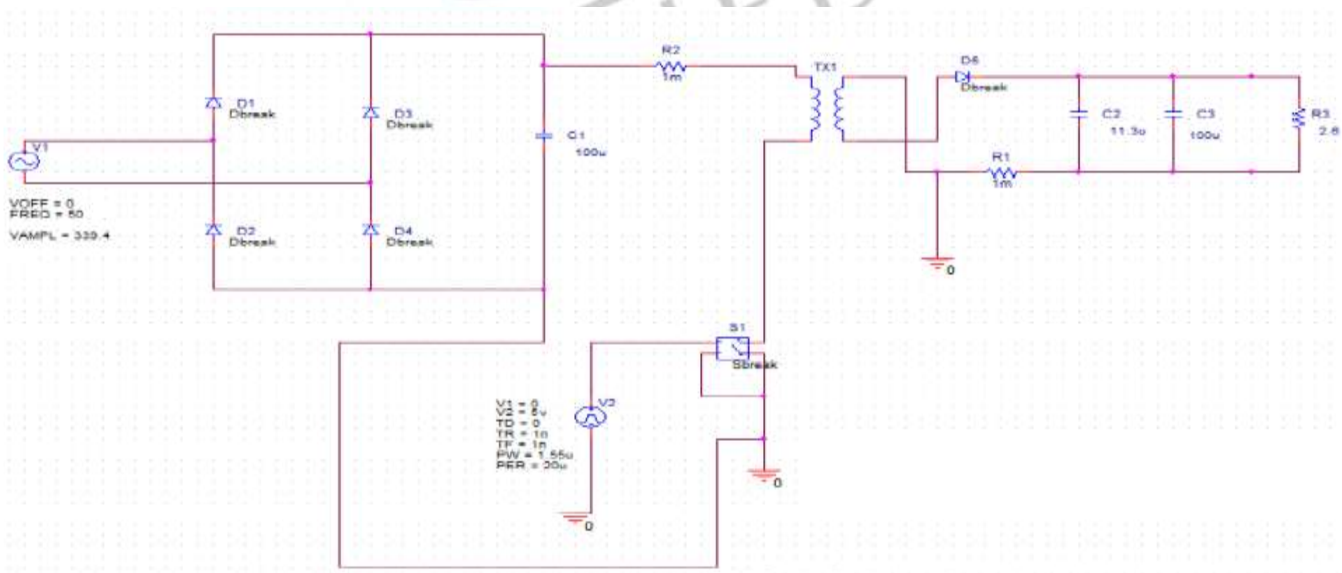

Figure 13: Simulated circuit of cell charger with voltage ripple less than 5%.

Figure 14 shows the output voltage waveform with voltage ripple less than 5%. The output value for voltage is nearly 5.1 V which is the desired output voltage. The percentage of ripple can be calculated by looking into the maximum and minimum output voltages, which is shown below:

$V_{o(max)}$ = 5.3307 V and $V_{o(min)}$ = 5.0910 V. Hence,

$$\%\,ripple = \frac{Vo(max) - Vo(min)}{Vo(min)} \times 100 \;=\; \frac{5.3307 - 5.0910}{5.0910} \times 100 \;= 4.7\%$$

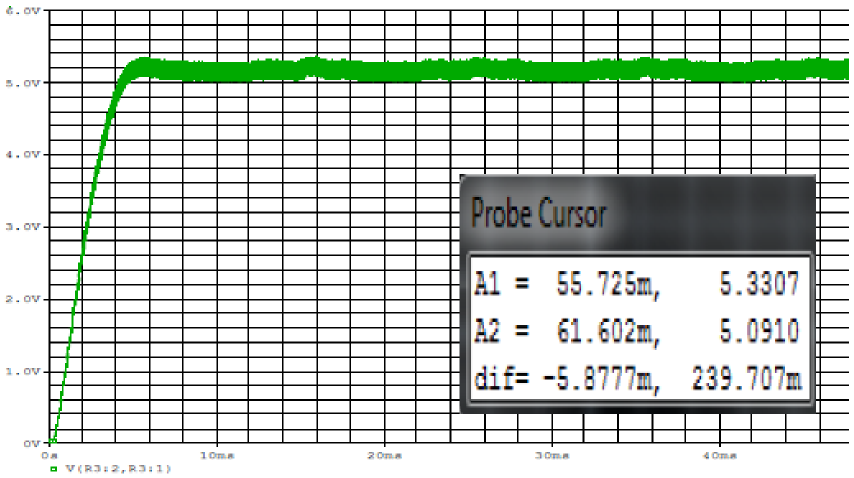

Figure 14: Output Voltage with voltage ripple less than 5%.

According to figures 15 and 16, it is seen that the output values for current and power are approximately 2.1A and 10W respectively

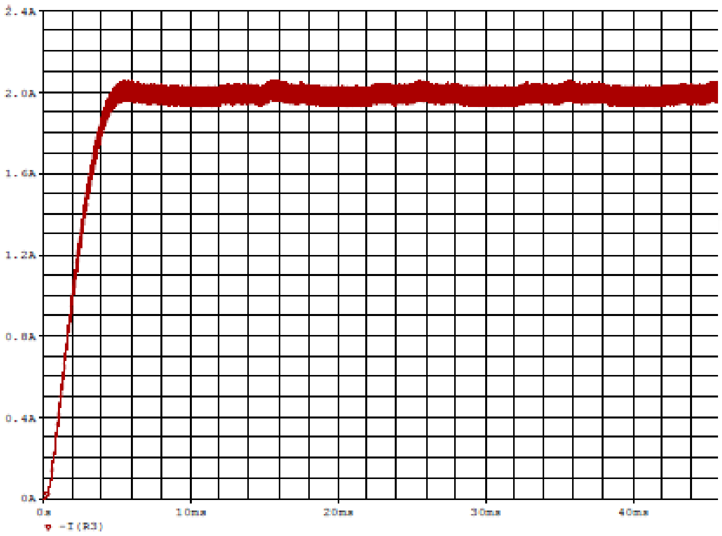

Figure 15: Output Current with for a case of voltage ripple less than 5%.

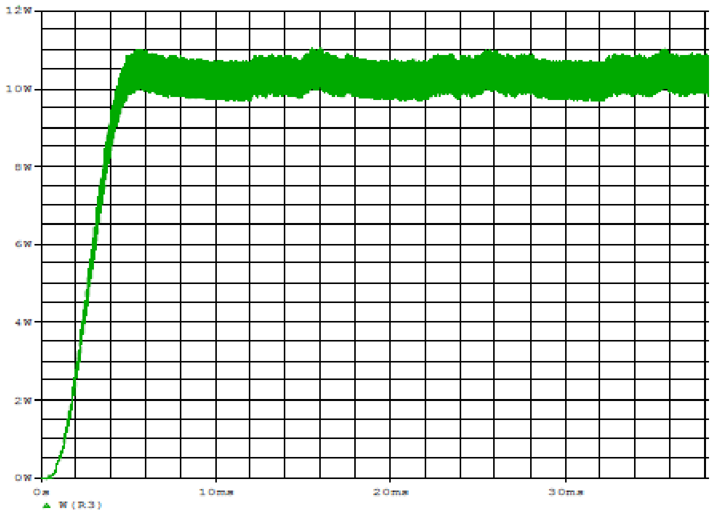

Figure 16: Output power with for a case of voltage ripple less than 5%.

IV. CONCLUSIONS

The optimization of the available components to its best end use efficiency has been focused on. With the same approach it was tried to formulate and design the iPad cell charger. Combination of the components has end up in the best possible results, by keeping in mind the specifications restrictions which have been provided. The simulation results show the steady state performance of output voltage, current and power. The output voltage ripple can be corrected using appropriate capacitor. The results obtained comply IEC 61000- 3-2 Standard.

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