Design and Simulation of a 2 KVA PV Solar-Based Charge Control System

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Abstract

There is much work currently in the field of renewable energy, particularly, solar energy to replace the traditional energy sources. In this paper, a solar charge control system has been designed with voltages of 24 V and 12 V and current capacity of 220 A. The design procedure is firstly set-up by adjusting the input voltage delivered from solar cells during the period (7 a.m.–5 p.m.) for maximum sun rise.

To assess the robustness of the designed circuit, the circuit has been simulated under different input voltages and external load conditions. The first test is verified by changing the input voltage supplied from the PV solar panel with the same voltage change during the test period. The results showed that the output voltage has remained at constant level. The other test is performed by changing the output load value such that it reaches approximately the load of batteries. It has shown that no change in total currents occurs. This could prove that the design technique give both stable and robust performance. Moreover, the designed charge controller can successfully deliver a charge power of 2KW. This power is considerably high when compared with other circuits.

The design of the charge control system is based on simulated results and it has been verified using *PSpice*.

Keywords: PV solar system**,** Charge controller, Darlington circuits, PSpice.

تصميم وبناء منظومة مسيطر شحن شمسي بقدرة 2KV

الخلاصة

هنالك عمل متزايد حالياً في مجال الطاقة المتجددة وخصوصاً الطاقة الشمسية وذلك لاستبدال مصادر الطاقة التقليدية. تم في هذا تصميم مسيطر شحن الكتروني والذي يعتبر أحد العناصر الأساسية لمنظومة الخلايا الشمسية، ضمن المواصفات التالية 12V, 24V وبتيار تصل قيمته إلى [240A]. واعتمد التصميم على قيم الفولتيات التي تتولد بخلايا شمسية ما بين الساعة (7) صباحاً إلى الساعة (5) مساءً. وتم فحص هذا المسيطر بهذه القيم من الفولتيات وباستخدام أعلى وأقل حمل متوقع وكانت النتيجة إن الفولتية والتيار الخارجين مستقرة وبشكل مقبول.

إن مسيطر الشحن هذا يمكن أن يقوم بشحن قدرة تصل إلى [2 KVA] وتعتبر هذه القدرة عالية نسبياً عند مقارنتها مع بعض الأجهزة الأخرى من مسيطرات الشحن.

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إن جميع النتائج تم الحصول عليها بواسطة برنامج *PSpice* وتم استخدام بعض الخلايا الشمسية المتوفرة على سطوح أبنية الجامعة التكنولوجية والتي كانت بالمواصفات التالية: [12V ،130W].

INTRODUCTION

In recent years, the solar power system has received increased attention as a renewable energy system to solve the clamping change problem and progressive demand of energy. Photovoltaic solar cells depend on the light of the sun and this source is a free natural source. On the other hand, the cost of the photovoltaic solar cells decreases from year to year. The function of the charge controller is to regulate the dc power flowing from photovoltaic panels into the load to produce a constant desired output voltage by comparing the output voltage with a fixed reference voltage and reducing this deference [1]. The charge controller is basically an electronic device existing in solar energy systems to stabilize the voltage supplied to batteries. In other words it protects the batteries from over charging current which may destroy and reduce the life time of batteries. The charge controller is an important part of the solar system as shown in Figure (1).

Many researchers have worked in this field. G. Forrest has designed and implemented a solar charge controller [12 V, 20 A] using power MOSFET transistor as a gate to transfer the solar energy between the PV panels and the battery of the solar power system [1]. NXP Semiconductors Company designed and implemented solar charge controller [12 V, 8 A] with the aid of the PWM technique [2]. N.J. Mohd designed and implemented a charge controller by using the PWM method using the *PSpice* simulator to analyze the circuit [3]. E. Lampa and K. Chinyama designed and implemented a charge controller with the aid of a microprocessor [4]. In comparison with the mentioned works, this paper deals with higher current capacity controllers in the range of 220 A.

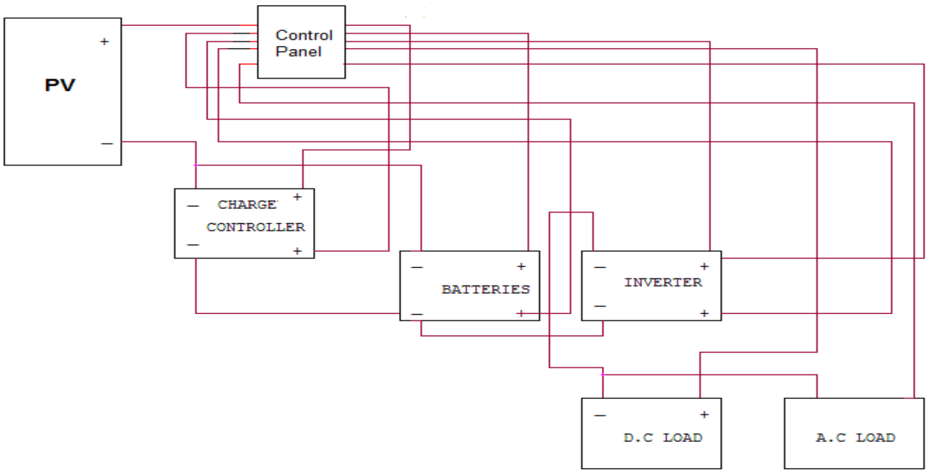

Figure (1): Block Diagram of a Typical Solar System.

Theory of Operation

Before proceeding in the design of the proposed charge controller, one should take into account all available information about energy and load. This information is suitable to satisfy the target of the electronic circuit design. The operation of the charge controller includes the energy transfer between the PV solar panels and the batteries.

Firstly, one may use a relay connected to the solar cells which directly energize the relay coil as shown in Fig. (2). The terminals of the relay are connected between the negative poles of the batteries and the ground points. This could reduce the sparking effect in relay contacts for more efficient operation and thereby to increase the lifetime of the relay, and to prevent the opposite currents from passing backward from load into the solar system. In addition, the existence of diodes in series with the PV panels could further protect the solar cell from reverse battery currents, especially when no sunlight is applied.

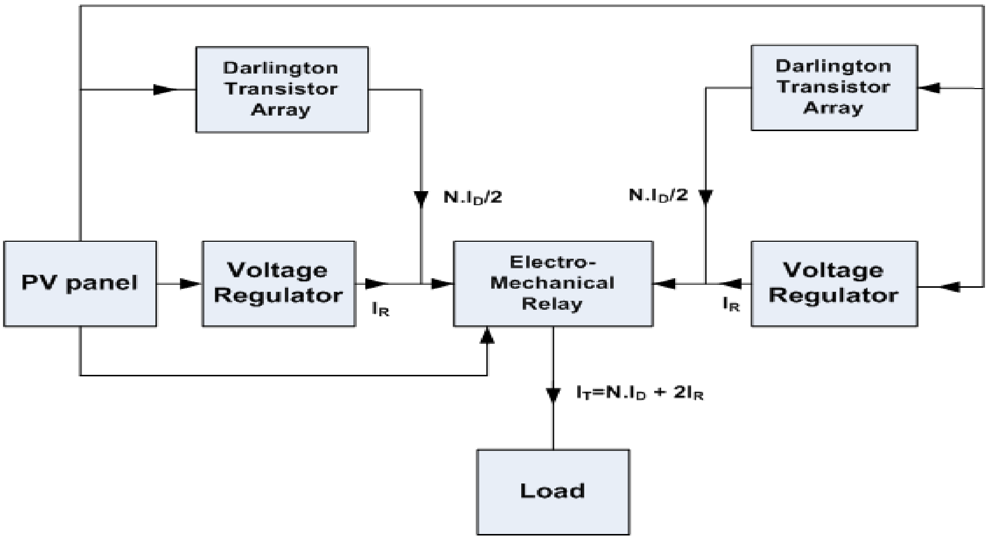

Figure (2): Block Diagram of the Suggested Design of the Charge Controller.

The energy transfer is based on the fact that there is an energy transfer if the PV voltage is greater than the battery voltage, while no transfer occurs when the battery voltage is greater or equal to the PV voltage. This energy transfer occurs through the Darlington transistor array [1].

From Fig. (1), one can deduce that the stabilization of the PV output voltage with variable input voltage and load is based on the following regulation equation:

$$\%VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100 \qquad \ldots(1)$$

Where:
VR is the percentage voltage regulation,
V_{NL} is the no-load output voltage, and
V_{FL} is the full-load output voltage.

Practically, the value of the charging voltage should be taken greater than the battery voltage and is estimated from [5]:

$$V_C = 1.18 \times V_B \qquad \ldots(2)$$

Where
V_C is the output voltage of the charge controller and V_B is the battery voltage. Based on Fig. (2), the total current of the charge controller is given by:

$$I_T = N.I_D + 2I_R \qquad \ldots(3)$$

Where
I_T is the total current of the charge controller, I_R is the output current of each voltage regulator, I_D is the branch current of each Darlington stage, and N is the number of the complementary Darlington silicon power transistor stages.
For a one-ampere discharge rate, Peukert's law is often stated as [6]:

$$C_p = I^n.t \qquad \ldots(4)$$

Where
C_p is the capacity of battery (A-Hour), I is the discharge current (A), t is the discharge time (Hour), and n is the Peukert's constant.

It is important to note that solar charge controllers are specified by both voltage and current quantities. This requires a charge controller to match the voltages of both the PV panels and batteries. Therefore, one must make sure that charge controller has enough capacity to handle the current from the solar panel [6]. The equation which relates the maximum current of the charge controller and the driven current from PV panel is given by [7]:

$$I_L = 1.56 I_{PV} \qquad \ldots(5)$$

Where
I_L is the load current fed to battery by the charge controller and I_{PV} is the current delivered by PV panel.

For safety purposes, an appropriate over-current protection has to be included before and after the controller.

To achieve low-cost safety requirement, the following basic formula for sizing a solar panel charge controller is given by [7]:

$$I_L = 1.2 I_{PV} \qquad \ldots(6)$$

It is clear from the block diagram presented in Fig. (2) that the Darlington combinations function as current boosters for the charge controller.

The Darlington pair is an important element in the present design of the charge controller. The configuration of the Darlington configuration is shown in Fig. (3). It is clear that the two transistors are connected to each other such that they behave like one transistor. However, the voltage between base and emitter is equal to 1.4 V, which is twice the value of the normal base-emitter voltage.

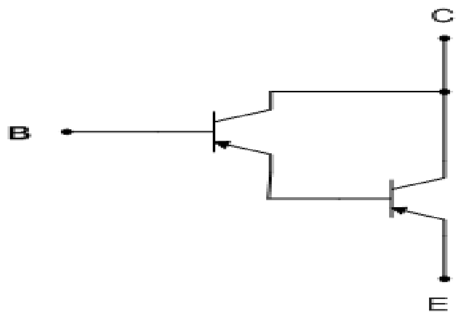

Figure (3): The Darlington PNP Transistor Pair.

The number of Darlington power transistors needed in the design of the charge controller depends on the maximum required power, and is given by:

$$P_T = N.P_{D\max} \qquad \ldots(7)$$

Where

P_T is the maximum power of the charge controller, N is the number of Darlington power stages, and P_{Dmax} is the maximum power for each complementary Darlington stage.

Figure (4) shows the proper operating area of the complementary Darlington silicon power transistors of type MJ11021, which is evidently suitable for the present design of the charge controller [8].

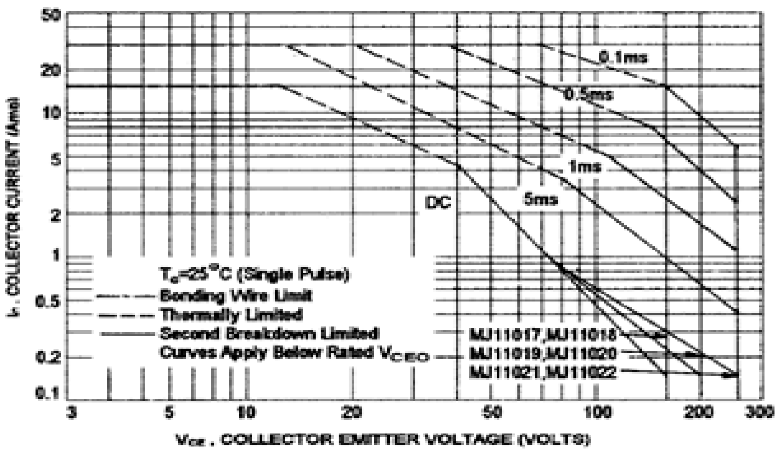

Figure (4): The Forward Bias Safe Operation Area of the MJ11021 Transistor.

The linear three terminal regulator type MC7812 is a monolithic integrated circuit used as a fixed-voltage regulator for wide variety of applications. It is clear from Fig. (5) that this regulator employs internal current limiter, thermal shutdown and safe-area compensation. With adequate heat sink, the regulator could deliver a current in excess of 1 A. Also external components can be connected with it such that it can give adjustable voltages and currents [9].

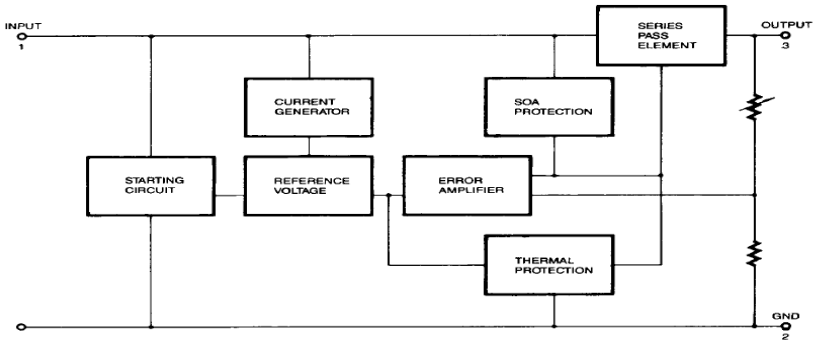

Figure (5): The Internal Block Diagram of the MC7812 [9].

Results and Design Verification

The desired system specifications are to achieve 14 V output with a typical charging current of 220 A. Since the battery voltage is 12 V, then based on equation (2), one can estimate the required output voltage of the charger controller as:

$$V_C = 1.18V_B = 1.18 \times 12 = 14V$$

The desired current of the overall circuit is 220 A. It is clear from Fig. (4) that the rated safe current of each Darlington pair is about 12 A . Then, the total number of the required Darlington pairs is calculated as:

$$N = \frac{220}{12} \cong 18$$

For safety purposes, the suggested total number of Darlington stages can be increased to N=20.

The resistor connected between the regulator common pin and the ground has been adjusted to 500 Ω to achieve an output voltage of 14 V. Figure (6) shows the complete circuit diagram of the charge controller resulting from the design procedure.

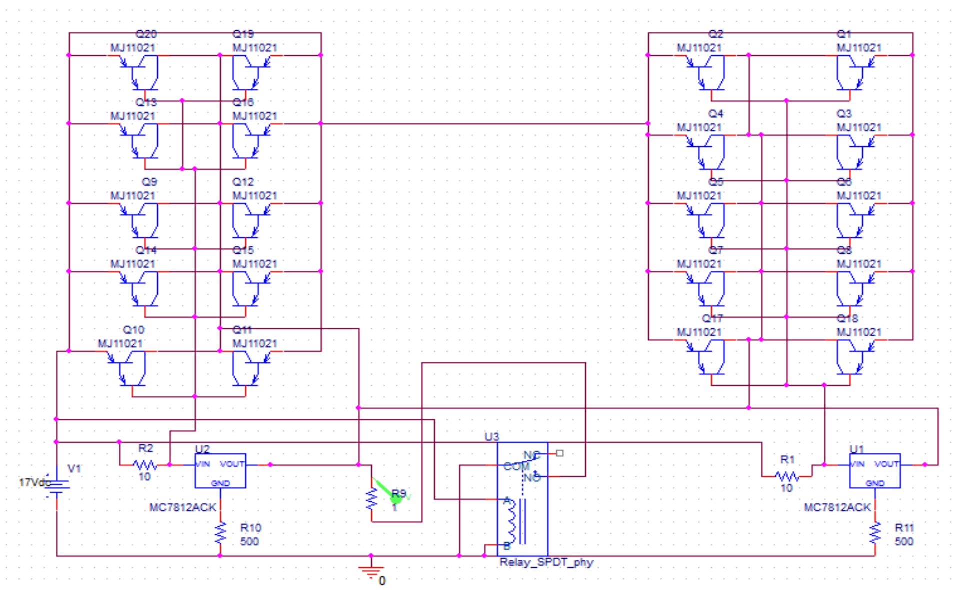

Figure (6): The Circuit Diagram of the Designed Charge Controller (14 V, 220 A).

In Figure (7), four traces of the output voltage are measured with four different input voltage levels at no-load (Actually with R_L=10 KΩ).

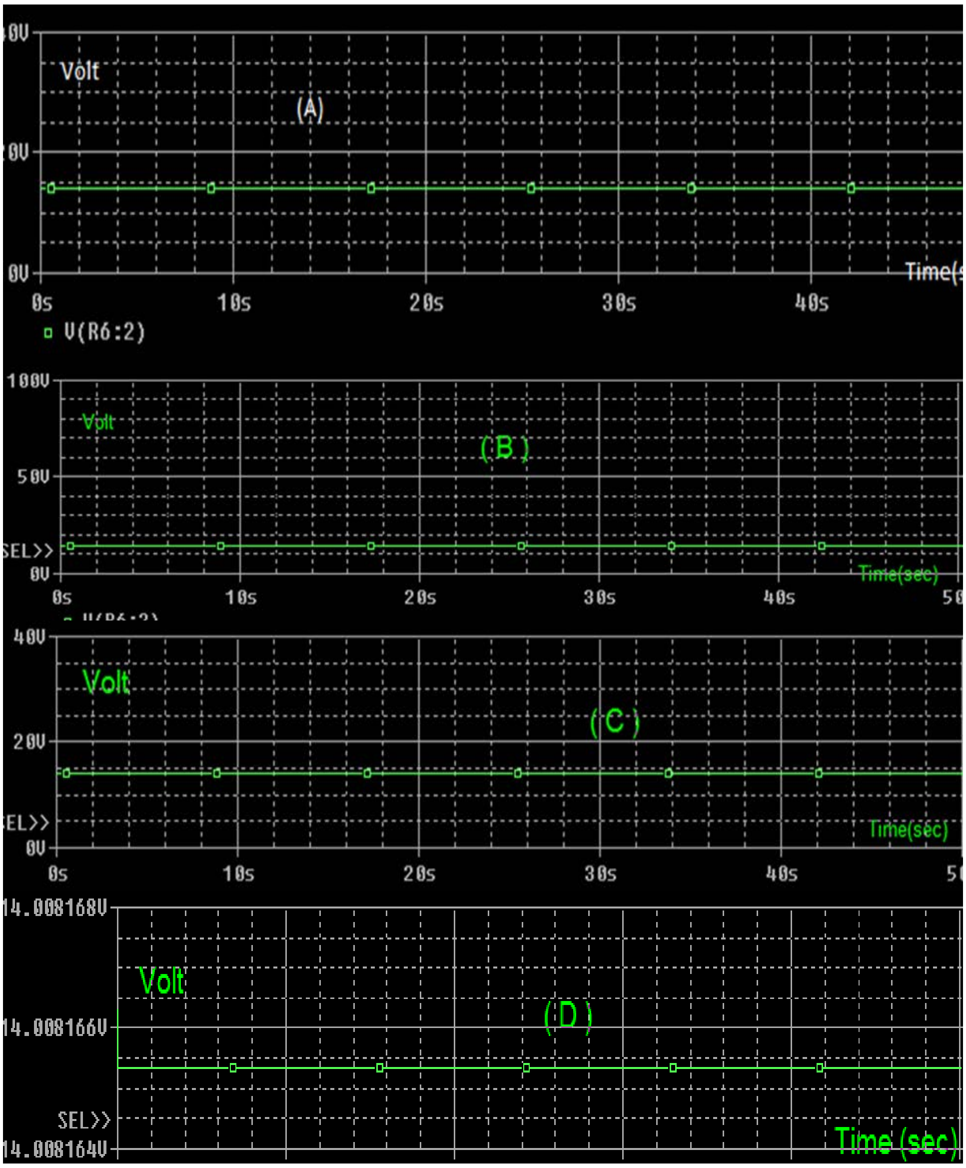

Figure (7): The Simulated Output Voltage of the Charge Controller with No-load at Four Input Voltages.

It is evident from the Fig. (7) that the change in output voltage is relatively small with the variation of input voltages.

In Figure (8), four traces of the output voltage are simulated with four different input voltage levels at full-load (With R_L= 0.1 Ω).

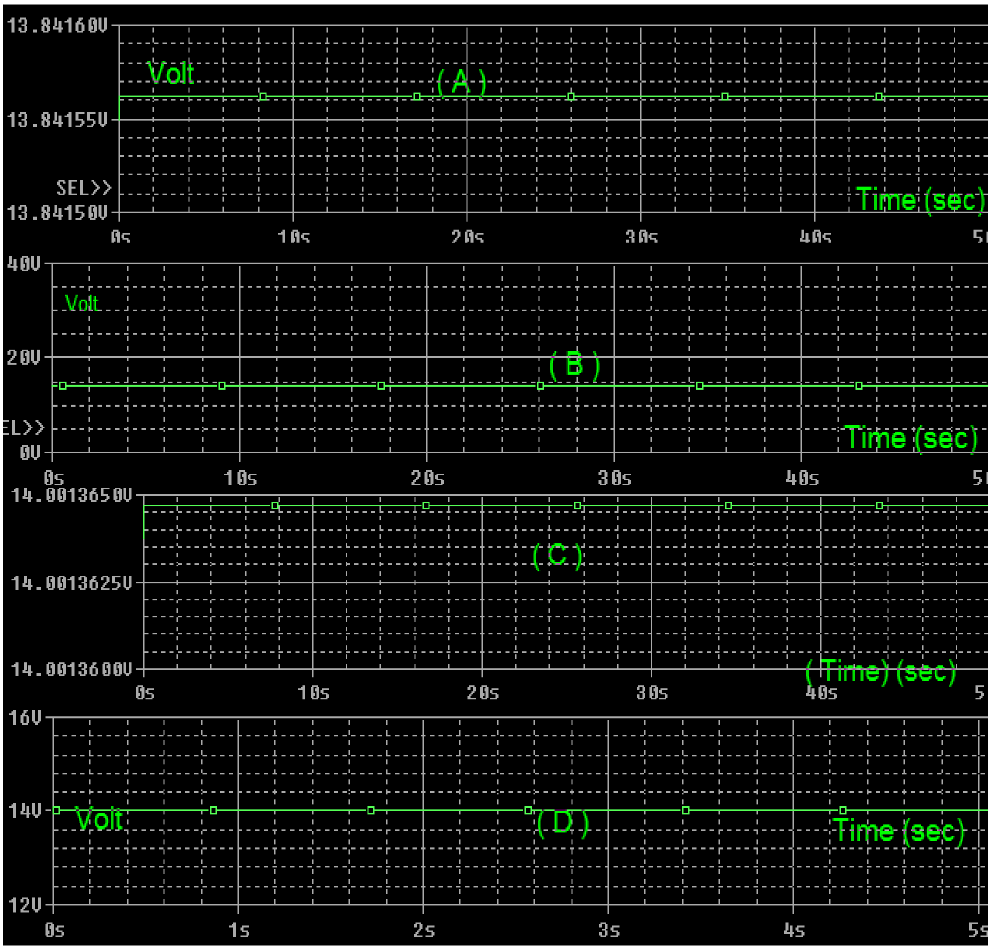

Figure (8): The Output Voltage of the Charge Controller at Full-load for Four Input Voltages.

Table (1) summarizes the obtained output voltage for different values of the input voltage. It is clear from Table (1) that there is a very small change in the output voltage in spite of the change in input voltage. This may give a conclusion that the design can give robust characteristics.

Table (1): Traces at different input voltages

Trace (Fig.8)	Full-Load		Trace (Fig.7)	No-Load		Percentage Regulation
	Input Voltage	Output Voltage		Input Voltage	Output Voltage	
A	17 V	13.84 V	A	17 V	14 V	1.36 %
B	18 V	14 V	B	18 V	14 V	0

C	19 V	14 V	C	19 V	14 V	0
D	20 V	14 V	D	20 V	14 V	0

Figure (9) presents the simulated currents of the circuit at full-load. As shown from this figure, the total current of the charge controller satisfies equation (3), where trace (A) shows the total current, trace (B) shows the current of the Darlington power stage, and trace (C) displays the regulator current.

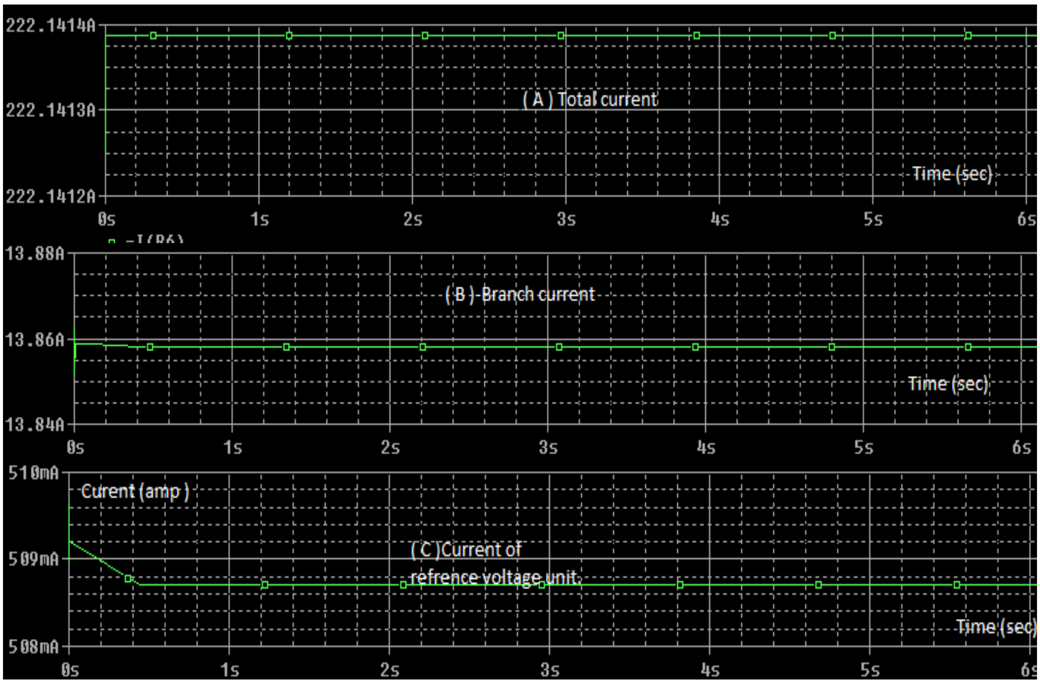

Figure (9): Current traces of the charge controller.

Conclusion

This paper focuses on designing a charge controller based on solar cells with a charging power of 2KW. Based on the simulated results, the following points could be highlighted:

- The congestion of low current problem can be solved using Darlington transistors. The combinations of such transistors could extend the range of current capacity.
- The results obtained showed that the designed circuit can maintain the output voltage with variation of input voltage and load conditions.
- It was noted that the IC voltage regulators function efficiently only with PNP transistor Darlington power stages. NPN transistor Darlington stages, and power MOSFETs can not operate with this type of regulators.

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