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Design, Simulate and Build a Photovoltaic-based Energy System for Mobile Device Chargers

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Abstract In modern times, the mobile devices and renewable energy have become so popular in our society. However, there was one important problem arises, that is the technologies cannot keep pace with technical development. The battery capacity of the mobile devices cannot satisfy the demand of customers. Therefore, a photovoltaic-based energy system for mobile device chargers is considered to be made. With the development of public transportation, that system is designed to be integrated into a bus stop for passengers' convenience. The two main parts of the control board of the system which are the buck converter and the Flyback converter are simulated with real electrical components' parameters in LTspice free software. Although this design is based on Vietnam's weather conditions, it can also be applied in other countries with some further adjustments.

Keywords Photovoltaic-based, Mobile Devices, Chargers, Simulation, Ltspice

1. Introduction

In modern times, the mobile devices with connectivity have become so popular in our society. However, there was one important problem arises, that is the technologies cannot keep pace with technical development. The evidence is that together with the full range of utility applications on mobile devices, battery power supply for them has been the considerable problem. Although there have been many improvements in battery's lifetime for the devices mentioned above, but the fact that one cannot maintain a smartphone's battery power for long time when he switches applications or surfs the web for entertainment. If he suddenly needs one emergency call or an email response and that smartphone already ran out of battery, it then brings him into a dilemma. Therefore, a photovoltaic-based energy system for mobile device chargers at public places is considered to be designed and built.

2. Content

2.1. Survey of Actual Needs

From 16th February to 16th May, 2014, a survey has been made by the authors in Vietnam for 291 people's responses via Google Docs. The language used in that survey is Vietnamese. The target of the survey were people from age 16 to 40 for their opinion about their habits in using mobile devices. As the figure 1 has shown, there were 97 per cent of people in that survey were using mobile phones, smartphones.

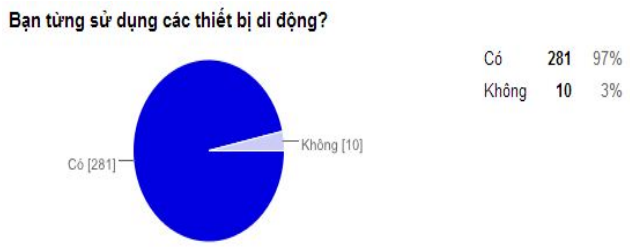

Figure 1. Percentage of mobile device users in the survey

The survey also indicated that 84 per cent of asked people agreed with the idea that: when using smartphones and tablets for running the applications, they ran out of battery very fast. The result was shown in figure 2 below. From the reason above, the figure 3 provided us the information that 73 per cent of surveyed people did want to have the energy supplier at public places or restaurants and coffee shops for their mobile device's chargers.

From the actual needs of the customers, this project duty is to integrate the solar power supplier into the bus stop in order to build the free charging system in Vietnam's public areas.

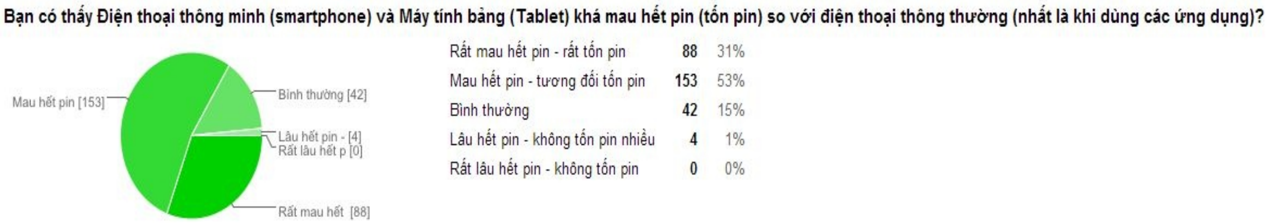

Figure 2. Percentage of customers about power consumption mobile devices

Figure 3. Percentage of surveyed people who desires a public charger

2.2. Ideas of Design

Nowadays, in our modern world, solar power is a kind of renewable energy source which has become popular in our daily lives. In comparison with non-renewable sources of energy such as fossil fuels and nuclear energy, solar energy has some advantages which are non-polluting, environmentally friendly and its resources are long-lasting. It also has advantages compared to wind power - another renewable energy resource. Solar power is created through solar panels and while wind power is generated by wind turbines which require many major mechanical parts, solar panels do not need so. The only disadvantage of solar power is its energy can only be produced when the sun is shining. Back up batteries are thought to be good solution, which can store surfeit power created during day time and provide that power to the system when there is no sun shining. Therefore, a photovoltaic-based energy system for the mobile device chargers at the bus stop is considered to be built to supply energy for the customer's mobiles via an eco-friendly way. Figure 4 illustrates that idea of design.

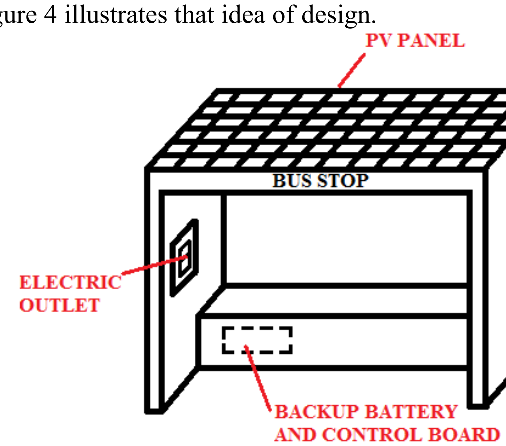

Figure 4. Design of photovoltaic-based energy system for the mobile device chargers at the bus stop

Because the solar panel produces an output that is DC and the power supply for the mobile devices' chargers is AC, we have two main ways of thinking for the charger's design. The first idea is that we use the DC-DC conversion combined with buck converter to get a power through USB connector to charge for the mobile devices as shown in figure 5. Although it is very convenient for the customers to charge their mobile devices through a USB gate, this design still has big drawback. When people charge their devices through USB connectors, the power supplier could have higher voltage or higher current than the mobile device manufacture's parameters without any guarantee and easy to damage the product.

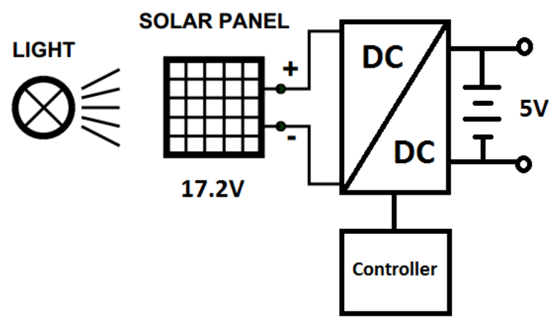

Figure 5. Design of simple solar supplying system

The second kind of design is that we use the DC-AC inverter to get power through AC charger to charge for the mobile devices as presented in figure 6. After taking DC power supplied from solar panel, the DC-AC conversion will convert DC power into AC current to fit the mobile device charger's design. For this design, the customer's device is well-protected thanks to the manufacture's charger. It will guarantee the mobile device by the parameter that was regulated by the manufacture and we do not need to worry about the problem that exists in the first idea.

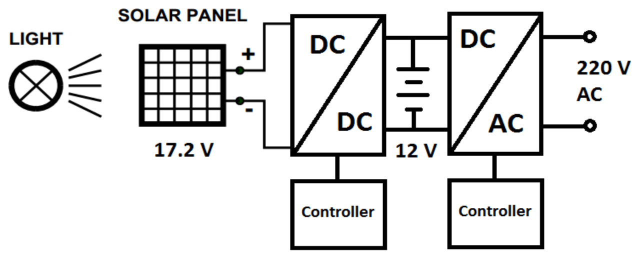

Figure 6. Solar supplying system with DC-AC converter

From the second idea above, we expect to find a new way to design the solar power supplier for mobile device's chargers. Based on the safety of the manufacture's genuine charger that we have discussed above, we will build up a solar power supporter with DC-DC converter combined with buck converter and Flyback converter as in the figure 7. In theory, if the genuine charger can use with AC current, it can also work with DC current. Therefore, from the DC power from PV panels, we will step it up to fit the regulation of the manufacture's design for the mobile device charger in order to use it.

In this project, the system is implemented so that it can support enough power for a tablet and a smartphone charging simultaneously. A tablet consumes 10.71 watts and a smartphone needs 5 watts. The working duration of this system is from 7 a.m. to 10 p.m. with the usage constant is 0.75. This product tends to have an efficiency at 85 percent. Moreover, another goal of this project is to implement the solar energy supplier which can work for one rainy day or one day of automation which means a battery capacity must be big enough to store energy for one-day use.

This project will use buck converter to step down the voltage from photovoltaic panel for back up battery charging. The Flyback converter is used for stepping up the voltage from the back up battery to 170V DC for mobile device chargers. From some of the reliable charger manufactures, with a charger has the range of voltage from X to Y, the efficiency of that charger is highest at the voltage (X+Y) / 2. [1] [2] Therefore, for the commercial chargers in the market, which have the voltage range from 100V to 240V, 170V is the value that the system is expected to produce. Although the chargers are used with AC power, they can also be used with DC power because mobile devices are electronic devices, not electro-mechanic devices. Both buck converter and Flyback converter are integrated into one circuit board.

From figure 7, the 4 functions of the micro-controller module are described. The first function is to measure input voltage and input current from the photovoltaic (PV) panel via line 1 and line 2 to track for maximum power point. The second function is to produce pulse width modulation (PWM) for the trigger module of buck converter and Flyback converter via line 5 and line 6. The third function of the micro-controller module is to check if the backup battery is full-charged or not through line 3. And its last function is to check if the backup battery is over-discharged or not through line 4. If the backup battery is full-charged, the micro-controller module will control the switch of buck converter to cut the electricity from PV panel. If the backup battery is over-discharged, the micro-controller module will control the switch of Flyback converter to cut the load or the chargers from the system..

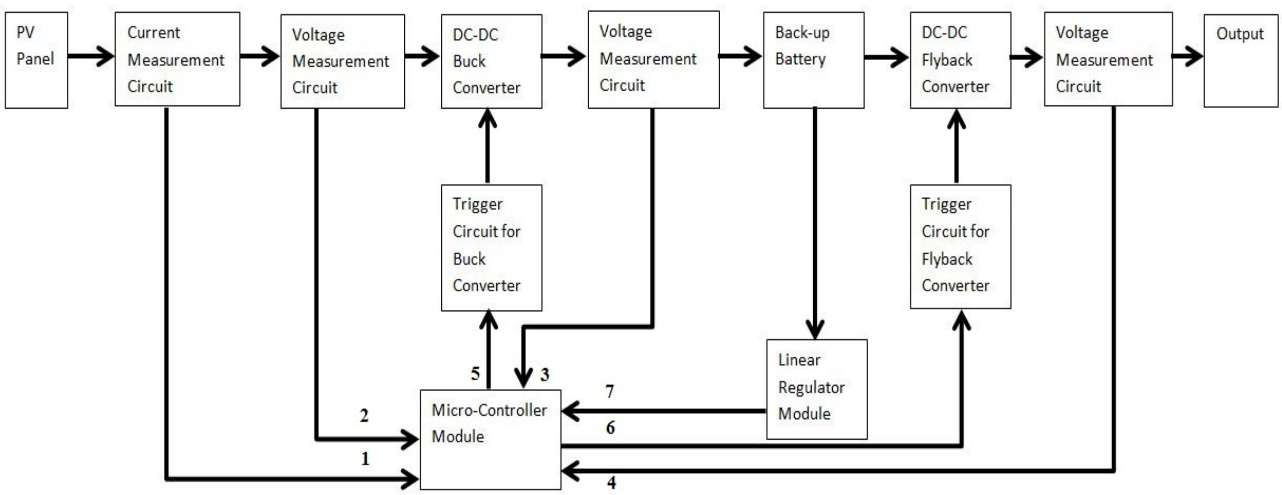

Figure 7. Block diagram of the photovoltaic-based energy system for the mobile device chargers

2.3. Calculation and Simulation

From the limitations of our project which are mentioned above, we have some calculations for our product design:

The needed power is: $P_{need} = P_{tablet} + P_{smartphone} = 10.71 + 5 = 15.71$ (W)

The output energy is: $E_{out} = P_{need} \times k_{usage} \times t_{usage} = 15.71 \times 0.75 \times 15 = 176.74$ (Wh) (with k_{usage} is the constant of usage and t_{usage} is the hours that the product has to work per day)

The efficiency of buck converter and Flyback converter is 0.85

The input energy from the solar panel must be: E_{in} = 176.74 / (0.85 x 0.85) = 244.62 (Wh)

Peak Sun Hours (PSH) in Ho Chi Minh City (and also Vietnam) is 5 hours

The maximum power of the solar panel must be: $W_p = E_{in}$ / PSH = 244.62 / 5 = 48.92 (W)

The storage duration is designed to be 1 day, therefore the energy storage per day would be:

$E_{stored} = E_{out}$ / 0.85 = 176.74 / 0.85 = 207.93 (Wh)

Battery Capacity must be: E_{stored} x Storage Duration / V_{system} = 207.93 x 1 / 12 = 17.34 (Ah)

(With V_{system} is battery's voltage and equal to 12V) [3]

Hence, the 50-Wp PV panel and 20-Ah 12-V battery are suitable for this project design.

In order to shortening the research time, the two main parts of the control board of the system which are the buck converter and the Flyback converter are simulated with real electrical components' parameters in LTspice free software. Via simulation program, adjustment of the parameters of the design is made without fear of damages as in the real circuit. Therefore, LTspice simulation helped the authors to freely choose and make final decision on electrical components for buck and Flyback converter circuit.

For buck converter, it is used for stepping down the voltage of 17.2V from the PV panel to 12V in order to store energy into the back up battery. Some calculations for buck converter's components are exhibited below:

Duty cycle of buck converter: $D = V_{out} / V_{in}$ = 12 / 17.2 = 0.7

T_{on} = 10 (s) , so T_{period} = 10 / 0.7 = 14.3 (µs), P_{out} = 15.71 / 0.5 = 18.48 (W)

$R_{out} = (V_{out})^2 / P_{out} = 12^2$ / 18.48 = 7.79 (Ω), $I_{out} = V_{out} / R_{out}$ = 12 / 7.79 = 1.54 (A)

From the formula: (1-D) x T_{period} x V_{out} = L x 2 x I_{out} [4]

We obtained L = (1-D) x T_{period} x V_{out} / (2 x I_{out}) = 16.714 (µH)

However, this calculation is in the critical inductance condition, for real condition, L must be approximately 10 times of the calculated value, so the inductor of 100 µH was chosen.

MOSFET IRF9540 was chosen to be the valve of the buck converter. IRF9540 is easy to use and it has faster switching speed with very low current at G pole. Diode 1N5822 was chosen because it is easy to be used. The two capacitors were connected parallel in the buck converter design. A 47 µF aluminum capacitor is used to consume energy and a 0.1 µF polypropylene capacitor is used for noise suppression to reduce voltage ripple at output.

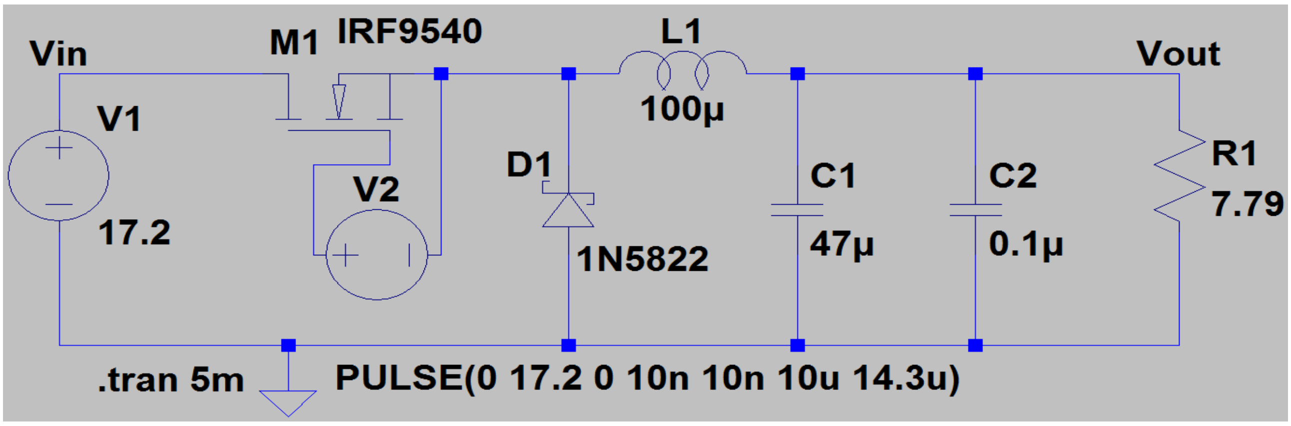

Figure 8. Buck Converter LTspice simulation circuit

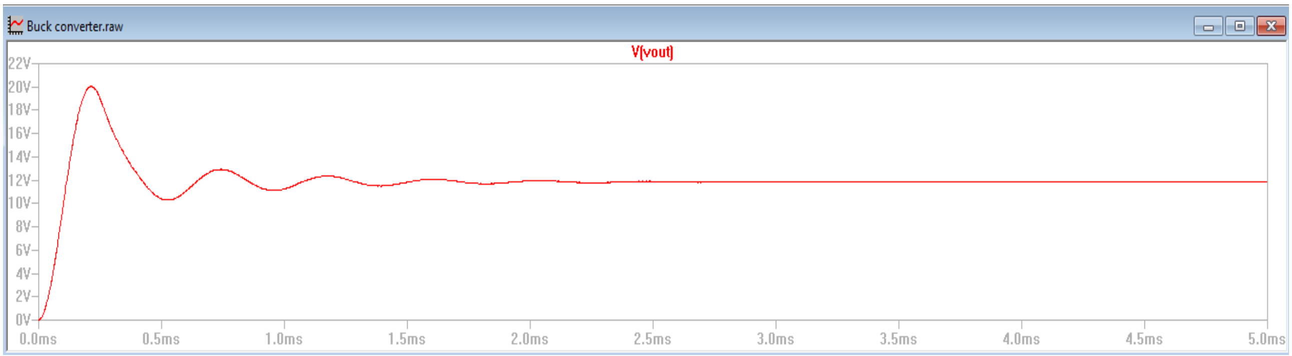

Figure 9. Buck Converter Output Voltage

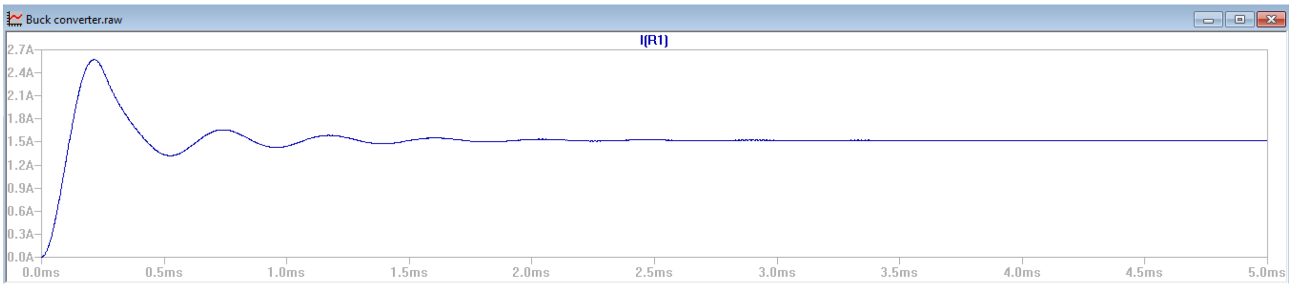

Figure 10. Buck Converter Output Current

Figure 9 and figure 10 have shown the sudden rises of buck converter's output voltage and output current but they became stable after 2ms. This problem can be fixed in reality by adjusting the duty cycle of the buck converter. For Flyback converter, it is used for stepping – up the voltage from 12V of the battery to 170V DC of the mobile device charger. Some calculation for Flyback converter's components are exhibited below:

P = 15.71W, V_{in} = 12V, V_{out}=12V, ± 1% so dV = 0.24 V

With 50 kHz switching frequency, we have T = 20 µs.

Duty cycle $D_1 = D_2$ =0.5, I_{out} = 15.71 / 12 = 1.31 A, $I_C = I_{out} / D_2$ = 2.62 A

With dt = 10 µs, I_C = CdV/dt, we have:

C = I_C dt / dV = 2.62 x 10 / 0.24 = 109.17 µF = 100 µF approximately.

Current ripple was chosen as ± 10%, so dI = 2 x 2.62 x 0.1 = 0.524 A

Because V_{out} = L dI / dt so: L = 12 x 10µs / dI = 229 µH = 200 µH approximately.

Hence, from the calculation, we choose an aluminum 100 µF capacitor and the primary winding value is 200 µH. Another capacitor which is made from ceramic and have a value of 0.1 µF is used parallel to a 100 µF capacitor in order to suppress noise and ripple.

We also have: $V_1/V_2 = N_2/N_1$ and $L_1 = (N_2/N_1)^2 L_2$. Thus: $N_2/N_1 = V_1/V_2$ = 12 / 170 = 0.07

$L_2 = L_1 / (N_2/N_1)^2$ = 200 µH / $(0.07)^2$ = 40816 µH = 40 mH approx.

2.4. Controlling Scheme and Hardware Implementation

A MPPT tracking algorithm will be used to control the duty cycle of a DC-DC converter. In this way, the algorithm will force the solar panel to operate at, or very close to, its maximum power point. There are a number of different MPPT algorithms have been developed over the years. The most dominant methods are the Perturb & Observe (P&O) Algorithm and the Incremental Conductance (INC) Algorithm. The INC method has the advantage over the perturb and observe method that it can determine the maximum power point without oscillating around this value. It can perform maximum power point tracking under rapidly varying irradiation conditions with higher accuracy than the perturb and observe method. However, the INC method can produce oscillations and can perform erratically under rapidly changing atmospheric conditions. The INC Algorithm is less confused by noise and system dynamics in comparison with the P&O Algorithm. However, in rapidly changing weather conditions, it exhibits worse confusion than the P&O Algorithm. Both algorithms offer high energy utilization efficiencies of up to 99% depending on weather conditions. [5] Therefore, the INC Algorithm will be used in this project as the control method to manage the duty cycle of the DC-DC converters as it is the more reliable of the two methods.

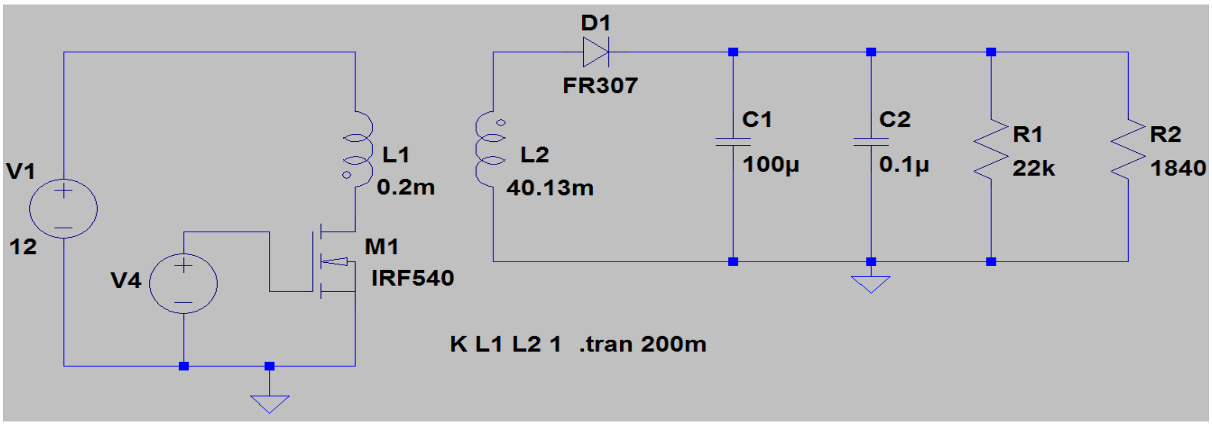

Figure 11. Flyback Converter LTspice simulation circuit

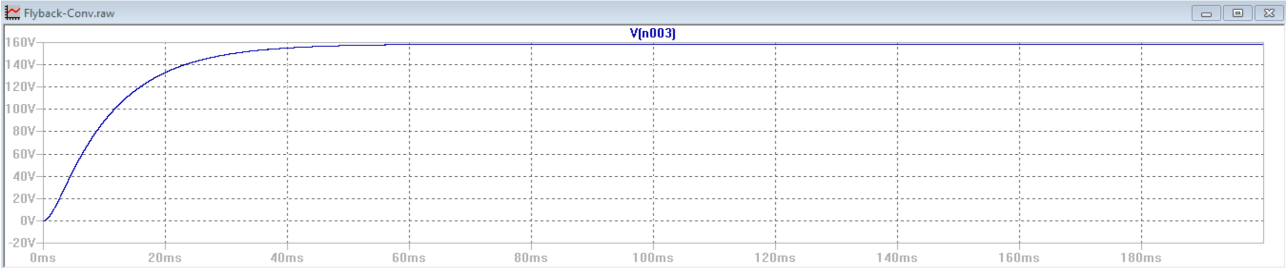

Figure 12. Flyback Converter LTspice output voltage

From the choice of INC MPPT Algorithm, the controlling scheme is built as below:

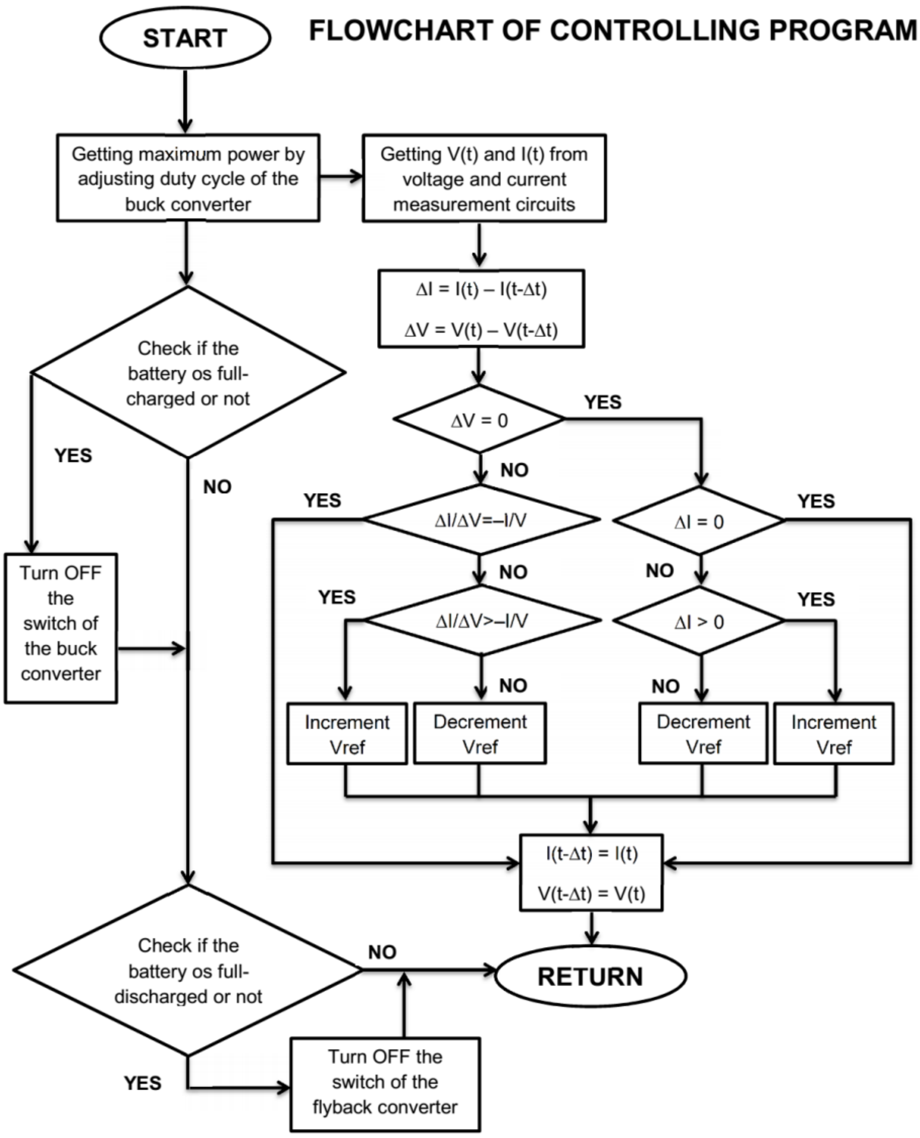

Figure 13. Flowchart of Controlling Program

From the flowchart of the controlling program above and the simulation results, the hardware is built in reality with Texas Instrument Launchpad TM4C123G.

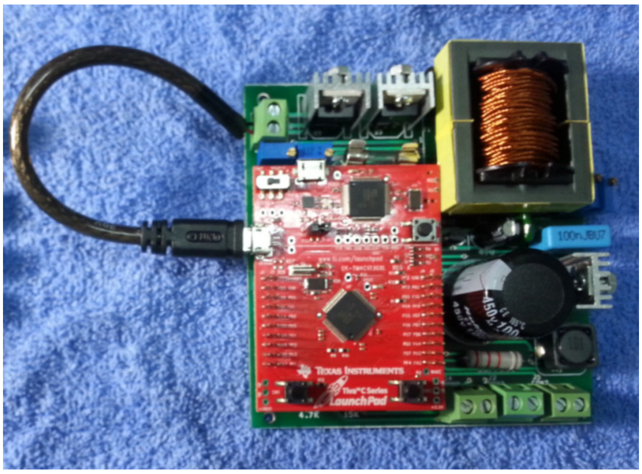

Figure 15. Controlling board with integrated Buck and Flyback converters

3. Conclusions and Future Works

From the product above, the authors want to indicate the new innovation of this product, which is to protect the customers' phones or tablets from voltage spikes by allowing customers to charge via the chargers, not via the cables. There are two kinds of power sources allowed in the market. The first one which is more popular is the battery bank to help customers to charge the mobile devices via USB cables. The second one allow customer to charge with 220VAC via the chargers but this solution is costly because of the inverter's price. With the listed reasons, the authors' new design is justified to be new innovation.

Together with the bad effects from global warming, solar energy and other kinds of renewable energy are being used widely around the world. When the consciousness of the people in developing country is not good enough, they may use the photovoltaic-based energy system with wrong purposes. For example, instead of using that system for their mobile device chargers, they use it for their hair-dryers or their mini fans, which could make the system become overloading. Therefore, because mobile devices are electronic devices, they can be charged via the system's DC current. DC power keeps our system away from the risks of overusing of electro-mechanic devices and allows people to use the photovoltaic-based energy system in the correct way.

After the success of this project, this idea can be developed for higher demand of customer. After development, this product can also have more than 1 tablet and more than 1 smartphone charge simultaneously. For instance, 2 tablets and 2 smartphones can be charged at the same time via this system. The system can be equipped with higher battery capacity for longer automation day. Moreover, this project can be applied for not only bus stops but also metro and subway stations. In Vietnam, metro will be the main transportation vehicle in the next decade, where people expect to have public energy supplying system for phone charging. Although the electricity from fossil fuel is now influencing the market of Vietnam, this solar energy system helps people to be familiar with green power and encourage the trend of using it in the future.

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