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Design of DC-DC Converter for ESP8266 Based IoT Sensor Nodes

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Abstract: In this article, we present a design of an improved DC-DC converter for low power Wireless Sensor Node using IoT. New research shows that the main drawback of future wireless sensor networks is energy storage, collection, and processing. WSNs are installed in remote locations and are powered by photovoltaic panels and batteries. In both cases, the power supply is variable. A DC-DC converter is a device that adjusts the source output voltage of a load. In this research, we have designed a DC-DC converter for ESP8266 based sensor nodes powered by battery. We have simulated the DC-DC converter using MATLAB with adding several protection and controlling features. This includes a PID controller for transient stability. This model output gives high efficiency DC power supply with very low ripple rate. Practically most of the failures in electronic devices occur due to power supply failures. This is the best solution for sensor nodes with long lasting life span.

Keyword: DC-DC Converter, IoT, PID Controller, Sensor Nodes

Introduction

IoT is a system which is used to remotely monitor and control physical phenomena in the environment. Mostly IoT is used for surveillance, agriculture, building automation, monitoring, military applications and tracking, etc. All the above applications the use of wired connections is practically complicated and thus, WSN is the most famous for the above-mentioned applications. In all the above situations, the most crucial necessity is to keep the sensor node alive, which means to keep sensor node without power failure, otherwise, that may affect the functionality of the entire system.

When we use a wireless device, the main requirement is the battery. For instance, if we use a mobile phone one of the major problems is battery capacity and running duration. That means our power supply should be highly efficient and sensor node energy consumption and operation algorithms have to have the capability to use microcontroller (sensor node controller) within its minimum energy consumption. Moreover, IoT systems uses expensive sensor and component, hence power supply should have to provide very smooth voltage and current for the protection of the sensor to avoid failure due to power fault. In this research, we design and simulate an improved and efficient DC-DC converter which can be used in such wireless sensor nodes.

Related Works

Several contributions are made on the DC – DC converter to power up wireless sensor nodes. Moreover, several electronic requirement manufactories publish their documentation focusing on product. Few recent works reported as below.

Himanshu Sharma, Ahteshamul Haqueand Zainul Abdin Jaffery have completed their research and survey for Solar energy harvesting wireless sensor network nodes, which contains a brief comparison in between all DC-DC converter and designing guide to solar based converter design. The performance analysis is more useful to this design for selecting an optimum converter for this design [4]

WSN Power Consumption

First and foremost some commercially available sensor nodes were selected to obtain the power consumption of WNS. ESP32 which has low power system with Xtensa single/dual- core 32-bit LX6 microprocessor with integrated Wi-Fi and dual-mode Bluetooth was selected. The ESP 32 controller is shown in the figure 1 below.

Figure 8 ESP 32 chip

A. Load calculation

To obtain sensor node power consumption, the ESP 32 data sheet was used to calculate power requirement of this controller. ESP 32 is 3.3V controller but most of ESP32 board manufacturers include 5V to 3.3V regulator in their system. Pertaining to that the converter output voltage should be 5VDC supply. To obtain the required current the power consumption specification of ESP 32 controller was preferred, of which the details based on their data sheets.

The typical current is 240mA when 19.5dBm wireless power. However, normally with good Wi-Fi signal controller does not require that much power. Normally it is around 190mA power when 16dBm RF power consumption.

In addition to that we have to connect some sensor into this controller. For instance, if we interface DS18B20 temperature sensor it will consume maximum 4-5 mA. At the same time, we allocate another 50 mA to other sensor. Therefore the typical output current becomes 250mA. In ESP 32 data sheet advice that power supply current should be 500mA hence our power supply also has the capability to 500mA current. The finalized total power requirement is as follows.

Table 11 Load power consumption

	Min	Typ	Max
Output voltage (1% ripples)	4.9VDC	5.0VDC	5.1VDC
Output current	25mA (sleep mode)	250mA	500mA

B. Energy sources

As an energy source lithium battery was used. To select battery voltage, the preferred sensors were those which are capable of being used with the sensor node. Mostly, the supply voltage sensors (connect with sensor node) is either 5VDC or 3.3VDC sensor but in some special cases have to interface industrial sensor (12-24vdc). Generally Industrial level sensor operating voltage is 12 - 24VDC.

Pertaining to that, 12VDC is the most optimum voltage. In order to interface with that type of sensor, it can be directly energized using battery. As per previous load calculation 250mA is rated load. However, that power is not consumed at all times because when node is idle the controller operates in sleep mode. Therefore, the sensor node operation time was arbitrarily selected as 8 hours while the same to be used for 5 days without intermediate charge.

$$Battery\ Capacity = \frac{V_{load} \times I_{load} \times T_{Working}}{V_{cell} \times DOD \times 0.8}$$

$$Battery\ capacity = \frac{5v \times 0.25A \times 8 * 2}{12 \times 0.8 \times 0.8}$$
$$= 6.5Ah$$

Equation 1 Battery capacity calculation

Design and Implementation

The system consists of one DC-DC converter with controller and protection circuit. The design needs to fulfill the following basic requirements to be a preferred converter.

I. High voltage stability.
II. Prevent from over voltages.
III. Maintain low voltage and current ripple.
IV. Smooth operation in low power level.
V. High efficiency level (For long-lasting battery life)
VI. Small size

A. Converter switching frequency

The switching frequency may depend on the application. Normally the higher frequency gives following benefits,

I. Decreased ripple level
II. Improve dynamic performance
III. Smaller inductor and capacitor
IV. Decreased total physical size of the converter (smaller components)

The higher the switching frequency, the smaller are the inductor and capacitor needed, and a better dynamic.

ESP 32 microcontroller uses MHz range clock pulse. The selection of MHz range switching frequency might affect the controller as a power disturbance. Pertaining to that, the switching frequency was selected as 180 kHz which lowers the controller operation frequency and enough to keep dynamic performance and maintain switching losses as low as possible.

B. Buck (step-down) converter

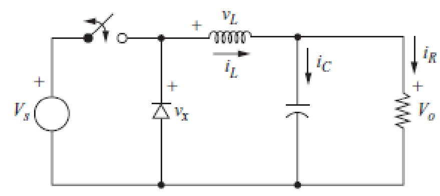

Figure 2 Buck converter circuit diagram

Initial design of DC to DC step down converter is shown in the above figure 2. Buck converter always produces low voltage level as the output compared with input (supply) voltage. In smooth dc/dc power supply output current is always greater than zero. Thus, the circuit is assumed to be operating in the continuous conduction mode. The converter input output equation is $V_0 = V_s D$ [3].

1) Inductor value

To calculate the Inductor value Equation 2 is used. In this circuit 20 percent (50 mA) Δi_L may be acceptable and further voltage smoothing is done by the capacitor. Practically the Inductor ripple current lies in between 20 to 40%.

$$L = \frac{(V_s - V_0)D}{\Delta i_L f}$$

$$L = \frac{(12-5) \times \frac{5}{12}}{0.2 \times 0.25 \times 180000} = 3.24 \times 10^{-4} H$$

Equation 2 Inductor value

To ensure continuous current operation in the circuit, the inductor value was increased by 25 percent. Furthermore, the value was rounded off to; $L = 5 \times 10^{-4} H$.

2) Capacitor Value

To calculate Inductor value Equation 3 was used. The voltage (50mV) ripple was assumed to be 1%.

$$C = \frac{(1-D)}{8L\left(\frac{\Delta V_0}{V_0}\right)f^2}$$

$$C = \frac{\left(1-\frac{5}{12}\right)}{8 \times 5 \times 10^{-4}\left(\frac{0.01}{5}\right)180000^2} = 2.25\mu F$$

Equation 3 capacitor calculation

Considering the market availability of capacitors, the capacitance was selected as C=2.2μF.

C. Initial DC-DC Converter Design using MATLAB.

The buck converter was designed using the parameters calculated above. The designed buck converter is as shown in the figure below.

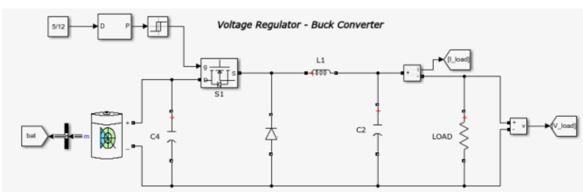

Figure 3 Initial model

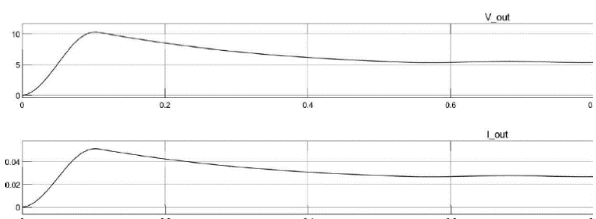

Figure 4 Voltage and current waveform

As per above figure, high voltage and current spike at the transient at period can be observed but circuit gives smooth 5V supply at steady state period. If this circuit is energized in an actual application, then definitely the sensor node will be damaged due to over voltage issue. To improve the transient stability and general protection scheme, the following function was added.

1) *Good controlling system (PID) with Soft starting circuit rather that fixed PWM.*

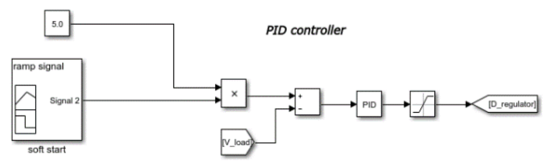

Figure 5 PID controller

In this research the brief explanation about controller was not included. After adding the above controlling circuit, the output waveform is as follows.

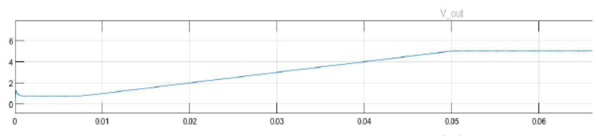

Figure 6 Output waver form after controller added

2) *Over voltage protection – Crowbar circuit*

The most valuable component in the sensor node is the sensors and the controller. Due to some faulty condition there was a high possibility to increase voltage up to battery voltage. To protect the circuit from over voltages, use the crowbar circuit at the output stage [1]. Crowbar circuit uses a thyristor and voltage sensing circuit. When the output voltage increases up to a certain amount the SCR was triggered. SCR is connected parallel to the output terminal of the converter. If SCR was triggered the output is instantly short-circuited via SCR. Pertaining to that, overcurrent protection was activated and the expensive elements were saved from over voltages. The output waveform and shunt SCR is shown in the figure 7 below.

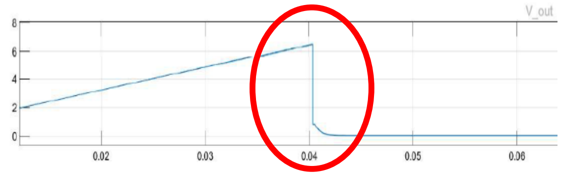

Figure 7 Overvoltage protection performance

3) Reduce high frequency ripples

Normally electrolytic capacitors have poor response to high frequency ripples. Pertaining to that ceramic capacitors were used in output stage since ceramic capacitors has greater performance in high frequency signals.

4) Battery protection circuit

To protect battery, form short circuit and other general hazard the following protection circuit was included to MATLAB model.

i. Battery under voltage protecting / over discharge – If battery over discharge during operation period that may affect to battery lifetime.
ii. Over temperature protection

If faults were detected by protection circuit it will suddenly reduce converter duty cycle to 0%.

Results

After adding all above feature into power supply model that will give very smooth output voltage with very low ripple rate nearly 0.66%. The output voltage waveform is shown in the figure 6.

The duty cycle variation of PWM signal for keep constant voltage is shown in following figure.

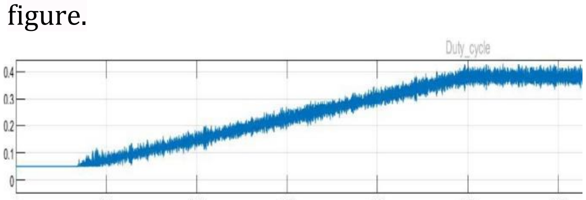

Figure 8 Duty cycle variation

Summary

We were able to come up with a successful design of DC-DC converter for ESP8266 based IoT sensor nodes. Two parameters were used to evaluate the above data which are voltage ripple and inverter efficiency. In practical situation, the sensor node works in different load condition as discussed previously. As per above values the converter gives best performance in 500mA load and nearly gives 94% efficiency in typical load.

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