Efficient Low Voltage Amplification Using Self Starting Voltage Regulator for Storage System

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Abstract—This paper presents a storage system design based on energy harvesting to achieve battery-less for Wireless Sensor Network (WSN) application. The storage system is part of the Wireless Sensor Energy Harvesting to store and amplify the energy harvested from the surroundings. Finding a new sources of renewable energy has becomes a fashionable among researchers nowadays in particular harvesting the energy from the surrounding. However the challenge raised is to boost up the energy that known are very low. Thus the proposed method must be consumes very little power and suitable for ambient environmental sources such as vibration, wind and RF energy and be able to boost up the energy for storage system. The output of the harvested voltage is insufficient for most applications, therefore the system will boost up the input voltage level using DC to DC converter topology to higher dc voltage.The DC to DC converter shall be designed to suit the types of storage required. The output voltage of this DC converter should be sufficient to charge either capacitor or supercapacitor that will be use in this system as the energy storage system. The supercapacitor will provide power to energize any system such as in this case wireless sensor network[1]. In the case of wireless sensor network for example, the node would require the energy during transmitting and receiving data only whereas during standby mode or sleep mode, the amount of energy required would be very small[2]. Therefore the storage system will make use of this standby time or sleep mode of the sensor node to store as much energy as possible. The presented DC to DC converter in this paper has high efficiency upto 85.4% with input voltage between range 300mV to 600mV.

Keyword-storage system, energy harvesting, WSN, DC to DC converter, supercapacitor

I. INTRODUCTION

In many of applications nowadays, battery-less or self-powered operation is the best option to choose as we are forwarding to the 'green world'. The used of batteries causing a huge negative impact on the environment because they are not appropriately recycled [3]. In order to achieve battery-less system we will need a storage system that can stored energy which will be derived from the surrounding like vibration, light or motion and it is called energy harvesting. The energy storage system is used for renewable energy application as well as improving the power quality in the transmission and distribution of power system. The topics of energy harvesting become more famous and attract global attention recently. Table I shows a few sources of harvested energy that been extracted from the unused ambient energy from surrounding and directly converted into usable form of electrical energy [4].

TABLE I
Estimated energy harvested [5]

Energy harvesting sources	Setting	Output power ($\mu W / cm^2$)
Vibration/Motion	Human	4
	Industry	100
Temperature difference	Human	25
	Industry	1000-10000
Radio Frequency (RF)	GSM	0.1
	WiFi	0.001
Light	Indoor	10
	Outdoor	10000

There is a lot of energy storage systems options which are can be divided into two major categories such as large scale storage devices that can be used in transmission application and the other one is small scale storage devices which will be located at consumer's site [6].

In this project, piezoelectric element has been used to convert the ambient sources such as vibration into electrical energy which will go through into the AC-DC rectifier first then will be directly connected to DC-DC converter before the energy go to the energy storage system block [4][7]. The power from the energy storage will be applied to the load such as wireless sensor network (WSN) which are likely currently been used in most of health monitoring. We are using capacitor as our temporary system storage. As we know capacitor is capable to store the energy inside and can be used at anytime.

We are also proposed for using supercapacitor or ultracapacitor instead of regular capacitor as it provides more long lifetime which can be last for 10years compared to normal capacitor [1][8]. It also able to charged and discharge almost unlimited time and most importantly is its free hazardous released which can damage the environment.

The proposed method is very useful especially in wireless sensor network as it is more convenient and efficeint due to self-powered. The power stored will give energy to the wireless sensor network for transmitting and receiving data. During the standby and sleep mode the system storage will store as much energy as posible as at this stage the wireless sensor network will consume a very minimum amount of energy. Using batteries in traditional way for powering WSN is no more a practical way as replacing batteries is such troublesome works and quite costly though. Once the battery power runs out, the WSN as well will stop working and the health monitoring will loss signal from the patient. That is where the energy storage is very important which it can continuously supply the power for WSN.

II. METHODOLOGY

The whole system consists of piezoelectric element, AC-DC rectifier, DC-DC converter (boost-up converter) and energy storage which are ilustrated through Fig. 1 below.

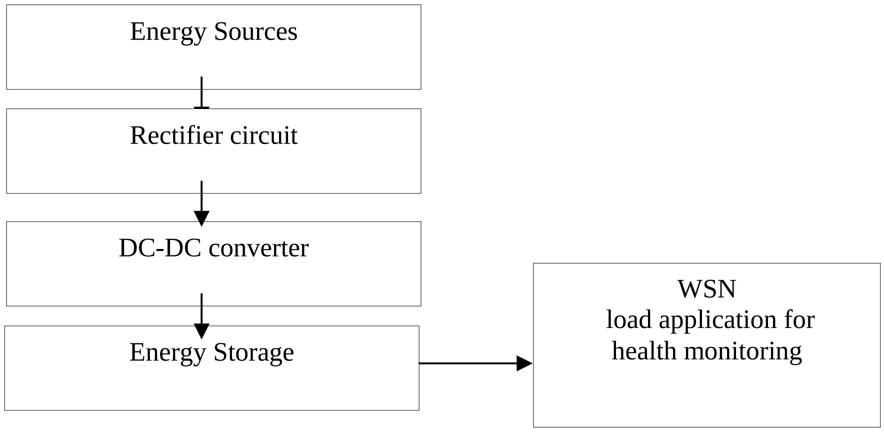

Fig. 1: Block diagram of energy harvesting circuit for system storage

A. Energy Sources

The source of energy is derived from the ambient environment such as vibration and wind and it is called energy harvesting or energy scavenging which is very low power and low voltage. In this project we applied two types of energy source; one is RF energy and the other one is vibration energy. RF energy was emitted by radio wave of electromagnetic field such as TV signal, cellular base station and wireless networks. The energy will be derived from the receiving antenna then be converted into useable DC voltage through the a power generating circuit. The vibration energy is the energy that can be found in so many ways and very low voltage and can be as low as 600mV AC power source. The vibartion energy sources can be derived from piezolelectric element which shown in Fig. 2 below.

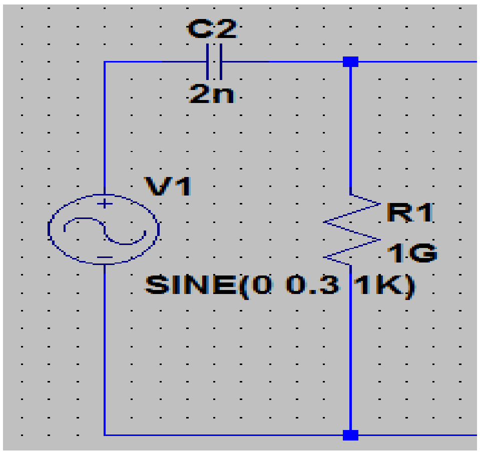

Fig. 2 : A piezoelectric element in electric model, draw in LTspice tool

B. AC to DC Rectifier Circuit

AC to DC rectifier is the first step of energy harvesting circuit which will be connected at the output of piezoelectric harvester and convert the AC voltage into DC voltage. Instead of using diode full wave rectifier, mosfet full wave rectifier has been chosen in order to make sure that the rectifier circuit will works at very low voltage[9]. Diode full wave rectifier will not working due to the forward voltage is higher than the input voltage.

The rectified voltage will have a lot of ripple as shown in results that been captured by LTspice software. In order to reduce the ripples, capacitor will be added at the output of the rectified circuit and this will also help to regulate the voltage as fixed DC output voltage level. Fig. 3. shows the circuit for Mosfet full wave rectifier.

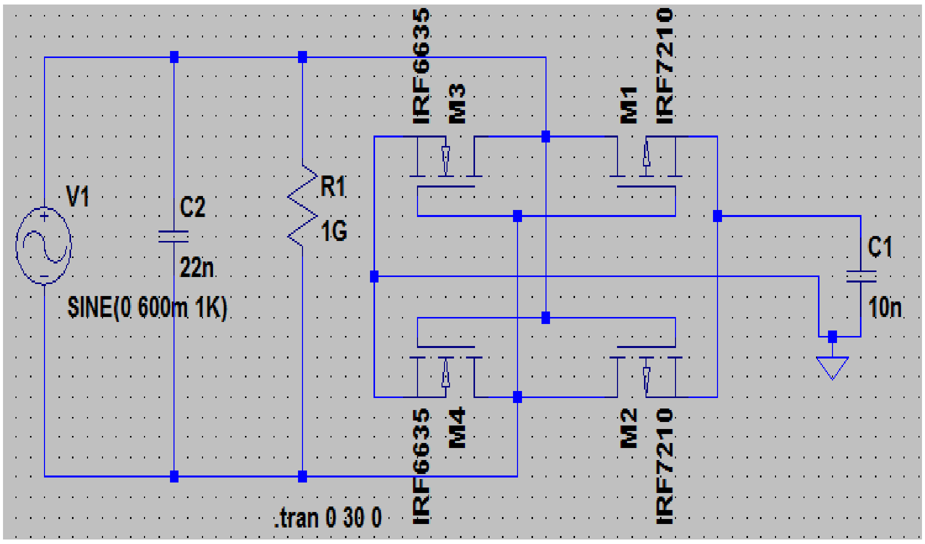

Fig. 3: Mosfet full wave AC to DC rectifier circuit in LTspice tool.

C. DC to DC Converter

For the DC to DC converter, we choose normal step up converter with adding of self oscilating and starting aid circuit so that the circuit will be working even at low input voltage. A basic step up converter[10][11] circuit comprised of an inductor, a swithcing device typically a MOSFET , a diode as a second switch and the output capacitor as shown in Fig. 4 below.

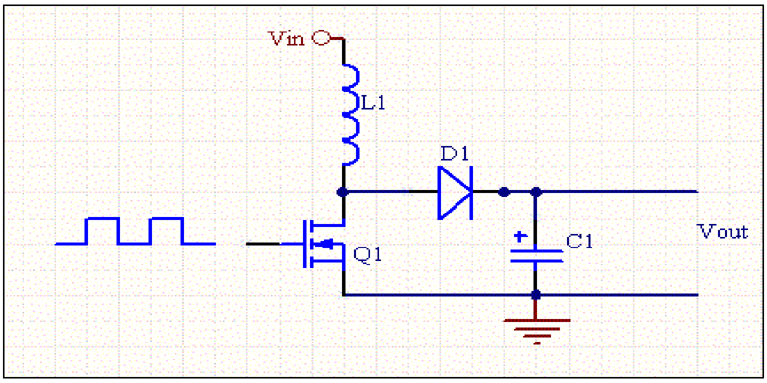

Fig. 4: Basic circuit diagram of step-up converter[12]

Q1 is closed at the first cycle while D1 is open and the currents begin to flow at inductor and increases according to the time constant, this is called the storage phase. At the second cycle, Q1 will open while D1 is closed so the currect flows from Vin to the load and decreases and the energy stored in the inductor is dicharged into the load. This is called delivery phase.

Here is the design equation that been used for the component selection for the circuit design. The equation is derived assuming that the converter is in the continuous mode which the inductor's current never goes to zero.

When Q1 is on, the equation is below:

$V = L\frac{di}{dt}$ then $i = \frac{Vt}{L} + i_o$ where i_o is the minimum inductor current

$i_{pk} = \frac{(V_{in} - V_{mos}).T_{on}}{L}$ Where i_{pk} is peak inductor current, V_{mos} is voltage drop across the mosfet

When Q1 is off, the current is:

$i_o = i_{pk} - \frac{(V_{out} - V_{in} + V_d).T_{off}}{L}$ where V_d is Voltage drop across the diode

by equating i_{pk}, the equation become:

$$\frac{(V_{in} - V_{mos}).T_{on}}{L} = \frac{(V_{out} - V_{in} + V_d).T_{off}}{L}$$

$$V_{in}.T_{on} + V_{in}.T_{off} = V_{out}.T_{off} + V_{mos}.T_{on} + V_d.T_{off}$$

$$V_{in}.(T_{on} + T_{off}) = (V_{out} + V_d).T_{off} + V_{mos}.T_{on}$$

$$V_{in} - V_{mos}.D = (V_{out} + V_d).(1 - D)$$

$$\therefore V_{out} = \frac{V_{in} - V_{mos}.D}{(1 - D)} - V_d$$

From above equation, as known $T_{on} = D$, $T_{off} = 1 - D$

if we neglet the voltage drops across the mosfet and diode, the equation will become:

$V_{out} = \frac{V_{in}}{(1 - D)}$ where D is the Duty cycle.

For inductor components selection, the equation can be expressed as below:

$$L = \frac{(V_{out} - V_{in} + V_d).(1-D)}{(i_{load}).f}$$ where i_{load} is load current and f is the frequency for driving the mosfet.

D. Energy Storage

This is the important part as the energy storage will supply the power for WSN application instead of using the batteries that need for replacement if the batteries power runs out. If the energy storage doesn't work propoerly or didin't supply enough power then the WSN will not working as well. In this project, capacitor will be used as temporarily storage system and in the future we've planned to store the energy in supercapacitor to supply the load application. Table II. below shows the comparison between normal capacitor and supercapcitor where becomes under considerations to choose which is more suitable for low power applications.

TABLE II
Comparison between regular capacitor and supercapacitor

Comparison	Normal capacitor	Supercapacitor
Capacitance	Low capacitance	High capacitance
Medium	Single layer of dielectric medium	Two layer of dielectric medium
Storage capacity	several thousand times for the storage capacity and uses a moist separator	ideal for energy storage that undergoes frequent charge and discharge cycles at high current and short duration.
Voltage limit	withstand high volts	confined to 2.5V–2.7V. Need to be connected in series to achieve high voltage
Discharge curve	delivers a steady voltage in the usable power band	the voltage of the supercapacitor decreases on a linear scale from full to zero voltage
Cost	Very cheap	expensive in terms of cost per watt
Charging time	In miliseconds	1-10second

III.RESULTS AND DISCUSSION

The model simulation of mosfet full wave rectifier and boost up converter modelling was done using LTspice software. Based on Fig. 5 and Fig. 6 below, it shows the result of mosfet full wave rectifier and the boost converter. .The result of step up converter shows that the converter is able to boost up the input voltage even lower than 1V. This is assuming that the energy harverter source is very low voltage and can be as low as 0.6V. This output voltage will temporarily stored in the capacitor before going to the proposed energy storage which is supercapacitor.

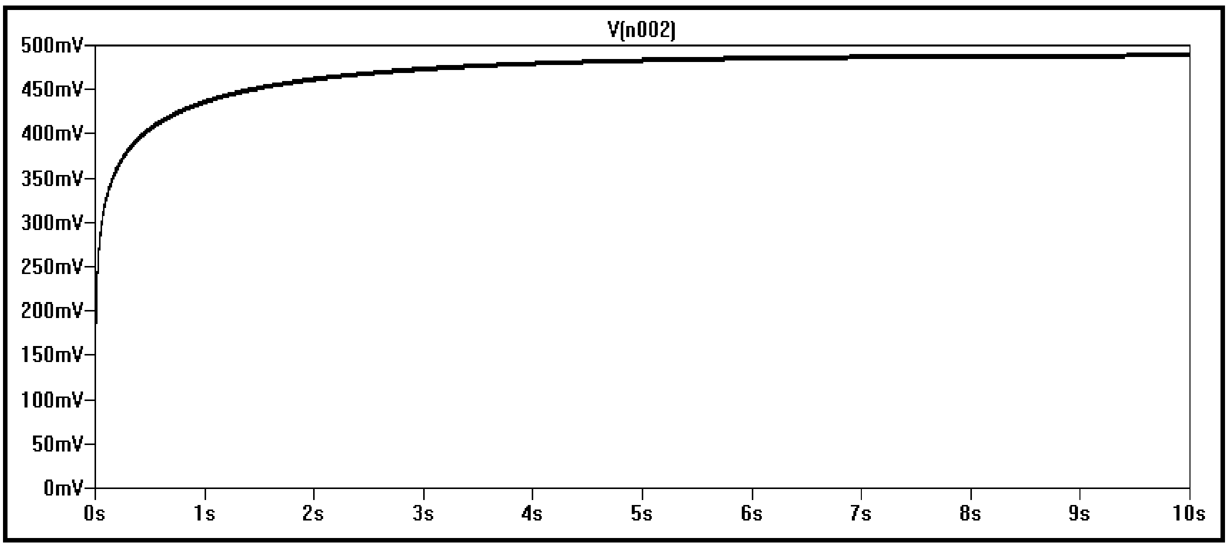

Fig 4: MOSFET full wave output rectifier

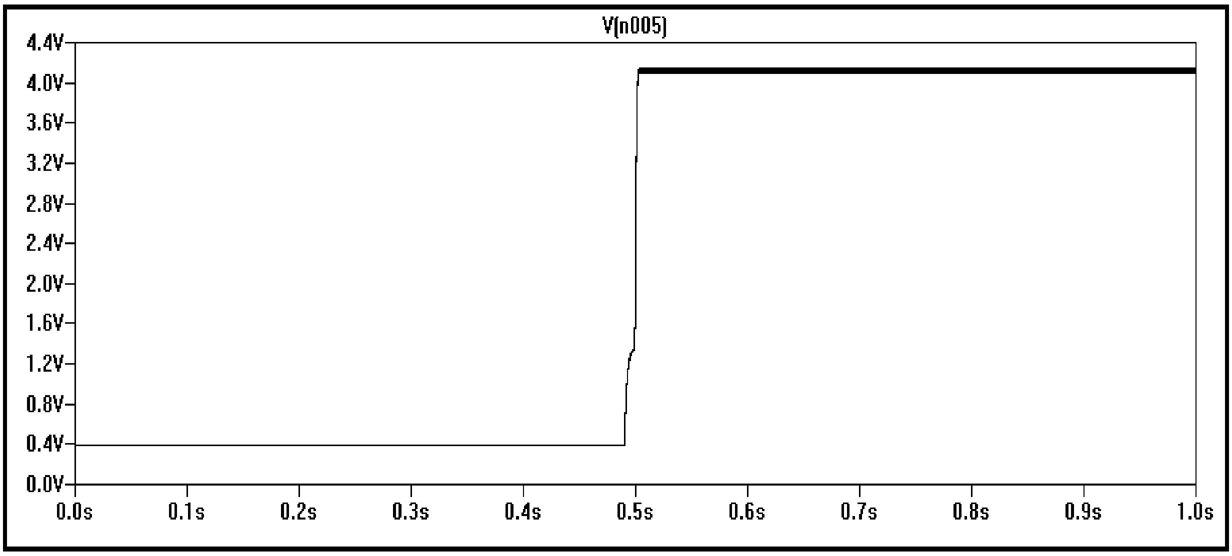

Fig 5: output voltage of DC to DC converter

The results show that the converter efficiency is around 85.4%. The output current is 90mA thus the total power output is P=VI equal to 369mW and it is enough to supply the Wireless sensor network application according to [13].

IV. CONCLUSION

The model of the whole system energy harvesting circuit was developed by LTspice simulation and the results can be seen in the result section above. DC to DC converter which is use a regular step up converter is able to boost up the input voltage from 0.6V up to 4.1V and the efficiency is 85.4%. For future work mainly will be focused on the hardware design of DC-DC converter to verified that the system storage is working for the real application and not just in the simulation.

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