A Power Converter System for Energy Harvesting Toward Zero Net Battery Power

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1. Introduction Recently, energy harvesting (EH), which is a technology to obtain electric power from the environment around us, is attracting attention [1-6]. In [4], since the battery and the transducer are connected in parallel to the power conversion circuit, three converter operations are required: from the battery to the load, from the generator to the load, and from the generator to the battery. Because boost and buck operations are necessary for this converter system, the control circuit is complicate, and thereby the power loss with the control circuit operation can become large. Therefore, in this paper, we propose a simple power converter system with the battery and the transducer connected in series which requires only buck operation.

2. Proposed circuit Fig.1 is a block diagram of a proposed circuit. Parameters are as follows: V_{BAT}; voltage of battery, V_{EH}; voltage generated by EH, V_{IN}; input voltage to converter, V_{REG}; output voltage of converter, R_{EH}; internal resistance of EH, R_L; load resistance, I_{BAT}; current flowing from battery, I_{IN}; input current of converter, I_{REG}; output current of converter, I_{LOAD}; load current, I_{BACK}; current returned to battery, and η; conversion efficiency of converter. V_{IN} is increased by connecting the battery and EH in series. In the converter, only the buck operation is carried out to increase the output current. V_{REG} is set to be ΔV larger than V_{BAT}. $V_{IN} - I_{LOAD}$ relationship is calculated as (1). V_{IN}^{opt} to maximize I_{LOAD} is given by (2), which defines the maximum power point of the system. From (1) and (2), I_{LOAD}^{max}, $\mathrm{I_{LOAD}}$ at $\mathrm{V_{IN}} = V_{IN}^{opt}$, is given by (3). Next, we define BLE (Battery Life Extension) to indicate how long the battery life is extended. The power consumption P_{conv} is defined as $I_{LOAD} \times V_{BAT}$ when a battery with no converter outputs I_{LOAD} at V_{BAT}, whereas the power consumption P_{prop} is defined as $I_{BAT} \times V_{BAT}$ in the proposed circuit. BLE is defined as P_{conv}/P_{prop}. When BLE > 1, the battery life is considered to be extended. When $I_{BACK} = I_{BAT}$, the power consumption of the battery can be net zero.

3. Validation To validate (3), SPICE simulation was run as shown in Fig.2 under the condition of $V_{BAT} = 3\mathrm{V}, \Delta V = 0.1\mathrm{V}, I_{BAT} = 0\mathrm{A}$. Since V_{EH} and $\mathrm{R_{EH}}$ are proportional to the series number of TEG elements and R_{EH} is inversely proportional to the parallel number, two cases of $R_{EH} = 600\Omega$ and $V_{EH} = 0.6\mathrm{V}$ [7] or $R_{EH} = 2.4\mathrm{k}\Omega$ and $V_{EH} = 1.2\mathrm{V}$ were investigated. The converter was modeled by a transformer with power efficiency of η. In Fig. 2, theoretical curves (3) are also plotted. When $\eta \geq 92\%$ at $V_{EH} = 0.6\mathrm{V}$ and about $\eta \geq 84\%$ at $V_{EH} = 1.2\mathrm{V}$, the proposed converter system can drive the load at $I_{LOAD} = 10\mu\mathrm{A}$ without battery power consumption. In addition, the system can operate even at lower η with more TEG elements connected in series. Fig. 3 shows the results of SPICE simulation and numerical calculation of BLE for various I_{LOAD}. Parameters were $\Delta V = 0.1\mathrm{V}, V_{EH} = 0.6\mathrm{V}, R_{EH} = 600\Omega$, $\eta = 0.9, V_{BAT} = 3\mathrm{V}, 1.5\mathrm{V}$. It was found that the lower the voltage of the battery, the higher the BLE even at higher load current.

4. Conclusion A power converter system with the battery and the transducer connected in series was proposed and its electrical characteristics were presented. The system performance was validated with SPICE simulation. When η is sufficiently high, battery can consume zero net power. Energy transducer should be composed such that V_{EH} and R_{EH} become higher to make the system more effective. The proposal converter system will be compared with a boost converter system. Because the input voltage of the converter is increased from the battery voltage in the proposal system, the converter can be designed in a standard CMOS technology which doesn't provide special low-Vt transistors for low cost.

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References

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$$I_{LOAD} = \frac{1}{R_{EH}V_{REG}}\left[-\eta\left\{V_{IN} - \frac{\eta(V_{BAT}+V_{EH})+V_{REG}}{2\eta}\right\}^2 + \frac{\{\eta(V_{BAT}+V_{EH})+V_{REG}\}^2}{4\eta} + \{I_{BAT}R_{EH}V_{REG} - (V_{BAT}+V_{EH})V_{REG}\}\right] \quad (1)$$

$$V_{IN}^{opt} = \frac{\eta(V_{BAT}+V_{EH})+V_{REG}}{2\eta} \quad (2)$$

$$I_{LOAD}^{max} = \frac{1}{R_{EH}V_{REG}}\left[\frac{\{\eta(V_{BAT}+V_{EH})+V_{REG}\}^2}{4\eta} + \{I_{BAT}R_{EH}V_{REG} - (V_{BAT}+V_{EH})V_{REG}\}\right] \quad (3)$$

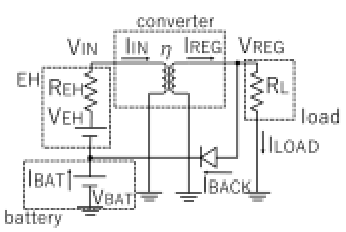

Fig. 1. Block diagram of a proposal system

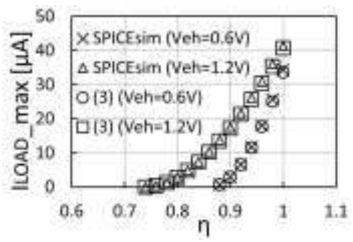

Fig. 2. η vs I_{LOAD}^{max}

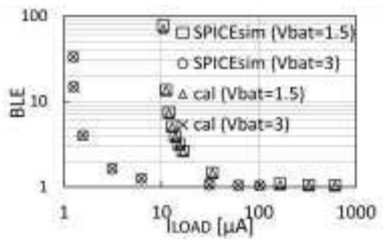

Fig. 3. I_{LOAD} vs BLE