Resonant matching power management circuit based on coil electromagnetic energy acquisition

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Abstract

It is gradually being valued by researchers at home and abroad by converting the electromagnetic field energy around the wire into electric energy and supplying power to the sensor node through the coil type electromagnetic energy harvester. Based on the output characteristics of the magnetic field energy harvester, a series resonant power management circuit is designed, and the supercapacitor of the energy storage component is charged and the supercapacitor is protected. Compared with the non-matching circuit and the parallel resonant circuit, the charging power of the circuit is improved. . Experiments show that in the case of a small current with a wire current of 2A, the series resonant matching circuit can increase the output power of the energizing coil by 2.6 times and the charging speed of the super capacitor by 4 times.

Keywords

Electromagnetic energy harvesting, resonant matching, power management.

1. Introduction

The development of wireless sensor network systems and MEMS technology has facilitated people's lives. More and more wireless sensor nodes are used in many fields such as environmental monitoring, industrial process monitoring, building monitoring, and military. Traditionally, wireless sensor nodes are typically powered by batteries, and relying solely on battery power greatly limits the application site and lifetime of the system. Therefore, the use of environmental energy harvesting to solve the power supply problem of sensor nodes has broad market and scientific research value [1-2]. If the ubiquitous solar energy [3], wind energy, thermal energy, tidal energy, acoustic energy, vibration energy, and electromagnetic energy can be converted into electrical energy as wireless sensors Node power supply, with the increasing number of electrical equipment, power cables are widely distributed in factories, homes, workshops, power systems and other places. Therefore, the electromagnetic energy around the wire becomes a potential energy source for good energy harvesting. Tebesh et al. proposed an adaptive power management circuit consisting of a Buck regulator for piezoelectric vibration energy harvesters [4]. Rodríguez et al. studied electric field energy harvesting to solve the problem between power line and energy harvesting system. For the weak capacitive coupling problem, a self-triggered non-continuous working flyback converter is designed[5].

This paper analyzes the working principle and output characteristics of the electromagnetic energy harvester, and designs a series resonant power management circuit that can be applied to the sensor node. This circuit can improve the output power of the collector on the basis of the traditional electromagnetic energy harvester. When the current effective value is 2A, the coil is 3000匝, and after matching, the maximum output power of the energizing coil is obviously improved, which is 2.6 times before the matching, and the charging speed of the super capacitor can reach 4 times when there is no matching.

2. Resonance matching

According to the circuit principle, in a circuit loop composed of a resistor, an inductor and a capacitor, the impedance Z can be expressed as:

$$Z = R + j\omega L - j\frac{1}{\omega C} \qquad (1)$$

Where R is the resistance, ωL is the inductive reactance, and $1/\omega C$ is the capacitive reactance.

For the energy-carrying coil, $\omega L >> 1/\omega C$, the capacitive reactance can be neglected, the entire energy-carrying coil is inductive, and the coil will output a large reactive power, thereby reducing the output power of the energy-carrying power supply. When the auxiliary angle of the equivalent impedance of the coil is zero, the coil will become a resistive output. At this time, the output active power is the largest, the reactive power is the smallest, and the circuit will resonate. It can be seen from Equation 1 that when $\omega L = 1/\omega C$, the circuit resonates, the resonant frequency is:

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad (2)$$

In this paper, the resonant frequency is 50Hz power frequency, and the inductance L is determined by the energizing coil, so the circuit can be resonated by matching the capacitor C, thereby increasing the active power of the coil output.

The capacitor is tested in series with the energizing coil to determine the matching capacitor value. In the figure, the 3000 energy-carrying coil is placed in the wire, and the wire current is 1A. The capacitance value is determined by continuously changing the capacitance value and measuring the voltage across the capacitor. The output voltage of the energy-carrying coil changes with the capacitance curve. See Figure 1. When the matching capacitor is 0.57μF, the output voltage is maximum, and the coil circuit resonates in 50Hz alternating current.

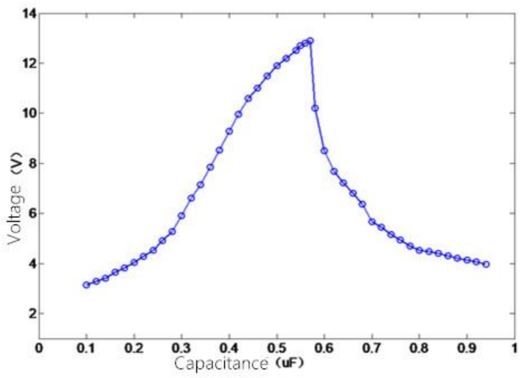


Figure 1 Curve of coil output voltage with capacitance

3. Power management circuit

Since the output power of the coil is small, it is generally impossible to directly drive the load. Therefore, the power management circuit is required to store and release the power to supply power for low-power loads such as wireless sensor nodes. 2 is a block diagram of the overall structure of the power-receiving power management circuit, which is mainly composed of a resonant matching circuit, a protection circuit, a rectifier circuit, an energy storage circuit, a regulated output circuit, an auxiliary power supply, a voltage monitoring and a control circuit.

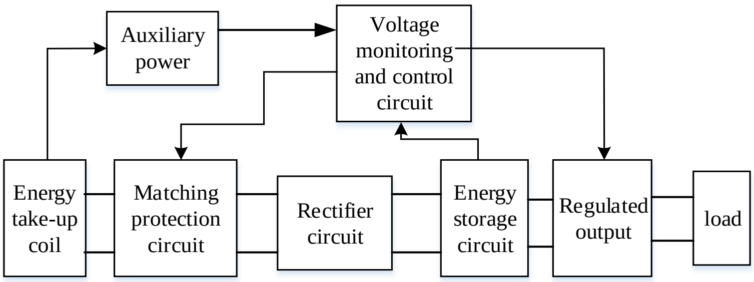


Figure 2 Power management circuit block diagram

This paper designs a control circuit to stop charging the capacitor to protect the super capacitor when the voltage across the super capacitor reaches the preset threshold voltage. Figure 3 is a schematic diagram of the control circuit and the bidirectional switch circuit. In this paper, the control circuit uses MAXIN's comparator MAX917. By selecting resistors R1, R2, and R3, the threshold voltage of the comparator can be determined, and the overall power consumption can be controlled within 5μW. Set high voltage threshold VH=5V, low voltage threshold VL=4.7V, supply voltage is 5V, then threshold voltage VHB=5-4.7=0.3V to reduce comparator power consumption, control current flowing through R3 is not more than 1μA, calculation Available:

$$R_3 = \frac{V_{REF}}{I_{R3}} = \frac{1.2V}{1\mu A} = 12M\Omega \tag{3}$$

Therefore:

$$R_1 = R_3 \frac{V_{HB}}{V_{CC}} = 48K\Omega \tag{4}$$

$$R_2 = \frac{1}{\frac{V_H}{V_{REF} \cdot R_1} - \frac{1}{R_1} - \frac{1}{R_3}} = 15.8K\Omega \tag{5}$$

The bidirectional switch is constructed by connecting two passive NMOS tubes in series. Since the NMOS tube has a single-conductivity and the output of the energy-carrying coil is AC, as shown in Figure 3.11, when the voltage is greater than the turn-on voltage of the MOS tube, the bidirectional switch leads. Pass, short the output coil and stop supplying power to the back-end circuit. In this paper, the MOS tube uses NVD6824N-MOSFET produced by ON Semiconductor.

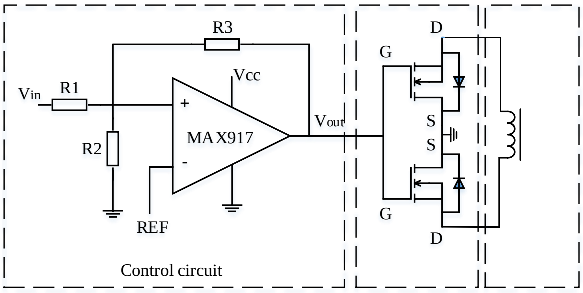


Figure 3 control circuit and bidirectional switch schematic

Figure 4 shows the working flow chart of the protection control circuit. The two threshold voltages V_H and V_L are set. The control circuit monitors the voltage across the supercapacitor in real time. When the input signal is higher than V_H, the comparator outputs 5V high level and controls the bidirectional switch K to conduct. Short-circuit the energizing coil to stop charging the supercapacitor; when the supercapacitor supplies power to the back-end circuit, the voltage is continuously reduced. When the voltage across the supercapacitor is less than V_L, the comparator outputs a low level, the control switch K is disconnected, and the coil continues to The super capacitor charges until the voltage exceeds the threshold voltage.

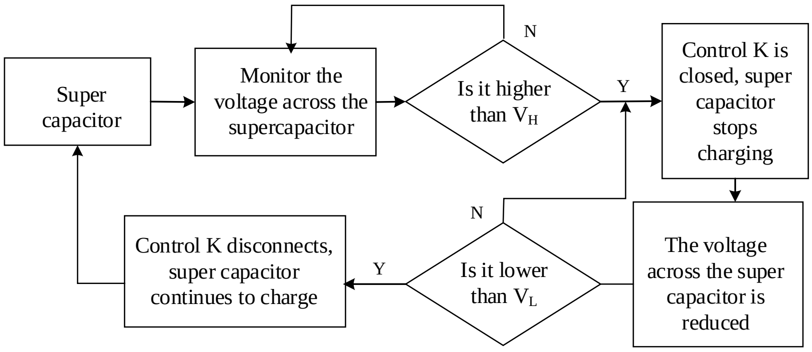
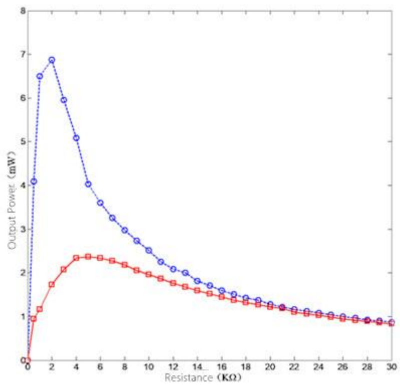


Figure 4 protection control circuit work flow chart

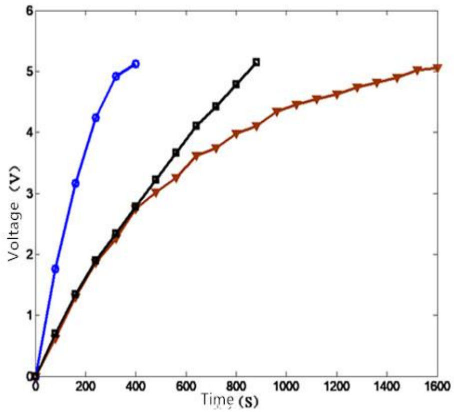
This article uses the ultra-low-power linear regulator of model S-1313. The output voltage of the chip is 3.3V, and the input voltage is 3.3~5.5V. The comparator MAX917 is also used to design the control circuit. The threshold voltage is set to 3.3V~4.5. V, when the super capacitor is charged to 4.5V, the LDO circuit works normally, ensuring that the sensor node can be initialized normally. When the voltage across the super capacitor is less than 3.3V, the output LDO circuit is enabled to ensure that the super capacitor is normally charged.

4. Conclusion

As can be seen from Fig. 5, the maximum output power of the energizing coil after matching is significantly improved, which is 2.6 times that before the matching. Therefore, when the primary side current is small, the resonant matching can significantly improve the output power of the energizing coil. After the capacitor is matched, the charging speed of the super capacitor is four times that of the previous one.



(a) Comparison curve of output power of coil before and after matching



(b) Super capacitor charging test comparison chart

Figure 5 Comparison of test results

Figure 6 is a graph showing the experimental results of the output circuit. In order to quickly charge the capacitor, a 470μF capacitor is used instead of the super capacitor. When the capacitor is charged to 4.5V, the regulated output circuit starts and outputs 3.3V. After the capacitor is charged to 5V, the protection control circuit is activated to limit the voltage across the capacitor to between 4.7V and 5V. The voltage across the capacitor drops and the regulated output circuit turns off when it drops to 3.3V。

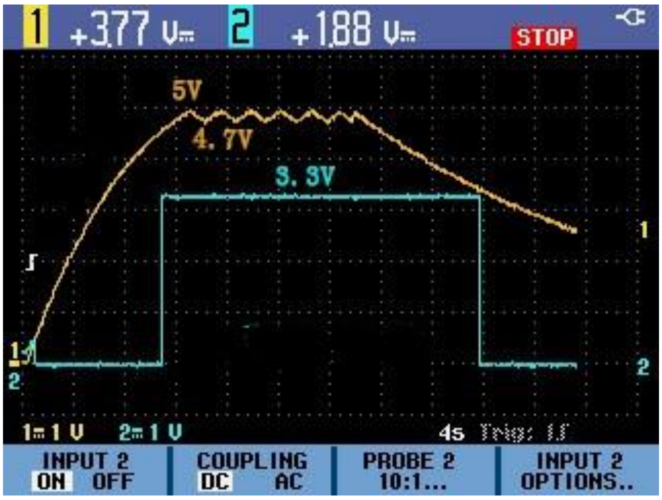


Figure 6 Control circuit and voltage regulator output circuit test results

This paper mainly designs a resonant matching power management circuit for the energy-carrying coil. First, the impedance of the energizing coil is made purely resistive by means of resonant matching, thereby increasing the active power output of the energizing coil. Secondly, the induced alternating current is rectified to charge the super capacitor, and the charging rate of the super capacitor before and after the energizing coil is matched is compared. After the resonant matching, the maximum output power of the energizing coil is 2.6 times that before the matching, and the charging speed of the super capacitor is 4 times that of the previous one.

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