Nuclear Power Plant Autonomous Surveillance System with Solar Cell

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1. Introduction

After Fukushima nuclear accident, safety of Nuclear Power Plants(NPPs) is attracting public attention. Accordingly, safety and surveillance of NPPs have been researched more actively since the accident. Among many methods to monitor NPPs, aerial robots(ARs) defined as unmanned aerial vehicle, which can equip various sensors, GPS, and actuator are being presented to monitor environment of NPPs [1]. ARs can be used to detect the point of nuclear accident where human cannot access due to unexpected additional explosion and high radioactive contamination. But it is hard to operate AR for more than 30 minutes even in case of fully charged condition, because of lack of battery capacity. AR should be charged every 30 minutes to surveil continuously but that is difficult to charge AR automatically using wire. So the way to charge AR wirelessly was proposed to solve the automatically charging problem [2] but the suggested solution needs external energy source such as power grid, that means the solution will not work well in the case of disconnection with power grid by nuclear accident.

In this paper, method to overcome charging problem of ARs without the external energy source is proposed for autonomous surveillance system of NPPs and is verified by fabricated prototype of the system.

2. Concept and Design of the System

2.1 Wireless AR Charging System with Solar Cell Panel

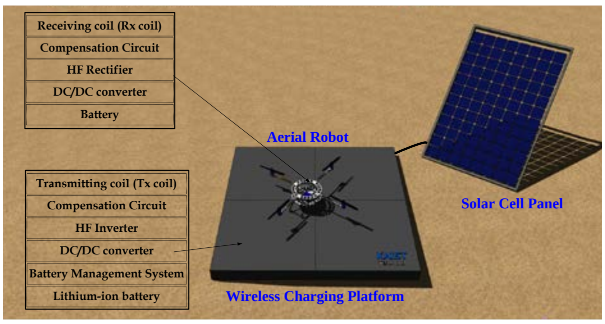


Fig. 1. Overall system component.

The proposed system is composed of solar cell panel, wireless charging platform and AR, as shown in Fig. 1. As solar cell panel is used to supply energy to wireless charging platform, the proposed system can detect environment of NPPs autonomously even though energy supply from power grid ceases due to the accident of NPP. Transmitting(Tx) coil, High Frequency(HF) inverter, DC/DC converter, compensation circuit, Battery Management System(BMS), and lithium-ion battery are included in wireless charging platform to transfer energy to AR. AR part consist of Receiving(Rx) coil, compensation circuit, HF Rectifier, DC/DC converter, and battery.

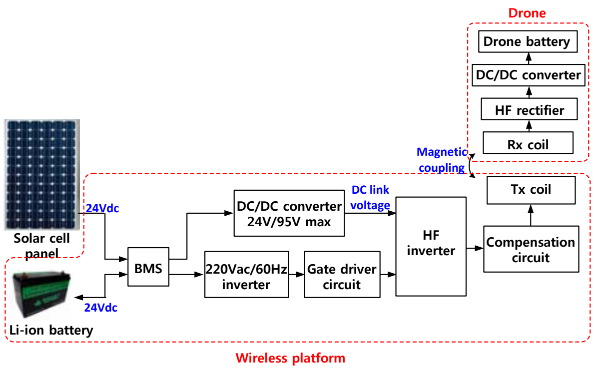
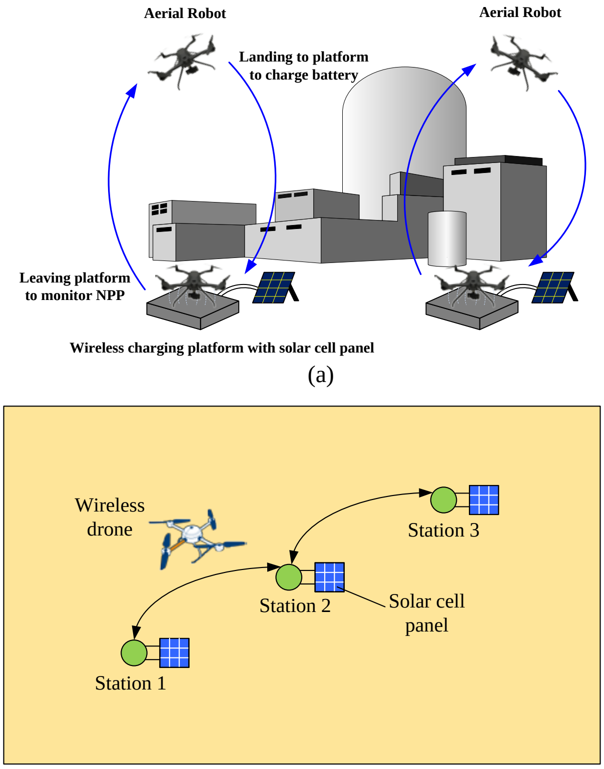


Fig. 2. Block diagram of wireless AR charging system.



(a)

(b)

Fig. 3. Operation concept of (a) continuous surveillance system, (b) the AR with extended operation range.

Wireless AR charging system is shown in Fig. 2. Output voltage of solar cell panel or battery is boosted up by DC/DC converter to supply proper high DC link voltage to HF inverter. High frequency current flows through inverter, compensation circuit, and Tx coil so that AC magnetic field between Tx coil and Rx coil is made, which induces AC voltage at Rx coil. The AC voltage is rectified to DC voltage, which is dropped by DC/DC converter and the dropped voltage charges battery of AR.

2.2 The Operation Concept of the System for NPPs

If there are two ARs in surveillance area, when battery of one AR, which is conducting surveillance, is almost discharged, the AR can relieve the other AR, which has charged. Consequently, the continuous surveillance can be achieved as shown in Fig. 3(a). If multiple number of stations with solar cell are operated, wide area can be monitored with less number of ARs as shown in Fig. 3(b). If regular surveillance is required in wide area, the way shown in Fig. 3(b) can be useful.

2.3 The Design of System

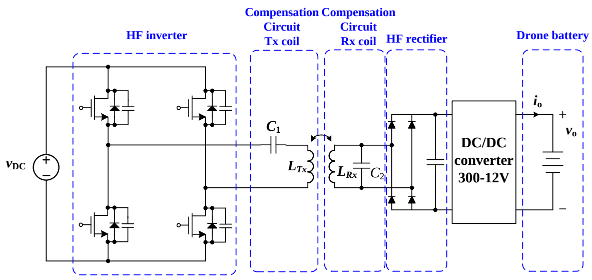


Fig. 4. Equivalent Circuit of Wireless Platform.

Wireless platform in Fig. 2 can be expressed to equivalent circuit as shown in Fig. 4. In Fig. 4, V_{DC} is output of DC/DC converter, which is supplied with energy by battery or solar cell. Switching frequency of HF inverter is 800 kHz. Tx coil is compensated by series topology to enhance power factor and simplicity of system and Rx coil is compensated by parallel topology to reduce weight and number of turns of Rx coil. DC/DC converter is used to charge battery of AR which is charged with 12 V

3. Experimental Verification

3.1 Fabrication of Experimental Sets

Because operating frequency was too high to use with ferrite core, Tx coil of loop type was fabricated without ferrite core as shown in Fig. 5. In the same manner, Rx coil was also fabricated as coreless loop type and HF rectifier, DC/DC converter are attached to AR as shown in Fig. 6. Fabricated Tx coil and Rx coil parameters are shown in Table I.

Fabricated prototype is shown in Fig. 7. Variable capacitors were used to adjust output voltage minutely.

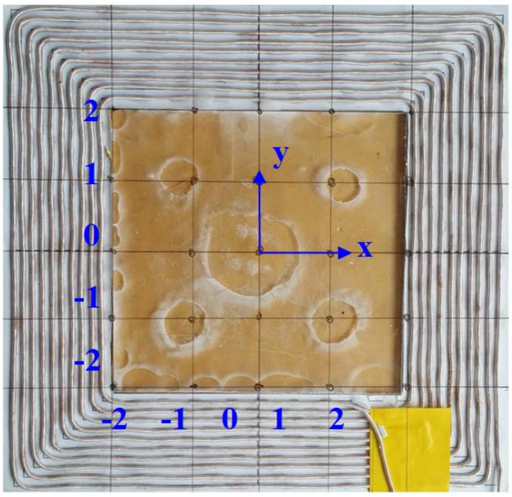


Fig. 5. Coreless Tx coil.

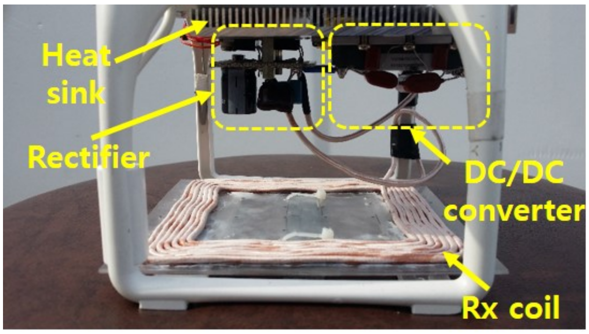


Fig. 6. Coreless Rx coil with rectifier and DC/DC converter.

Table I: Parameter values of Tx and Rx circuit

Parameter	Value (unit)
L_{Tx}	44.7 (uH)
L_{Rx}	10.4 (uH)
C_1	893 (pF)
C_2	3.21 (nF)
N_1	10 (turns)
N_2	6 (turns)

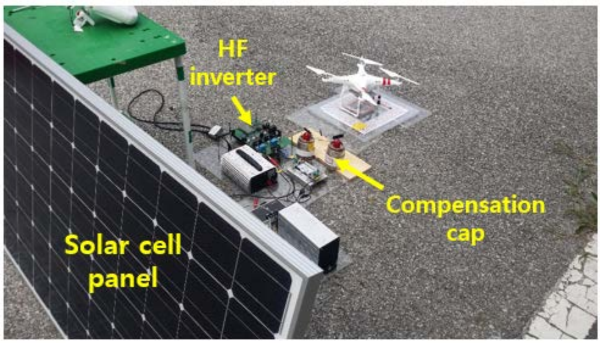


Fig. 7. Fabricated prototype of the proposed system.

3.2 Experimental Result

When xy coordinate was applied in way shown in Fig. 5. Power larger than 25 W, which takes about 3 hours to fully charge the battery used in our experiment, was charged at most area and larger than 32 W was charged at edge and center part because magnetic flux density of those part was stronger than other part as shown in Fig. 8. Assuming our wireless charging system is used and AR can operate for 30 minutes in the fully charged condition, more than six ARs are required to achieve the continuous surveillance system, which is inefficient because many ARs should be used. so the additional research is required to increase output power. Maximum power and efficiency were 40 W and 52 % respectively.

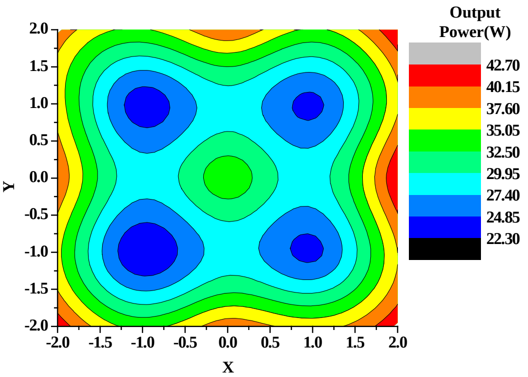


Fig. 8. Output power distribution.

4. Conclusions

In this paper, autonomous surveillance system without external energy source is proposed and verified by experiment. Power more than 25 W was charged at most area above Tx coil and maximum efficiency was 52 %. But output power of 25 W is inefficient to achieve the efficient system because too many ARs are required for continuous surveillance. So additional research should be conducted to increase output power.

REFERENCES

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