A Review on Different Parameters Considered for Improvement in Power Conversion Efficiency of Rectenna

Chapter · January 2020

DOI: 10.1007/978-981-13-8715-9_10

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Abstract Radio Frequency Energy Harvesting is a technique used for gathering electromagnetic energy from various ambient RF sources like cell towers & Wi-Fi hotspots, and convert it into usable direct current (DC) voltage form. The performance of rectenna is measured with the help of parameters like power conversion efficiency (PCE) & sensitivity. High efficient design of rectenna is needed as it can be used in various applications like, wireless power harvesting networks (WSN and IoT), Smart City, Medical & Healthcare, RFID and Smart Jewelry applications. This paper reviews different parameters needed to be optimized which are used for improvement in PCE of rectenna.

Keywords RF energy harvesting · Rectenna · Power conversion efficiency

1 Introduction

(PCE) defines as the ratio of the power given to the load and power received at antenna. While calculating power conversion efficiency (η_{PCE}), the efficiency of the antenna (η_A), efficiency of rectifier or voltage multiplier (η_R), and efficiency of impedance matching network (η_M) are considered, it is calculated as;

$$\eta_{PCE} = P_{load}/P_{received} \quad (1)$$

where, P_{load} is power at load and $P_{received}$ is harvested power at the antenna. Parameters that decide the value of PCE contains effects of components used, leak in the circuits, topologies used for design, as well as varying cut-off values of components used in rectenna.

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A. Kumar and S. Mozar (eds.), *ICCCE 2019*, Lecture Notes in Electrical Engineering 570, https://doi.org/10.1007/978-981-13-8715-9_10

This paper reviews different parameters needed to be optimized which are used for improvement in PCE of rectenna. Section 2 describes parameters need to be optimized for improvements in power conversion efficiency. Various applications of rectenna are summarized in Sect. 3 & finally conclusion is drawn from these discussions.

2 Parameters Need to Be Optimized for Improvement in Power Conversion Efficiency

A rectenna contains an antenna and rectifier, it also contain impedance matching network for matching between antenna & rectifier. For improvement in PCE performance of all components present in rectenna needed to be improved, in this section we will see different parameters related to components included in rectenna, responsible for value of PCE.

2.1 Parameters Related to Antenna

Frequency of Operation In ambient environment radio waves are generally located in range of 800 MHz to 2.5 GHz. Operating frequency of rectenna is selected on basis of value of power density at that frequency. For larger frequency input power is also large. A crucial topic in ambient energy harvesting is that available power density is very low in ambient RF environment, which essentially restricts the availability of power for harvesting and this result in lower PCE. To increase harvested energy, antenna needs to collect the signals from different frequency bands; hence a multiband antenna is ideal for collecting more signals & to achieve more PCE.

Polarization The location of radio frequency source is unknown; due to this signal can be collected from different directions. Hence, omnidirectional antenna with circularly polarized; dual polarized [1]; dual circularly polarized [2] antennas will be a good choice for improvement in PCE.

Gain For antenna as a receiver, gain indicates effectiveness of conversion of received signal into electrical power. Antenna efficiency is increased when gain of antenna increased, so a high gain antenna is a good choice. For improvement in gain techniques like, rectenna array [3, 4], differential antenna [5, 6], use of defected ground structures, metamaterial rectenna, slotted antennas are implemented.

Impedance Most of antennas are designed for 50 Ω impedance, but by using increased impedance antenna having impedance in range of 100–200 Ω, matching network can be eliminated, thus improving PCE.

Substrate Material Generally a low cost, easily available substrate material like FR4 ($\varepsilon_r = 4.4$, tan $\delta = 0.02$) is used for antenna, but a substrate material with lower losses like Rogers RT6002 ($\varepsilon_r = 2.94$, tan $\delta = 0.0035$) improves PCE of rectenna.

2.2 Parameters Related to Impedance Matching Network

Impedance Matching Network (IMN) is used for transferring maximum power between radio frequency source & load. The performance of system reduced due to impedance mismatch, so an IMN is needed. But, in recent days trend of elimination of matching network is increased as due to presence of matching network 82% of total input power get wasted [7]. Some of the compact & efficient rectennas are presents in [8–10], which uses a high impedance antenna those are directly matched with impedance of rectifier, for elimination of matching network.

2.3 Parameters Related to Rectifier

Rectifiers are used for conversion of AC signals to DC signals, and voltage multiplier is a special type of rectifier that converts and improves AC input to DC output. For selecting rectifier or voltage multiplier for high efficiency rectenna following parameters are considered;

Topology Used The topologies used for rectifier are, half-wave, full-wave & bridge rectifier, in most of the RFEH applications full wave rectifiers are preferred as they provide twice output as compared to half wave rectifier. Fundamental configurations for a voltage doubler are Cockcroft-Walton & Dickson. In RF energy harvesting applications Dickson's performance is better than Cockcroft-Walton at input power greater than −7 dBm & Cockcroft-Walton's performance is better at input power bellow −7 dBm [11].

Type of Diode Mostly Schottky diode is used in low power harvesting applications because of its lower operating voltage & high switching speed. For increased PCE diodes having specifications such as, smaller series resistance R_S, larger breakdown voltage V_{br}, smaller junction capacitance Cj, and smaller turn-on voltage V_T are used [9].

Rectifier Conversion Efficiency Efficiency of rectifier is depend on various parameters like, frequency of operation, input power level, type of diode, topology used, substrate material, value of load resistance & matching with antenna [12]. It can be increased by optimizing signal waveforms, selecting optimal RF-DC conversion technique, constructing adaptive rectifier circuit, minimizing sensitivity by using resistance compression network, designing a custom IC in a boost converter, using load modulated two branch rectifier cooperating with ultra-low power management unit, using optimal rectifier topology, & optimizing load conditions [9].

Number of Stages of Voltage Multiplier As number of stages increases, losses are also increases which lead to lower PCE, therefore optimum number of stages are preferred. Selection of number of stages of voltage multiplier is also depend on available input power, for low power region (<−20 dBm) efficiency of rectifier decreases with increase in number of stages, while in high power region (>−20 dBm) efficiency increases for increased stages of multiplier [13].

Finally a comparison of highly efficient rectennas recently reported is as shown in Table 1.

Table 1 Performance comparisons of highly efficient rectennas recently reported

Ref. no.	Rectenna parameter	PCE (%)/technique used for improvement of PCE
[5]	Differentially feed square two layered slot antenna with single stage Villard voltage doubler, with dual matching network	53 @ 2 GHz, 31 @ 2.5 GHz and 15.56 @ 3.5 GHz/differential high gain antenna
[1]	Dual port L probe microstrip patch with single series diode rectifier with triple-stub tuning	40 for i/p power density of 500 $\mu W/cm^2$/multiport antenna
[8]	Combination of two off center feed dipole (OCFD) & radial stubs with single shunt rectifier	60 @ 0 dBm, 65 @ 5 dBm, 70 @ 10 dBm, and 75 @ 20 dBm for diodes SMS7630, HSMS2850, HSMS2860 and HSMS2820 respectively/elimination of matching network
[9]	Meandered dipole antenna	61.4, 50.7, 31.8 at Pin = −5dBm, Pin = −10 dBm, and Pin = −15 dBm/elimination of matching network
[10]	Planar folded dipole antenna with Dickson voltage doubler & a PJFET self-oscillating boost converter	Antenna can charge a battery to 3.78 V at 844 MHz for a received power of −11.7 dBm/elimination of matching network
[4]	20 elements tapered log periodic dipole array & voltage doubler with exponentially tapered microstrip line used as matching network	Produce a voltage of 1.7 V at a distance 20 m from cell tower/high gain antennae array

(continued)

Table 1 (continued)

Ref. no.	Rectenna parameter	PCE (%)/technique used for improvement of PCE
[2]	Log periodic crossed dipole antenna with single stage full wave voltage doubler	67 @ −5 dBm input power/multiband antenna
[14]	Printed dipole antenna with proposed rectifier	62 @ −10 dBm, 84 @ 5.8 dBm/multiband antenna
[15]	Rectangular microstrip antenna with pair of truncated corner on jean cotton material & rectifier with HSMS2850 diode	60 for 0 dBm & −3 dBm input power @ 2.45 & 5.8 GHz respectively/compact circularly polarized textile rectenna
[16]	Koch fractal loop antenna with full wave Greinacher rectifier	61 at 1.8 GHz for 10 μW/cm^2 power density/compact rectenna with in loop ground plane
[17]	Dual port rectangular slot antenna with solar cell	49 at 0 dBm & 20 at −17 dBm at 2.45 GHz/combination of RF & solar energy harvester

3 Applications of Rectenna

3.1 Wireless Power Harvesting Networks (WSN and IoT)

IoT is used for making communication between different devices without human interference and WSN is a part of IoT topology. WSN refers to a group of devoted sensors for checking and recording physical conditions of environment. WSN node contain different sensors like, temperature sensor, humidity sensor etc., and these devices are working on batteries also they are remotely located; a rectenna can replace these batteries & can be act as a source of energy for these devices. A low-cost energy harvesting device using rectenna for IoT applications is presented by [18]. It contains a 2.4 GHz insert fed rectangular microstrip patch antenna with a band pass filter, LC matching circuit & single diode (HSMS 2820) rectifier.

3.2 Medical and Healthcare

Idea of designing energy harvesting device in the form of necklace used for powering wireless electronic health and activity tracking monitors inside their pendants (Smart Jewelry) is presented in [11]. It contains a U shaped dipole antenna operating at 900 MHz with 8 stage Dickson rectifier & a DC-DC boost convertor.

4 Conclusion

The power conversion efficiency is used as a figure of merit for calculating performance of rectenna. Various techniques like use of multiband antenna, high gain antenna, dual port antenna, matching network elimination, use of proper topology and diode for design of rectifier, use of resistance compression network in rectifier, selection of optimized value of load resistance are used for improvement in PCE. This paper reviews different parameters needed to be optimized which are used for improvement in (PCE) of rectenna, it also summarizes recently reported high efficiency rectennas and some of its applications.

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