International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 4
DOI: https://doi.org/10.17762/ijritcc.v11i4.6373
Article Received: 20 January 2023 Revised: 22 February 2023 Accepted: 01 March 2023

Investigation of Different Optimization Techniques for Rectenna

Anand Trikolikar[1,3], Swapnil Lahudkar[2,3]
[1]Research Scholar, Department of Electronics & Telecommunication Engineering,
AISSMS Institute of Information Technology,
Pune, India.
anandt15@gmail.com
[2]Professor, Department of Electronics & Telecommunication Engineering,
[3]JSPM's Imperial College of Engineering & Research, Wagholi,
Pune, India.
swapnillahudkar@gmail.com

Abstract— Rectenna optimization is important for increasing the efficiency and power output of devices that convert radio frequency (RF) energy into DC power. This can be accomplished by optimizing the design and components used in the rectenna, as well as changing the operating frequency and input power level. Optimization algorithms in rectenna design aid in determining the required geometry parameters of the antenna and rectifier, as well as to find the optimal values of passive components used in the design. This paper investigates various algorithms and optimizers based on these which are used for rectenna optimization.

Keywords-Rectenna, Rectenna Optimization, Antenna Optimization, Rectifier Optimization, RF Energy Harvesting.

I. INTRODUCTION

The method of changing a set of parameter values to meet predetermined performance goals is known as optimization. Optimizer make a comparison of computed and preferred responses and make changes to design parameters to bring the computed response closer to the goal. Various optimizers based on different optimization algorithms are available, but error function compositions and search methods are the parameters used to differentiate them. The difference between the computed and desired responses is measured by the error function & the search method; on the other hand controls the process by which optimizer generates new model parameters.

II. ALGORITHMS USED FOR RECTENNA OPTIMIZATION

1. **Random Search:** It is a direct search method which not require gradient of problem to be optimized. The algorithm is implemented by first identifying and selecting the "best" state vector, and then arbitrarily generating a unique state vector that is typically a neighbor of the present "best" state vector. If the new state is superior to the present "best", the new vector becomes the new "best" state vector [1]. In this method optimal solution is not always guaranteed.

2. **Gradient Descent:** This algorithm uses a gradient-based search method to find the optimal rectenna configuration. It involves starting with an initial solution and using the gradient of the performance function to update and improve the solution over multiple iterations. This allows the algorithm to converge quickly to the optimal solution.

3. **Genetic Algorithm:** This algorithm uses principles of natural selection and genetics to find the optimal solution to a problem. This algorithm uses a set of heuristics based on the principles of natural evolution and reproduction to search for the optimal rectenna configuration. It involves creating a population of potential rectenna designs, evaluating their performance, and using genetic operators such as selection, crossover, and mutation to evolve and improve the designs over multiple iterations. In the context of RF energy harvesting, the algorithm can be used to optimize the antenna & rectifier design by simulating different rectenna configurations and selecting the most efficient ones for further optimization.

4. **Particle Swarm Optimization:** This algorithm simulates the behavior of a group of particles in search of the optimal solution to a problem. This algorithm uses a swarm of particles to explore the search space and find the optimal rectenna configuration. The particles move in the search space and update their positions based on the current global and local best solutions. This allows the algorithm to converge quickly to the optimal solution while avoiding getting stuck in local minima. In the context of RF energy harvesting, the algorithm

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 4
DOI: https://doi.org/10.17762/ijritcc.v11i4.6373
Article Received: 20 January 2023 Revised: 22 February 2023 Accepted: 01 March 2023

can be used to optimize the rectenna design by simulating different rectenna configurations and selecting the ones that result in the highest energy conversion efficiency.

5. **Differential Evolution:** It is population-based evolutionary computational algorithm for the optimization which uses a differential operator to create a new solution [1]. Optimized solutions are produced by combining current candidate solutions rendering to simple formulae, and then choosing the candidate solution with the finest score or fitness for the given problem [1].

6. **Ant Colony Optimization**: This algorithm simulates the behavior of ants in search of the optimal solution to a problem.

7. **Simulated Annealing:** This algorithm is a metaheuristic that simulates the process of annealing in metallurgy to find the optimal solution to a problem. This algorithm uses a probabilistic search method to find the optimal antenna configuration. It involves randomly exploring the search space and accepting new solutions based on their performance and a pre-defined probability distribution. The probability distribution is gradually reduced as the algorithm progresses, allowing it to converge to the global optimal solution.

8. **Artificial Neural Networks:** This algorithm uses a network of interconnected nodes to simulate the behavior of the human brain in solving complex problems.

9. **Nelder-Mead Simplex:** This algorithm uses a simplex-based search method to find the optimal antenna configuration. It involves starting with a set of initial solutions, evaluating their performance, and using the simplex method to update and improve the solutions over multiple iterations. This allows the algorithm to converge quickly to the optimal solution.

10. **Pattern Search:** This technique is a straightforward, effective, and derivative-free optimization technique. It seeks the minimum for a given function, which is frequently not differentiable, stochastic, or even continuous [1]. This algorithm can find a solution even when no information for the gradient of the fitness function is given. To find the solution, this algorithm investigates a set of points surrounding the existing point whose fitness function value is less than the value at the current point [1].

III. OPTIMIZATION OF ANTENNA & RECTIFIER

Rectenna optimization employs a variety of optimization techniques, which are presented in the preceding section; this section presents a comparison of various optimization methods used for rectenna. The Table 1 lists various algorithm used in literature for antenna and rectifier optimization.

TABLE 1: COMPARISION OF VARIOUS OPTIMIZAION ALGORITHMS USED FOR RECTENNA

Ref. No.	Antenna / Rectifier optimized	Optimization Algorithm used	Optimization applied
2	Rectenna Array	Convex Optimization	To improve gain of array antenna
3	Rectangular Microstrip Patch Antenna	Multi objective Genetic algorithm	To optimize defected ground structure for dual band response & improved gain.
4	Wearable patch antenna	Hybrid Fuzzy Flamingo Swarm Optimization	For multiband frequency operation.
5	Frequency Selective Surface based antenna	artificial hummingbird algorithm	For dual band frequency operation.
6	HSMS285C based triple band Greinacher voltage-doubler rectifier	Genetic Algorithm	For designing parameter of IMN & rectifier
7	E shape Patch antenna & HSMS285C based triple band rectifier.	Moth Search Algorithm for antenna & Genetic Algorithm For designing parameter of IMN.	For geometry Parameter optimization of antenna & rectifier.
8	Rectangular Microstrip Patch Antenna	Random Search, Decision Tree, Support Vector Regression, Artificial Neural Network	Used to predict geometry parameter of antenna.
9	Meandered Patch antenna	Particle swarm optimization	For finding parameter of antenna structure.
10	Rectifier	Analysis of Variance	For selecting parameter of schottky diode
11	A 2.45 GHz HSMS 285X diode	Genetic Algorithm	For Finding optimized values of passive

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 4
DOI: https://doi.org/10.17762/ijritcc.v11i4.6373
***Article Received**: 20 January 2023 **Revised**: 22 February 2023 **Accepted**: 01 March 2023*

	rectifier.		components like R, L & C as well as length and width of Tx lines used in IMN.
12	Modified Inverted F antenna	Quasi-Reflected (QR) variant of Opposition Based Learning (OBL) technique in Teaching Learning Based Optimization (TLBO)	for finding parameter of antenna and maximize S_{11}
13	Insert feed RMSA with H & E slot	Genetic algorithm	Applied for increase the performance of antenna in terms of parameters such as S_{11} & gain.
14	Microstrip antenna	Improved particle swarm optimization (PSO)	To obtain high gain & multi frequency operation
15	NA	NA	Guidelines are given for selection of rectifier, matching network, antenna, parameters.
Ref. No.	**Antenna / Rectifier optimized**	**Optimization Algorithm used**	**Optimization applied for**
16	RMSA & single frequency rectifier	Parameter Tuning Method	Tuning of parameters used to improve performance of rectenna in terms of S_{11} & Gain of antenna, S_{21} of LPF.
17	CMOS Rectifier @ 2.45 GHz	Deep Neural Network	Improvement in PCE
18	Hybrid fractal antenna	Genetic algorithm & Curve fitting	Genetic algorithm for finding parameter of antenna and curve fitting for developing equation which relates dimension of antenna with resonant frequency.
19	BAT1503-W based 5.8 GHz rectifier.	Iterative method	Accurately design matching and filtering circuit in rectifier.
20	RMSA	Cuckoo Search (CS) algorithm, the Differential Evolution (DE) algorithm, and Quantum-behaved Particle Swarm Optimization (QPSO)	Novel mathematical weighted estimation model containing antenna efficiency, operating frequency, and bandwidth is designed for RMSA.
21	Pixel antenna	Mixed Integer Linear Programming	Applied for antenna to be worked at particular frequency.
22	HSMS8101 based 2.45 GHz rectifier	Space Mapping Optimization	To reduce design time in EM simulation.
23	Slotted Ring antenna	Particle swarm optimization	Return Loss & Axial Ratio is optimized using PSO.

The findings of comparison present in Table 1 are as follows:

1. The algorithms like Genetic, PSO, Cuckoo Search, and Differential Evolution are used to find best value for the geometry parameters of antenna which leads in performance improvement in S_{11}, gain and axial ratio.

2. Machine learning algorithms such as Random Search, Decision Tree, Support Vector Regression, and ANN are used to guess dimension of patch antenna.

3. The algorithms such as Genetic is used to design optimum value of length & width transmission lines used in impedance matching network of rectifier as well as value of load resistance, to obtain resonance at desired frequency with maximum value of S_{11} & power conversion efficiency (PCE).

4. Machine Learning algorithms such as Deep Neural Network and Analysis of Variance (ANOVA) are used to select schottky diode for rectifier with optimum parameters which leads in improvement in PCE.

5. Algorithms such as Iterative optimization & parameter tuning are used to accurately design antenna, IMN & rectifier for improvement in performance of rectenna.

IV. SELECTION OF PROPER OPTIMIZER

Appropriate selection of optimizer is essential for better solution of problem, following table shows comparison between various optimizers present in ADS [24] used for parameter optimization.

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 4
DOI: https://doi.org/10.17762/ijritcc.v11i4.6373
***Article Received**: 20 January 2023 **Revised**: 22 February 2023 **Accepted**: 01 March 2023*

TABLE 2: OPTIMIZERS USED FOR RECTENNA OPTIMIZAION

Sr. No.	Name of Optimizer	Type of Optimizer	Error Function Formulation	Search Method	Operates with Discrete variable	Operates with contentious variable	Use
1	Random	Local	Least-Squares	Random	Yes	Yes	When more number of variables are to be optimized.
2	Gradient	Local	Least-Squares	Gradient	No	Yes	Used for simple circuit, but converge on a solution quickly.
3	Quasi-Newton	Local	Least-Squares	Quasi-Newton	No	Yes	When less number of variables are to be optimized as it takes more time to optimize.
4	Least P^{th}	Local	Least P^{th}	Quasi-Newton	No	Yes	
5	Genetic	Global	Least-Squares	Genetic	Yes	Yes	Useful for numerous complicated optimization problems, which includes discrete value & tolerance optimization.

Following steps are used to select proper optimizer for given problem;
1. Start with random optimizer and find a decent set of initial values.
2. Then proceed with Gradient as it uses gradient information of error function of circuit.
3. The gradient of an error function suggests which parameter values should be moved in which direction to reduce the error function.
4. For complex optimization problems, optimizers such as Genetic can be selected.
5. Even after optimization process, manual tuning of variable values are needed to achieve desired performance.

V. TECHNIQUES FOR OPTIMIZATION OF RECTENNA

To optimize the overall RF energy harvesting system, the following techniques are used:

1. ***Use a high-efficiency rectifier circuit:*** The rectifier circuit plays a crucial role in the RF energy harvesting system as it converts the RF signal into DC power. Using a high-efficiency rectifier circuit can help to improve the overall efficiency of the system.

2. ***Use high-quality RF antennas*:** The RF antennas are responsible for capturing the RF signal and transmitting it to the rectifier circuit. Using high-quality RF antennas can help to improve the signal-to-noise ratio, which in turn can improve the rectifier's efficiency.

3. ***Select an appropriate rectifier design*:** Different rectifier designs have different efficiency levels. Selecting the appropriate rectifier design for the specific RF energy harvesting system can help to improve the overall efficiency of the system.

4. ***Optimize the load resistance:*** The load resistance plays a crucial role in the rectifier's efficiency. Optimizing the load resistance to match the specific RF energy harvesting system can help to improve the rectifier's efficiency.

5. ***Use of low-loss components*:** The components used in the rectifier circuit can affect its efficiency. Using low-loss components can help to improve the rectifier's efficiency.

Beside above techniques followings points also considered for optimized design of rectifier used in RFEH system.

- Design the rectifier circuit to have low output impedance, which will maximize the power transfer from the RF source to the load.
- Use a capacitor in parallel with the rectifier output to smooth out any ripple in the rectified output, which will improve the performance of the load.
- Use a low-noise rectifier circuit to minimize the amount of noise generated during the rectification process.
- Implement a feedback control system to optimize the rectifier operation for different RF sources and loads.
- Monitor the rectifier performance and adjust the circuit design and operating parameters as needed to maximize the efficiency and power output of the rectifier.

Overall, optimizing the performance of an RF energy harvesting system requires careful consideration of the design of the system and its operating environment. By choosing the right components and operating the system in an optimal manner, it is possible to maximize the amount of RF energy that is harvested and converted into useful power.

VI. CONCLUSION

Optimization of RF energy harvesting systems refers to the process of improving the performance and efficiency of these systems. This can be achieved through a variety of methods, such as selecting the appropriate antenna design, optimizing the rectifier circuit, and choosing the right storage device for the harvested energy. Additionally, factors such as the distance between the RF energy source and the energy harvesting system, the orientation of the antenna, and the operating frequency of the system will govern the performance of rectenna. In this paper, we investigate various optimization algorithms and optimizers used for rectenna, and we conclude that parameter optimization is required for significant improvement in rectenna performance.

ACKNOWLEDGMENT

The authors would like to thank the editor and reviewers whose comments and suggestions helped in increasing the quality of the manuscript.

REFERENCES

[1] A. A. Plasokar and S. L. Lahudkar, " Exploration of Optimization Algorithms for Optimization of Antenna and Antenna Arrays", ANNALS of Faculty Engineering Hunedoara – INTERNATIONAL JOURNAL OF ENGINEERING, 2021, https://annals.fih.upt.ro/ANNALS-2021-3.html

[2] A. Georgiadis and N. B. Carvalho, "A Convex Optimization Approach for the Design of Supergain Electrically Small Antenna and Rectenna Arrays Comprising Parasitic Reactively Loaded Elements," in *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 6, pp. 4674-4682, June 2022, doi: 10.1109/TAP.2022.3142312.

[3] M. C. Derbal, M. F. Nakmouche, M. Nedil, A. Amma, D. E. Fawzy and M. F. Abo Sree, "Dual Band Antenna Design Using Pixeled DGS for Energy Harvesting Applications," 2022 9th International Conference on Electrical and Electronics Engineering (ICEEE), Alanya, Turkey, 2022, pp. 147-150, doi: 10.1109/ICEEE55327.2022.9772605.

[4] Kumar, T.R., Madhavan, M. "Design and Optimization of Wearable Microstrip Patch Antenna using Hybrid Fuzzy Flamingo Swarm Optimization Algorithm for RF Energy Harvesting". Iran J Sci Technol Trans Electr Eng (2022). https://doi.org/10.1007/s40998-021-00470-5

[5] A. D. Boursianis, M. S. Papadopoulou, S. Koulouridis, A. Georgiadis, M. M. Tentzeris and S. K. Goudos, "Dual-Band Frequency Selective Surface Design Using Artificial Hummingbird Algorithm," 2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/URSI), Denver, CO, USA, 2022, pp. 982-983, doi: 10.1109/AP-S/USNC-URSI47032.2022.9886108.

[6] Papadopoulou, Maria S., Achilles D. Boursianis, Christos K. Volos, Ioannis N. Stouboulos, Spyridon Nikolaidis, and Sotirios K. Goudos. 2021. "High-Efficiency Triple-Band RF-to-DC Rectifier Primary Design for RF Energy-Harvesting Systems" *Telecom* 2, no. 3: 271-284. https://doi.org/10.3390/telecom2030018

[7] Boursianis, Achilles D., Maria S. Papadopoulou, Stavros Koulouridis, Paolo Rocca, Apostolos Georgiadis, Manos M. Tentzeris, and Sotirios K. Goudos. 2021. "Triple-Band Single-Layer Rectenna for Outdoor RF Energy Harvesting Applications" Sensors 21, no. 10: 3460. https://doi.org/10.3390/s21103460

[8] Nazmia Kurniawati, Arif Fahmi, and Syah Alam, "Predicting Rectangular Patch Microstrip Antenna Dimension Using Machine Learning," Journal of Communications vol. 16, no. 9, pp. 394-399, September 2021. Doi: 10.12720/jcm.16.9.394-399

[9] Reham M. Yaseen, Dhirgham Kamal Naji, and Amina M. Shakir, "Optimization Design Methodology of Broadband OR Multiband Antenna for RF Energy Harvesting Applications," Progress In Electromagnetics Research B, Vol. 93, 169-194, 2021.

[10] Contreras, Andry and Maryory Urdaneta. "Analysis of Variance of the Diode Parameters in Multiband Rectifiers for RF Energy Harvesting." Radioengineering 30 (2021): 150-156.

[11] RR Silva, S T M Gonçalves Christian Vollaire Arnaud Bréard Gláucio Lopes Ramos Cássio Gonçalves do Rego, "Analysis and Optimization of Ultra-Low-Power Rectifier with High Efficiency for Applications in Wireless Power Transmission and Energy Harvesting", Journal of Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 19, No. 1, March 2020, DOI: http://dx.doi.org/10.1590/2179-10742020v19i11864

[12] A. Karampatea, A. D. Boursianis, S. K. Goudos and K. Siakavara, "Triple-band Inverted-F Antenna Using QR-OBL TLBO Algorithm for RF Energy Harvesting Applications," 2020 9th International Conference on Modern Circuits and Systems Technologies (MOCAST), 2020, pp. 1-4, doi: 10.1109/MOCAST49295.2020.9200251.

[13] S. Vijay Gokul , M. Suba Lakshmi , T. Swetha, 2020, Design of RF Energy Harvesting Antenna using Optimization Techniques, INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT) Volume 09, Issue 03 (March 2020).

[14] Y. Fu and S. Yang, "An Improved PSO for Design Optimizations of a Multiband Rectenna for Miniature Energy Harvester," 2020 IEEE 19th Biennial Conference on Electromagnetic Field Computation (CEFC), Pisa, Italy, 2020, pp. 1-4, doi: 10.1109/CEFC46938.2020.9451363

[15] Erika Vandelle, Simon Hemour, Tan-Phu Vuong, Gustavo Ardila, Ke Wu, "Rectenna Optimization Guidelines for Ambient Electromagnetic Energy Harvesting", Wireless Power Transmission for Sustainable Electronics, 2020.

[16] A. Contreras, B. Rodríguez, L. Steinfeld, J. Schandy and M. Siniscalchi, "Design of a Rectenna for Energy Harvesting on Wi-Fi at 2.45 GHz," 2020 Argentine Conference on Electronics (CAE), 2020, pp. 63-68, doi: 10.1109/CAE48787.2020.9046372.

[17] H. W. Ho and W. W. Y. Lau, "Automated Design Optimization for CMOS Rectifier Using Deep Neural Network (DNN)," 2019 IEEE Wireless Power Transfer Conference (WPTC), 2019, pp. 599-603, doi: 10.1109/WPTC45513.2019.9055537.

[18] B. S. Dhaliwal, A. Kaur, S. Pattnaik and S. S. Pattnaik, "Optimization of Hybrid Fractal Antenna Using Curve Fitting and GA Approach for RF Energy Harvesting Application," 2019 IEEE Indian Conference on Antennas and Propagation (InCAP), 2019, pp. 1-4, doi: 10.1109/InCAP47789.2019.9134573.

[19] Q. Zhang, J. -H. Ou, Z. Wu and H. -Z. Tan, "Novel Microwave Rectifier Optimizing Method and Its Application in Rectenna Designs," in IEEE Access, vol. 6, pp. 53557-53565, 2018, doi: 10.1109/ACCESS.2018.2871087.

[20] He, M., Wang, Z., Leach, M. et al. Bio-inspired optimization algorithms applied to rectenna design. Big Data Anal 3, 1 (2018). https://doi.org/10.1186/s41044-017-0026-4

[21] S. Shen, C. -Y. Chiu and R. D. Murch, "Optimization of 2.45-GHz pixel rectenna for wireless power transmission using mixed integer linear programming," 2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, San Diego, CA, USA, 2017, pp. 351-352, doi: 10.1109/APUSNCURSINRSM.2017.8072218.

[22] Fang Zhang and Xin Liu, “Rectenna Design with Space Mapping Optimization”, 6th International Conference on Electronic, Mechanical, Information and Management (EMIM 2016).

[23] K. Kim, J. Lee, K. Choi, T. Chung and H. Kim, "An Optimal Design of Compact Ring-Slot Antenna for a Rectenna System With Numerical Manipulation," in IEEE Transactions on Magnetics, vol. 50, no. 2, pp. 973-976, Feb. 2014, Art no. 7024104, doi: 10.1109/TMAG.2013.2283541.

[24] https://www.keysight.com/in/en/lib/resources/softwarereleases/ads-2016.html

Author’s Profile:

Mr. Anand Trikolikar received the M.Tech. degree in E&TC Engineering from Dr. Babasaheb Ambedkar Technological University, Lonere, Maharashtra, India in 2011. He is currently pursuing PhD degree from AISSMS Institute of Information Technology, Pune, India. He is working as Assistant Professor in the Department of E&TC, Imperial College of Engineering & Research, Wagholi, Pune, India. His research interests are Energy Harvesting, Antenna Design and Communication Engineering.

Dr. Swapnil Lahudkar obtained his PhD degree in 2012 from Bharati Vidyapeeth University, College of Engineering. He is currently working as Professor in the Department of Electronics & Telecommunication at JSPM’s Imperial College of Engineering, Pune. He is the author of more than 40 papers in peer reviewed journals. His area of interest includes Communication, Antenna Design and Signal Processing.