Journal of Engineering and Technology Management 72 (2024)

DESIGN AND IMPLEMENTATION OF CHARGING UNIT FOR MARITIME APPLICATIONS

[1]Prof.B.Somashekar, [2]Gokul S, [3]Mohammed Zaki Ul Iyan, [4]Vignesh R, [5]Rahul B V,

Department of EEE, Dr. T. Thimmaiah Institute of Technology

Abstract— Our research endeavors to tackle the formidable challenges inherent in Underwater Wireless Power Transfer (UWPT), with a primary focus on optimizing charging efficiency and seamlessly adapting to the demanding underwater conditions. Leveraging solar power energy as the primary source, our system seamlessly switches to grid energy when solar energy levels are insufficient. The core objective revolves around designing a WPT system that achieves remarkable efficiency and unity power factor, critical for ensuring seamless power transmission in underwater environments. Through extensive prototyping and testing, our WPT system demonstrates the ability to transmit an output voltage of approximately 9V over an 6cm inside water gap, covering a maximum sliding distance of 8cm. This significant achievement underscores the system's capability to surmount the barriers of underwater power transfer, paving the way for sustainable operations in challenging aquatic environments. Moreover, our approach integrates diverse energy sources, including solar and grid energy, to enhance adaptability and energy generation capabilities, enabling consistent and optimized power generation vital for prolonged and reliable underwater applications. By amalgamating cutting-edge technologies and innovative design paradigms, our research endeavours to properly the advancement of underwater WPT. This integration of diverse energy sources not only ensures adaptability but also lays the groundwork for transformative solutions in underwater power transmission. Our work represents a significant step forward in addressing the challenges of underwater power transfer, offering promising prospects for sustainable and efficient energy transmission in aquatic environments.

Key Words: Underwater Wireless Power Transfer (UWPT), Underwater Charging Systems, Underwater Energy Transfer Efficiency, Environmental Monitoring.

I. INTRODUCTION

In an era where underwater exploration and utilization of aquatic resources are becoming increasingly vital, the efficient transmission of power beneath the waves presents a formidable challenge. Underwater wireless power transfer (UWPT) stands at the forefront of technological innovation, promising to revolutionize operations in aquatic environments. Our research is dedicated to surmounting the obstacles inherent in underwater power transmission, with a primary emphasis on optimizing efficiency and adaptability to the demanding underwater conditions. The core objective of our endeavour is to design and develop a robust WPT system capable of seamlessly adapting to the dynamic challenges of underwater environments. Central to our approach is the utilization of solar power energy as the primary source, harnessing the abundant energy from the sun to power underwater operations. However, recognizing the intermittent nature of solar energy availability, our system seamlessly integrates with grid energy sources, ensuring uninterrupted power supply even in adverse conditions. Efficiency and unity power factor are paramount in ensuring the seamless transmission of power underwater. Our research is dedicated to achieving remarkable efficiency levels, coupled with unity power factor, to optimize power transmission efficiency. Through extensive prototyping and rigorous testing, we aim to validate the efficacy of our system in transmitting power over significant distances underwater, overcoming the inherent challenges of underwater power transfer. One of the key achievements of our research is the demonstration of our WPT system's capability to transmit an output voltage of approximately 9V over an 6cm in water, with a maximum sliding distance of 8cm. This milestone not only underscores the technical prowess of our system but also positions it as a viable solution for powering underwater equipment and operations.

Moreover, the integration of diverse energy sources, including solar and grid energy, enhances the adaptability and reliability of our system, ensuring sustained power generation in challenging aquatic environments. Our research represents a significant leap forward in the field of underwater WPT, laying the groundwork for transformative solutions in underwater power transmission. By amalgamating cutting-edge technologies and innovative design paradigms, we aim to propel the advancement of underwater power transmission, enabling sustainable and efficient energy transmission in aquatic environments. Through collaborative efforts and continuous refinement, our research endeavours to unlock new possibilities for underwater exploration and utilization, ushering in a new era of innovation beneath the waves. The exploration of Underwater Wireless Power Transfer (UWPT) represents a frontier in engineering, poised to revolutionize various underwater applications. However, this domain encounters significant obstacles, primarily concerning charging time and power transfer efficiency, particularly when reliant on solar energy sources.

The underwater environment presents unique challenges, including increased attenuation and limited power transmission capabilities, making the optimization of WPT systems an intricate task. Addressing these challenges is crucial, prompting the development of innovative solutions. This study focuses on integrating the transformer induction concept and adaptive robotic technology to mitigate the limitations encountered in UWPT. By leveraging these concepts, the objective is to create a WPT system capable of not only enhancing charging efficiency but also adapting to the dynamic underwater conditions, thereby improving overall performance. The proposed system's design emphasizes achieving high efficiency and unity power factor, crucial for effective power transfer. A primary goal is to establish a prototype that can successfully transmit an output voltage of approximately 9V over an 6cm water with a maximum sliding distance of 8cm. Additionally, the utilization of both solar and grid energy sources adds a versatile dimension to the system, allowing for optimized power generation, essential for sustained operations in challenging underwater environments. This introduction sets the stage for exploring the novel approach of integrating transformer induction and adaptive robotics in addressing the critical challenges faced in underwater WPT. The subsequent sections develop deeper into the technical aspects and experimental validations of this innovative system, aiming to demonstrate its feasibility and potential for revolutionizing power transfer in underwater settings.

II. WPT METHODS OF UNDERWATER APPLICATIONS

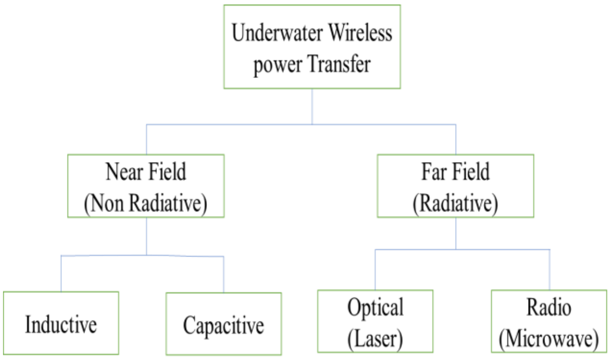

Fig 1. WPT Techniques

1. Radiative WPT

- Which is commonly referred as far-field WPT, contains WPT techniques based on lasers or Microwaves.
- Radio Microwave face high attenuation at high frequencies in seawater. A few researchers made efforts for underwater wireless power transfer (UWPT) through radio waves but resulted in low efficiency.
- Laser based WPT is not realistic because of its low efficiency and it is also harmful to interface caused by ambient light.

2. Non-Radiative WPT

- The nonradiative WPT systems involve inductive and capacitive power transmission techniques.
- In this power transmission techniques, the power transfer through magnetic and electric fields is restricted to short distances up to tens of centimeters.
- The capacitive wireless power transfer contains submerged electrodes however, CWPT has been neglected due to low coupling capacitance.
- In IWPT, the coil diameter or number of turns should be increased to improve efficiency IWPT system can involve shield materials e.g. ferrite material for better performance.

III. CIRCUIT DIAGRAM

- Transmission Section

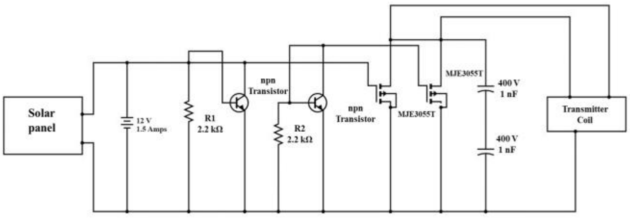

Fig 2. Transmission Section

- Receiving Section

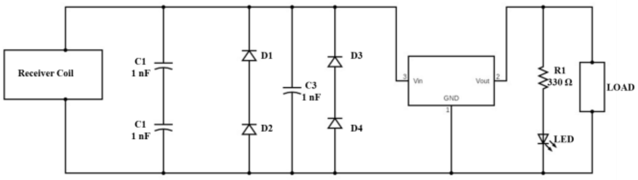

Fig 3. Receiving Section

Solar panels primarily function to convert sunlight into electricity. This generated electricity can then be utilized to power the wireless power transfer system, either directly or by charging a battery for later use. Battery (12 V, 1.5 Ah): The primary function of the battery is to store electrical energy generated from various sources, such as solar panels or a charging station, in the form of chemical energy. This stored energy can then be used to power devices wirelessly when needed, providing a continuous power supply even when the primary power source is unavailable. Step down Transformer (230/12 V): A step-down transformer plays a crucial role in wireless power transfer systems by converting high voltage AC to a lower voltage, providing electrical isolation, potentially matching impedance, and stabilizing the output voltage to ensure safe, efficient, and reliable power transfer. DC – AC Converter: A DC-AC converter, also known as an inverter, is a device that converts direct current (DC) electricity into alternating current (AC) electricity. Its primary function is to enable devices or systems that run on AC power to be powered by a DC power source. Transmitter Coil: The transmitter coil is a critical component of wireless power transfer systems, responsible for generating the magnetic field necessary for transferring energy wirelessly to receiver coils, optimizing efficiency, facilitating proper alignment, and ensuring safety and compliance with regulations.

IV. BLOCK DIAGRAM

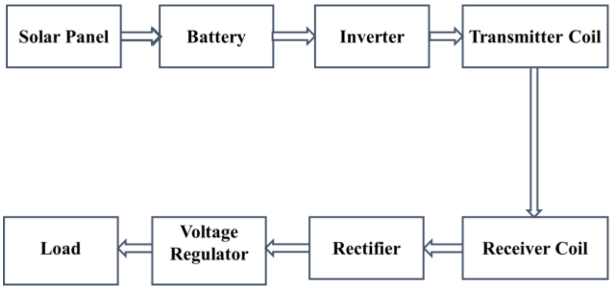

Fig 4. Block Diagram

Transmission Section

A solar panel installed on the ship's surface captures sunlight and converts it into electrical energy. This energy can be used to power various systems on the ship or stored in a battery for later use. The solar panel can be connected to a battery system. The battery serves as an energy storage device, storing excess energy generated by the solar panel. It ensures a continuous power supply, especially when there's insufficient sunlight or during night-time. An inverter is necessary to convert the direct current (DC) electricity generated by the solar panel and stored in the battery into alternating current (AC) electricity. AC is commonly used for power transmission. The transmitter coil is a crucial part of the UWPT system. It's connected to the inverter and generates an alternating magnetic field. This field carries the electrical energy, which is then transmitted wirelessly through the water to a receiver coil.

Receiver Section

The receiver coil is positioned on the underwater vehicle and is designed to capture the wirelessly transmitted energy from the transmitter coil on the ship. It receives the alternating magnetic field and converts it back into electrical energy. The alternating current received by the receiver coil needs to be converted into direct current (DC) for use by the vehicle's systems. A rectifier circuit is used for this purpose, converting the AC signal into a pulsating DC signal. The pulsating DC signal from the rectifier needs to be regulated to ensure a stable voltage output. A voltage regulator circuit is employed to maintain a constant voltage level required for the vehicle's components. LEDs can serve as indicators to show the status of the received power, providing visual feedback on whether the system is receiving and converting power effectively. Voltage sensors can monitor the voltage level of the battery connected to the receiver system. These sensors provide information about the battery's charge level, ensuring it stays within safe operating limits.

V. HARDWARE EXPERIMENT

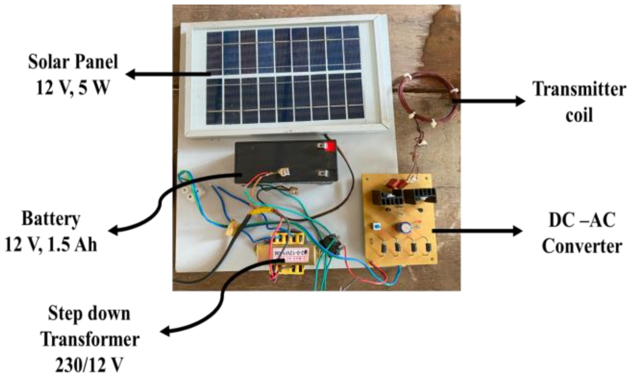

Fig 5. Hardware Model of Transmission Section

The above Fig 5 shows the hardware model of transmission section

- **Solar Panel (12 V, 5W):** Solar panels primarily function to convert sunlight into electricity. This generated electricity can then be utilized to power the wireless power transfer system, either directly or by charging a battery for later use.
- **Battery (12 V, 1.5 Ah):** The primary function of the battery is to store electrical energy generated from various sources, such as solar panels or a charging station, in the form of chemical energy. This stored energy can then be used to power devices wirelessly when needed, providing a continuous power supply even when the primary power source is unavailable.
- **Step down Transformer (230/12 V):** A step-down transformer plays a crucial role in wireless power transfer systems by converting high voltage AC to a lower voltage, providing electrical isolation, potentially matching impedance, and stabilizing the output voltage to ensure safe, efficient, and reliable power transfer.
- **DC – AC Converter:** A DC-AC converter, also known as an inverter, is a device that converts direct current (DC) electricity into alternating current (AC) electricity. Its primary function is to enable devices or systems that run on AC power to be powered by a DC power source.
- **Transmitter Coil:** The transmitter coil is a critical component of wireless power transfer systems, responsible for generating the magnetic field necessary for transferring energy wirelessly to receiver coils, optimizing efficiency, facilitating proper alignment, and ensuring safety and compliance with regulations.

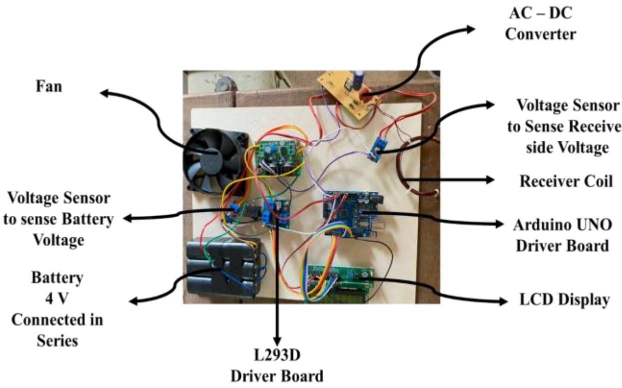

Fig 6. Hardware Model of Receiving Section

The above Fig 6. Shows the hardware model of receiving section

- **Receiver Coil:** The receiver coil is a critical component in wireless power transfer systems, responsible for converting the magnetic energy received from the transmitter coil into electrical energy, optimizing power transfer efficiency, ensuring proper alignment, and facilitating safe and effective wireless charging or power transfer.
- **Voltage Sensor:** A voltage sensor is an electronic device that detects and measures the voltage level in an electrical circuit or system. Its primary function is to provide information about the voltage present in the circuit or system for various purposes.
- **AC -DC Converter:** AC-DC converters play a crucial role in converting AC power from the mains supply into the DC power required by a wide range of electronic devices and systems, providing voltage conversion, filtering, regulation, efficiency optimization, and protection features
- **Arduino UNO:** The Arduino Uno can monitor key parameters of the WPT system, such as voltage, current, and temperature, using sensors or feedback mechanisms. This information can be used to adjust system

parameters in real-time, detect faults or abnormalities, and provide feedback to the user.

- **LCD Display:** An LCD display can indicate the charging status of devices wirelessly charged within the system. It can show information such as the battery level, charging progress, or estimated time remaining until full charge. This feedback allows users to monitor the charging process conveniently.
- **L293D Driver Board:** The L293D driver board provides an easy-to-use and cost-effective solution for controlling DC motors and stepper motors in various robotics, automation, and DIY projects, offering features such as bidirectional motor control, current amplification, built-in protection, and compatibility with microcontrollers.

VI. EXPERIMENTAL SETUP

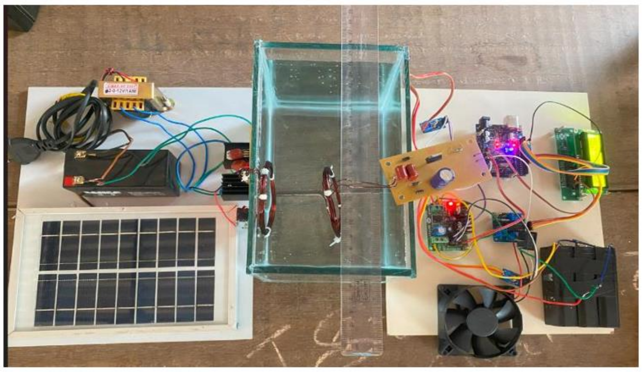

Fig 7. Experimental Setup of UWPT for Normal Water

The above Fig 7 shows the experimentl setup of UWPT where transmitter and receiver coil is placed in side the tank filled with normal water of 1.5 ltrs. We determined that the voltage were able to transfer from transmitter to receiver side efficiently.

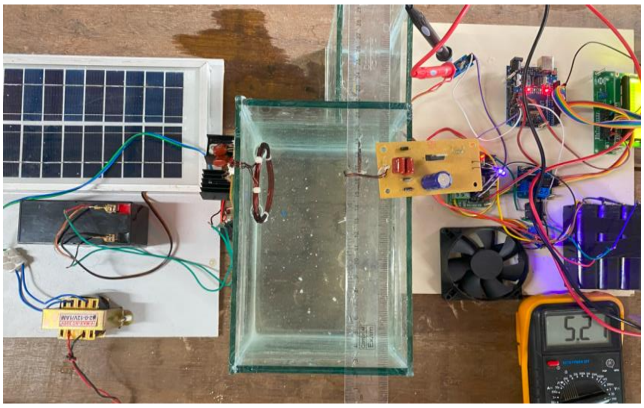

Fig 8. Experimental Setup of UWPT for Sea Water

The above Fig 8 shows the experimentl setup of UWPT where transmitter and receiver coil is placed in side the tank filled with Sea water of 1.5 ltrs. We determined that the voltage were able to transfer from transmitter to receiver side efficiently.

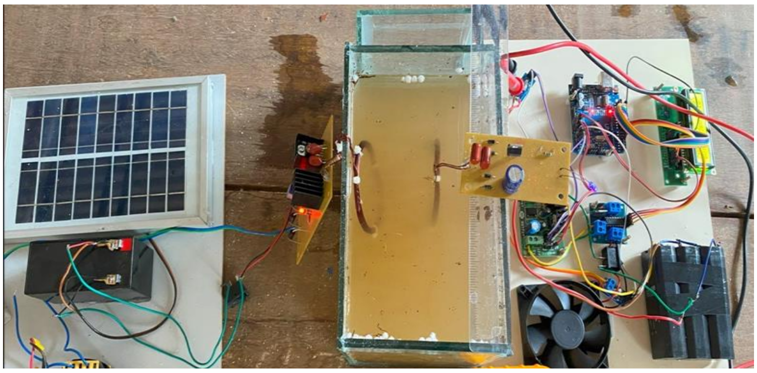

Fig 9. Experimental Setup of UWPT for Normal Water

The above Fig 9 shows the experimentl setup of UWPT where transmitter and receiver coil is placed in side the tank filled with dust water of 1.5 ltrs. We determined that the voltage were able to transfer from transmitter to receiver side efficiently.

VII. ACHIEVED RESULTS

Table 1:- Voltage parameter of UWPT for Different Medium (Normal Water)

Transmitted Voltage = 12 V					
Sl No	Distance in cm	Received Voltage in volts for Different Mediums			
		Air	Wood	Plastic	Cardboard
1	2	11.4	6.50	8.62	7.82
2	4	10.1	4.96	7.3	6.8
3	6	8.5	3.9	6.5	5.3
4	8	6	3.49	5.21	4.5
5	10	4.6	1.91	4.9	3.9
6	12	3.8	1.88	3.03	1.9

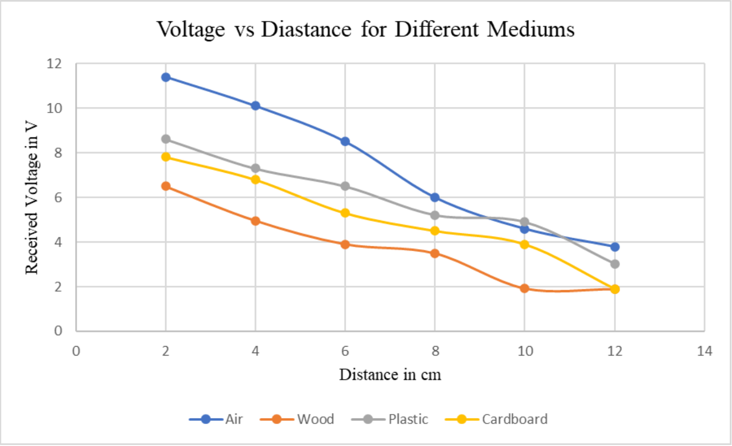

Fig 10 Graphical Representation for UWPT for Different Mediums (Normal Warter)

The experiment comparing multiple materials, including cardboard, wood, plastic, and air, was effectively carried out. The result was reported in Table 1 above under normal water circumstances. We recorded the receiving voltage by adjusting the distance from 2 to 12 cm while maintaining the transmission voltage of 12 V. From the above, the Received voltage (v/s) Distance is shown in Fig. 10. In comparison to other media, distance from the graph indicates that air facilitates voltage transfer more effectively. Using wood and cardboard as a medium, the voltage cannot be transferred effectively because wood functions as a dielectric substance, which means that it can store electric energy. This characteristic is not appropriate for voltage transmission.

Table 2:- Voltage parameter of UWPT for Different Medium (Sea Water)

Transmitted Voltage = 12 V					
Sl No	Distance in cm	Received Voltage in volts for Different Mediums			
		Air	Wood	Plastic	Cardboard
1	2	9.5	7.2	9.75	7.8
2	4	8.6	6.43	8.53	6.8
3	6	7.2	5.01	7.65	5.52
4	8	5.20	3.9	5.65	4.7
5	10	4.3	2.87	4.9	3.8
6	12	3.9	1.65	3.02	1.9

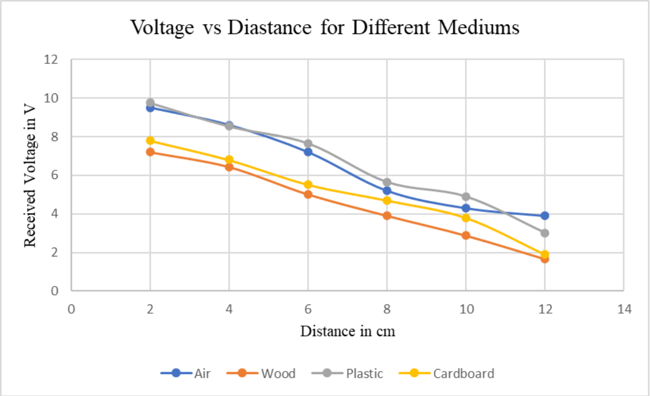

Fig 11: Graphical Representation for UWPT for Different Mediums (Sea Water)

The experiment comparing multiple materials, including cardboard, wood, plastic, and air, was effectively carried out. The result was reported in Table 2 above under sea water circumstances. We recorded the receiving voltage by adjusting the distance from 2 to 12 cm while maintaining the transmission voltage of 12 V. From the above, the Received voltage (v/s) Distance is shown in Fig. 11. In comparison to other media, distance from the graph indicates that air facilitates voltage transfer more effectively.

Table 3:- Voltage parameter of UWPT for Different Medium (Dust Water)

Transmitted Voltage = 12 V					
Sl No	Distance in cm	Received Voltage in volts for Different Mediums			
		Air	Wood	Plastic	Cardboard
1	2	10.95	6.8	8.7	7.6
2	4	8.1	4.7	7.2	6.6
3	6	6.38	3.8	6.3	5.1
4	8	4.2	3.1	4.34	4.1
5	10	3.18	1.9	3.5	3.7
6	12	2.19	1.2	2.02	1.6

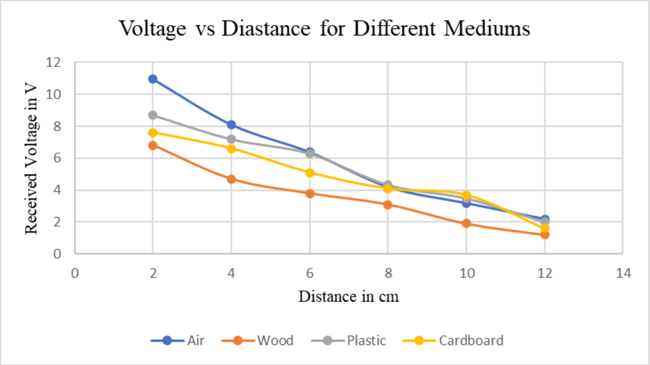

Figure 12: Graphical Representation for UWPT for Different Mediums (Dust Water)

The experiment comparing multiple materials, including cardboard, wood, plastic, and air, was effectively carried out. The result was reported in Table 3 above under sea water circumstances. We recorded the receiving voltage by adjusting the distance from 2 to 12 cm while maintaining the transmission voltage of 12 V. From the above, the Received voltage (v/s) Distance is shown in Fig. 12. In comparison to other media, distance from the graph indicates that air facilitates voltage transfer more effectively.

VIII. CONCLUSION

In conclusion, underwater wireless power transfer technology holds significant promise for enabling numerous applications in the exploration, monitoring, and utilization of the ocean's resources. Despite the challenges posed by the harsh underwater environment, advancements in this field have showcased the feasibility and potential for efficient and sustainable power delivery beneath the waves. As research and development efforts continue to improve the efficiency, range, and reliability of underwater wireless power transfer systems, we can expect to see expanded capabilities and innovation that will drive advancements in marine science, industry, and environmental monitoring. Ultimately, underwater wireless power transfer has the capacity to revolutionize how we power and communicate with underwater devices, paving the way for a more connected and sustainable ocean ecosystem.

- The UWPT experiment was successfully completed, using different material and typical normal water conditions to wirelessly transfer power from the transmitter coil to the receiver coil. In comparison to other media, we can conclude that air transfers voltage effectively. The voltage of the receiver was 11.4 V at a distance of 2 cm.
- The UWPT experiment was successfully completed, using different material and typical sea water conditions to wirelessly transfer power from the transmitter coil to the receiver coil. In comparison to other media, we can conclude that air transfers voltage effectively. The voltage of the receiver was 9.5 V at a distance of 2 cm.
- The UWPT experiment was successfully completed, using different material and typical dust water conditions to wirelessly transfer power from the transmitter coil to the receiver coil. In comparison to other media, we can conclude that air transfers voltage effectively. The voltage of the receiver was 10.95 V at a distance of 2 cm.

REFERENCES

[1] Sahoo A, Dwivedy SK, Robi PS. Advancements in the field of autonomous underwater vehicle. Ocean Eng 2019;181:145–60. https://doi.org/10.1016/j.oceaneng.2019.04.011.

[2] Jung H, Subban CV, McTigue JD, Martinez JJ, Copping AE, Osorio J, et al. Extracting energy from ocean thermal and salinity gradients to power unmanned underwater vehicles: state of the art, current limitations, and future outlook. Renew Sustain Energy Rev 2022;160:112283.

[3] Petillot YR, Antonelli G, Casalino G, Ferreira F. Underwater robots: from remotely operated vehicles to intervention-autonomous underwater vehicles. IEEE Robot Autom Mag 2019;26:94–101. https://doi.org/10.1109/MRA.2019.2908063.

[4] Atyabi A, MahmoudZadeh S, Nefti-Meziani S. Current advancements on autonomous mission planning and management systems: an AUV and UAV perspective. Annu Rev Control 2018;46:196–215. https://doi.org/10.1016/j.arcontrol.2018.07.002.

[5] As S, Dhongdi SC. Review of underwater mobile sensor network for ocean phenomena monitoring. J Netw Comput Appl 2022;205:103418. https://doi.org/10.1016/j.jnca.2022.103418.

[6] Paull L, Saeedi S, Seto M, Li H. AUV navigation and localization: a review. IEEE J Ocean Eng 2014;39:131–49. https://doi.org/10.1109/JOE.2013.2278891.

[7] Di Ciaccio F, Troisi S. Monitoring marine environments with Autonomous Underwater Vehicles: a bibliometric analysis. Results in Engin. 2021;9:100205. https://doi.org/10.1016/j.rineng.2021.100205.

[8] Macreadie PI, McLean DL, Thomson PG, Partridge JC, Jones DOB, Gates AR, et al. Eyes in the sea: unlocking the mysteries of the ocean using industrial, remotely operated vehicles (ROVs). Sci Total Environ 2018;634:1077–91. https://doi.org/ 10.1016/j.scitotenv.2018.04.049.

[9] Meinecke G, Ratmeyer V, Renken J. HYBRID-ROV - development of a new underwater vehicle for high-risk areas. OCEANS'11 MTS/IEEE KONA; 2011. p. 1–6. https://doi.org/10.23919/OCEANS.2011.6106913.

[10] Liblik T, Karstensen J, Testor P, Alenius P, Hayes D, Ruiz S, et al. Potential for an underwater glider component as part of the global ocean observing system. Methods in Oceanography 2016;17:50–82. https://doi.org/10.1016/j.mio.2016.05.001.

[11] Webb DC, Simonetti PJ, Jones CP. SLOCUM: an underwater glider propelled by environmental energy. IEEE J Ocean Eng 2001;26:447–52. https://doi.org/10.1109/48.972077.

[12] Majidian H, Wang L, Enshaei H. Part. A: a review of the real-time sea-state estimation, using wave buoy analogy. Ocean Eng 2022:111684. https://doi.org/10.1016/j.oceaneng.2022.111684.

[13] Curtin TB, Bellingham JG, Catipovic J, Webb D. Autonomous oceanographic sampling networks. Oceanography 1993;6:86–94. https://doi.org/10.5670/oceanog.1993.03.

[14] Bagchi AC. Emerging works on wireless inductive power transfer: AUV charging from constant current distribution and analysis of controls in EV dynamic charging. PhD Thesis. Utah State University; 2020.

[15] Tefferi M, Ghassemi M, Calebrese C, Chen Q, Cao Y. Characterizations of solidliquid interface in a wet-mate subsea HVDC connector. J Electrost 2018;94:51–9. https://doi.org/10.1016/j.elstat.2018.06.001.

[16] Wynn RB, Huvenne VA, Le Bas TP, Murton BJ, Connelly DP, Bett BJ, et al. Autonomous Underwater Vehicles (AUVs): their past, present and future contributions to the advancement of marine geoscience. Mar Geol 2014;352: 451–68. https://doi.org/10.1016/j.margeo.2014.03.012.

[17] Han Q, Chen H, Yang W, Zhang Y, Yang J, Chen Y. Analysis of reciprocating Oring seal in the pressure-balanced oil-filled wet-mate electrical connectors for underwater applications. Lubric Sci 2019;31:335–45. https://doi.org/10.1002/ ls.1475.

[18] Teeneti CR, Truscott TT, Beal DN, Pantic Z. Review of wireless charging systems for autonomous underwater vehicles. IEEE J Ocean Eng 2019;46:68–87. https://doi.org/10.1109/JOE.2019.2953015.

[19] Mohsan SAH, Khan MA, Mazinani A, Alsharif MH, Cho H-S. Enabling underwater wireless power transfer towards sixth generation (6G) wireless networks: opportunities, recent advances, and technical challenges. J Mar Sci Eng 2022;10: 1282. https://doi.org/10.3390/jmse10091282.

[20] Niu S, Xu H, Sun Z, Shao ZY, Jian L. The state-of-the-arts of wireless electric vehicle charging via magnetic resonance: principles, standards and core technologies. Renew Sustain Energy Rev 2019;114:109302. https://doi.org/ 10.1016/j.rser.2019.109302.

[21] Bi Z, Kan T, Mi CC, Zhang Y, Zhao Z, Keoleian GA. A review of wireless power transfer for electric vehicles: prospects to enhance sustainable mobility. Appl Energy 2016;179:413–25. https://doi.org/10.1016/j.apenergy.2016.07.003.

[22] Chhawchharia S, Sahoo SK, Balamurugan M, Sukchai S, Yanine F. Investigation of wireless power transfer applications with a focus on renewable energy. Renew

Sustain Energy Rev 2018;91:888–902. https://doi.org/10.1016/j. rser.2018.04.101.

[23] Mohamed AAS, Shaier AA, Metwally H, Selem SI. A comprehensive overview of inductive pad in electric vehicles stationary charging. Appl Energy 2020;262: 114584. https://doi.org/10.1016/j.apenergy.2020.114584.

[24] Amjad M, Farooq-i-Azam M, Ni Q, Dong M, Ansari EA. Wireless charging systems for electric vehicles. Renew Sustain Energy Rev 2022;167:112730. https://doi. org/10.1016/j.rser.2022.112730.

[25] Orekan T, Zhang P. Underwater wireless power transfer: smart ocean energy converters. Cham: Springer International Publishing; 2019. https://doi.org/ 10.1007/978-3-030-02562-5.

[26] Zhang B, Xu W, Lu C, Lu Y, Wang X. Review of low-loss wireless power transfer methods for autonomous underwater vehicles. IET Power Electron 2022;15: 775–88. https://doi.org/10.1049/pel2.12268.

[27] Ramírez IS, Bernalte Sanchez ´ PJ, Papaelias M, M´ arquez FPG. Autonomous underwater vehicles and field of view in underwater operations. J Mar Sci Eng 2021;9:277. https://doi.org/10.3390/jmse9030277.

[28] Kurs A, Karalis A, Moffatt R, Joannopoulos JD, Fisher P, Soljacic M. Wireless power transfer via strongly coupled magnetic resonances. Science 2007;317: 83–6. https://doi.org/10.1126/science.1143254.

[29] Park Y-J. Next-Generation wireless charging systems for mobile devices. Energies 2022;15:3119. https://doi.org/10.3390/en15093119.

[30] Jawad AM, Nordin R, Gharghan SK, Jawad HM, Ismail M. Opportunities and challenges for near-field wireless power transfer: a review. Energies 2017;10: 1022. https://doi.org/10.3390/en10071022.

[31] Park Y-J, Kim J-E, Na K-M, Yang K-D, Cho K-H. Optimization and analysis of multilayer planar spiral coils for the application of magnetic resonance wireless power transfer to wearable devices. Energies 2021;14:5113. https://doi.org/ 10.3390/en14165113.

[32] Van SD, Ngo HQ, Cotton SL. Wireless powered wearables using distributed massive MIMO. IEEE Trans Communed 2020;68:2156–72. https://doi.org/ 10.1109/TCOMM.2020.2965442.

[33] Mahmood MF, Mohammed SL, Gharghan SK. Ultrasound sensor-based wireless power transfer for low-power medical devices. J Low Power Electron Appl 2019; 9:20. https://doi.org/10.3390/jlpea9030020.

[34] Wang G, Liu W, Sivaprakasam M, Kendir GA. Design and analysis of an adaptive transcutaneous power telemetry for biomedical implants. IEEE Transactions on Circuits and Systems I: Regular Papers 2005;52:2109–17. https://doi.org/ 10.1109/TCSI.2005.852923.

[35] Campi T, Cruciani S, Maradei F, Montalto A, Musumeci F, Feliziani M. Centralized high power supply system for implanted medical devices using wireless power transfer technology. IEEE Transact. Med. Robotics and Bionics 2021;3:992–1001. https://doi.org/10.1109/TMRB.2021.3123404.

[36] Liu Y, Zhang J, Zhu C, Chan CC. A study on the safety analysis of an inductive power transfer system for kitchen appliances. Energies 2022;15:5218.https:// doi.org/10.3390/en15145218.

[37] Chow JP-W, Chung HS-H, Chan LL-H, Shen R, Tang SC. Optimal design and experimental assessment of a wireless power transfer system for home-cage monitoring. IEEE Trans Power Electron 2019;34:9779–93. https://doi.org/ 10.1109/TPEL.2019.2894182.

[38] Solanke TU, Khatua PK, Ramachandaramurthy VK, Yong JY, Tan KM. Control and management of a multilevel electric vehicles infrastructure integrated with distributed resources: a comprehensive review. Renew Sustain Energy Rev 2021; 144:111020. https://doi.org/10.1016/j.rser.2021.111020.

[39] Lazzeroni P, Cirimele V, Canova A. Economic and environmental sustainability of Dynamic Wireless Power Transfer for electric vehicles supporting reduction oflocal air pollutant emissions. Renew Sustain Energy Rev 2021;138:110537. https://doi.org/10.1016/j.rser.2020.110537.

[40] Covic GA, Boys JT. Modern trends in inductive power transfer for transportation applications. IEEE J. Emerg. Select. Topics in Power Electron. 2013;1:28–41. https://doi.org/10.1109/JESTPE.2013.2264473.

[41] Bentalhik I, Lassioui A, El Fadil H, Bouanou T, Rachid A, El Idrissi Z, et al. Analysis, design and realization of a wireless power transfer charger for electric vehicles: theoretical approach and experimental results. World Electric Vehicle J. 2022;13:121. https://doi.org/10.3390/wevj13070121.

[42] Li S, Mi CC. Wireless power transfer for electric vehicle applications. IEEE J. Emerg. and Select. Topics in Power Electron. 2014;3:4–17.

[43] Nguyen MT, Nguyen CV, Truong LH, Le AM, Quyen TV, Masaracchia A, et al. Electromagnetic field based WPT technologies for UAVs: a comprehensive survey. Electronics 2020;9:461. https://doi.org/10.3390/electronics9030461.

[44] Bie Z, Zhang J, Song K, Zhu C. A free-rotation asymmetric magnetic coupling structure of UAV wireless charging platform with conformal pickup. IEEE Trans Ind Electron 2022;69:10154–61. https://doi.org/10.1109/TIE.2022.3165297.

[45] Shi B, Wen F, Chu X. A multireceiver wireless power supply system with power equalization in stereoscopic space. Electronics 2021;10:713. https://doi.org/ 10.3390/electronics10060713.

[46] Song K, Ma B, Yang G, Jiang J, Wei R, Zhang H, et al. A rotation-lightweight wireless power transfer system for solar wing driving. IEEE Trans Power Electron 2018;34:8816–30. https://doi.org/10.1109/TPEL.2018.2886910.

[47] Yan Z, Song B, Zhang Y, Zhang K, Mao Z, Hu Y. A rotation-free wireless power transfer system with stable output power and efficiency for autonomous underwater vehicles. IEEE Trans Power Electron 2018;34:4005–8. https://doi. org/10.1109/TPEL.2018.2871316.

[48] Kim S-M, Choi J, Jung H. Experimental demonstration of underwater optical wireless power transfer using a laser diode. Chin Opt Lett 2018;16:080101. https://doi.org/10.1364/COL.16.080101.

[49] Park D, Chung WK, Kim J. Analysis of electromagnetic waves attenuation for underwater localization in structured environments. Int J Control Autom Syst 2020;18:575–86. https://doi.org/10.1007/s12555-019-0548-9.

[50] Kwak K, Park D, Chung WK, Kim J. Underwater 3-D spatial attenuation characteristics of electromagnetic waves with omnidirectional antenna. IEEE ASME Trans Mechatron 2016;21:1409–19. https://doi.org/10.1109/ TMECH.2015.2509466.

[51] Lin R, Li D, Zhang T, Lin M. A non-contact docking system for charging and recovering autonomous underwater vehicle. J Mar Sci Technol 2019;24:902–16. https://doi.org/10.1007/s00773-018-0595-6.

[52] Vu MT, Choi H-S, Nhat TQM, Nguyen ND, Lee S-D, Le T-H, et al. Docking assessment algorithm for autonomous underwater vehicles. Appl Ocean Res 2020; 100:102180. https://doi.org/10.1016/j.apor.2020.102180.

[53] Wu X, Sun P, Yang S, He L, Cai J. Review on underwater wireless power transfer technology and its application. Trans China Electrotech Soc 2019;34:1559–68. https://doi.org/10.19595/j.cnki.1000-6753.tces.180691.

[54] Kim J, Kim K, Kim H, Kim D, Park J, Ahn S. An efficient modeling for underwater wireless power transfer using Z-parameters. IEEE Trans Electromagn C 2019;61. https://doi.org/10.1109/TEMC.2019.2952320. 2006–14.

[55] Zhou J, Yao P, He R, Guo K, Zhang Y, Ma H. Dual resonant frequency inductive power transfer in an underwater tight coupling system. Energies 2021;14:242. https://doi.org/10.3390/en14010242.

[56] Christ RD, Wernli Sr RL. The ROV manual: a user guide for remotely operated vehicles. Butterworth-Heinemann; 2013.

[57] Capocci R, Dooly G, Omerdi´c E, Coleman J, Newe T, Toal D. Inspection-class remotely operated vehicles—a review. J Mar Sci Eng 2017;5:13. https://doi.org/10.3390/jmse5010013.

[58] Council NR. Undersea vehicles and national needs. National Academies Press; 1996.

[59] Aoki T, Tsukioka S, Kasutani Y, Nakae T, Terakubo S. Development of expendable optical fiber cable ROV system. OnePetro: The Third International Offshore and Polar Engineering Conference; 1993.

[60] Ochi H, Watanabe Y, Shimura T. An experiment of the underwater acoustic data transmission in deep sea. Oceans’ 04 MTS/IEEE Techno-Ocean’04 (IEEE Cat. No. 04CH37600) 2004;1:20–5. https://doi.org/10.1109/OCEANS.2004.1402889.

[61] Davis RE, Eriksen CC, Jones CP. Autonomous buoyancy-driven underwater gliders. The Technol. Applicat. Autonomous Under. Vehicles 2002;37–58. https://doi.org/10.1201/9780203522301.ch3.

[62] Rudnick DL. Ocean research enabled by underwater gliders. Ann Rev Mar Sci 2016;8:519–41. https://doi.org/10.1146/annurev-marine-122414-033913.

[63] Rudnick DL, Cole ST. On sampling the ocean using underwater gliders. J Geophys Res: Oceans 2011;116.

[64] Rudnick DL, Davis RE, Eriksen CC, Fratantoni DM, Perry MJ. Underwater gliders for ocean research. Mar Technol Soc J 2004;38:73–84. https://doi.org/10.4031/002533204787522703.

[65] Eriksen CC, Osse TJ, Light RD, Wen T, Lehman TW, Sabin PL, et al. Seaglider: a long-range autonomous underwater vehicle for oceanographic research. IEEE J Ocean Eng 2001;26:424–36. https://doi.org/10.1109/48.972073.

[66] Palm J, Eskilsson C. Mooring systems with submerged buoys: influence of buoy geometry and modelling fidelity. Appl Ocean Res 2020;102:102302. https://doi.org/10.1016/j.apor.2020.102302.

[67] Song D, Sun J, Xue B, Jiang Q, Wu B. Mooring system of ocean turbulence observation based on submerged buoy. China Ocean Eng 2013;27:369–78. https://doi.org/10.1007/s13344-013-0032-x.

[68] Murphy HM, Jenkins GP. Observational methods used in marine spatial monitoring of fishes and associated habitats: a review. Mar Freshw Res 2010;61: 236–52. https://doi.org/10.1071/MF09068.

[69] Zhang Z, Qi S, Li S. Marine observation beacon clustering and recycling technology based on wireless sensor networks. Sensors 2019;19:3726. https://doi.org/10.3390/s19173726.

[70] Moroni D, Pieri G, Salvetti O, Tampucci M, Domenici C, Tonacci A. Sensorized buoy for oil spill early detection. Methods in Oceanography 2016;17:221–31. https://doi.org/10.1016/j.mio.2016.10.002.

[71] Inzartsev A, Pavin A. AUV application for inspection of underwater communications. Underwater Vehicles 2009. https://doi.org/10.5772/6704.

[72] Inzartsev A. Underwater vehicles. BoD–Books on Demand; 2009.

[73] Board NS, Council NR. Autonomous vehicles in support of naval operations. National Academies Press; 2005.

[74] Button RW, Kamp J, Curtin TB, Dryden J. A survey of missions for unmanned undersea vehicles. RAND NATIONAL DEFENSE RESEARCH INST SANTA MONICA CA; 2009.

[75] Board OS, Council NR. Future needs in deep submergence science: occupied and unoccupied vehicles in basic ocean research. National Academies Press; 2004.

[76] Jiajia J, Xianquan W, Fajie D, Xiao F, Chunyue L, Zhongbo S. A basic bio-inspired camouflage communication frame design and applications for secure underwater communication among military underwater platforms. IEEE Access 2020;8: 24927–40. https://doi.org/10.1109/ACCESS.2020.2970746.

[77] Kinsey JC, Eustice RM, Whitcomb LL. A survey of underwater vehicle navigation: recent advances and new challenges. IFAC Confer. Manoeuvering and Control of Marine Craft 2006;88:1–12. Lisbon.

[78] Griffiths G, Jamieson J, Mitchell S, Rutherford K. Energy storage for long endurance AUVs. The Institute of Marine Engineering, Science and Technology; 2004.

[79] Yanyan Z. The concept and technology development of autonomous underwater vehicle technology—taking “bluefin-21” as an example. China Terminology 2014; 16:131.

[80] Bluefin 1.5 kWh subsea battery. 2018 [Online]. Available, https://gdmissionsystems.com/products/underwater-vehicles/bluefin-robotics/1-5-kwh-subsea-batter y. [Accessed 10 September 2022].

[81] Orr A. Bluefin-21’s search for MH370 nearing completion in the Southern Indian Ocean. 2014 [Online]. Available, https://www. smh.com.au/national/bluefin21s-search-for-mh370-nearing-completion-in-the-southern-indian-ocean20140422-3719u.html. [Accessed 10 September 2022].

[82] Blidberg D, Mupparapu S, Chappell S, Komerska R, Jalbert JC, Nitzelm R. The SAUV II (solar powered AUV) test results 2004. Europe Oceans 2005;1:545–50. https://doi.org/10.1109/OCEANSE.2005.1511773. IEEE; 2005.

[83] Crimmins D, Deacutis C, Hinchey E, Chintala M, Cicchetti G, Blidberg D. Use of a long endurance solar powered autonomous underwater vehicle (SAUV II) to measure dissolved oxygen concentrations in Greenwich Bay, Rhode Island, USA. Europe Oceans 2005;2:896–901. https://doi.org/10.1109/ OCEANSE.2005.1513175. 2005.

[84] Chen J, Li Y, Zhang X, Ma Y. Simulation and design of solar power system for ocean buoy. J Phys Conf 2018;1061:012018. https://doi.org/10.1088/1742-6596/1061/1/012018. IOP Publishing.

[85] Hegarty A, Westbrook G, Glynn D, Murray D, Omerdic E, Toal D. A low-cost remote solar energy monitoring system for a buoyed IoT ocean observation platform. In: 2019 IEEE 5th world forum on internet of things (WF-IoT). IEEE; 2019. p. 386–91. https://doi.org/10.1109/WF-IoT.2019.8767311.

[86] Arima M, Okashima T, Yamada T. Development of a solar-powered underwater glider. In: IEEE symposium on underwater technology and workshop on scientific use of submarine cables and related technologies. IEEE; 2011. p. 1–5. https://doi. org/10.1109/UT.2011.5774120. 2011.

[87] Stokey R, Allen B, Austin T, Goldsborough R, Forrester N, Purcell M, et al. Enabling technologies for REMUS docking: an integral component of an autonomous ocean-sampling network. IEEE J Ocean Eng 2001;26:487–97. https://doi.org/10.1109/48.972082.

[88] Allen B, Austin T, Forrester N, Goldsborough R, Kukulya A, Packard G, et al. Autonomous docking demonstrations with enhanced REMUS technology. Oceans 2006:1–6. https://doi.org/10.1109/OCEANS.2006.306952. IEEE; 2006.

[89] Hui SYR, Zhong W, Lee CK. A critical review of recent progress in mid-range wireless power transfer. IEEE Trans Power Electron 2013;29:4500–11. https:// doi.org/10.1109/TPEL.2013.2249670.

[90] Bellingham JG. Autonomous underwater vehicle docking. Springer Handbook of Ocean Engineering, Springer; 2016. p. 387–406.

[91] Boyer F, Lebastard V, Chevallereau C, Mintchev S, Stefanini C. Underwater navigation based on passive electric sense: new perspectives for underwater docking. Int J Robot Res 2015;34:1228–50. https://doi.org/10.1177/ 0278364915572071.

[92] Yazdani AM, Sammut K, Yakimenko O, Lammas A. A survey of underwater docking guidance systems. Robot Autonom Syst 2020;124:103382. https://doi. org/10.1016/j.robot.2019.103382.

[93] Eren F, Pe'eri S, Thein M-W, Rzhanov Y, Celikkol B, Swift MR. Position, orientation and velocity detection of unmanned underwater vehicles (UUVs) using an optical detector array. Sensors 2017;17:1741. https://doi.org/10.3390/ s17081741.

[94] Li D, Zhang T, Yang C. Terminal underwater docking of an autonomous underwater vehicle using one camera and one light. Mar Technol Soc J 2016;50. https://doi.org/10.4031/MTSJ.50.6.6.

[95] Mohammed Sabith, Muhammad Sayed, Nihal K, Geethu James. Underwater Wireless Power Transfer for Maritime Applications International Journal of Engineering Research & Technology (IJERT) http://www.ijert.org ISSN: 2278-0181 IJERTV9IS060335 Vol. 9 Issue 06, June-2020