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Reducing the Use of Electrochemical Sources of Electricity Through the Use of Wireless Power Supply

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1. Introduction

Ongoing technical developments are causing a continuous increase in the demand for more and more electrical devices. Because of the comfort of use, great emphasis is placed on the mobility of these devices. This has resulted in many electrical devices being equipped with energy storages (batteries or accumulators). Because of the elements used for their production, batteries and accumulators become hazardous to human health and natural environment at the end of their lives. Their proper management is necessary. A reduction in the negative impact of waste batteries and accumulators is obtained through recycling, which is enforced by law (Korkozowicz 2009, 2010). At this stage, we can follow the process of recycling end-of-life vehicles, which was presented in detail in the works of Chamier-Gliszczyński (Chamier-Gliszczyński 2010, 2011a, 2011b). Recycling, however, entails costs and is not neutral to the environment. Among other things, it requires energy, which results in the additional emission of CO_2 into the atmosphere. On top of this, it is still impossible to recycle 100% of the batteries and accumulators that are introduced into the market.

One optional solution may be to resign from electrochemical energy sources presented in the works Kasprzyk (2019), Tomczewski et al. (2019) and Burzyński et al. (2019) by using a different type of energy storage such as the supercapacitor. Supercapacitors have a number of advantages, though obviously they are not without certain disadvantages (Głuchy & Kasprzyk 2017, Głuchy et al. 2017, Kasprzyk et al. 2017). One of the most important features is their lifespans which may even extend to over 10 years (up to a million charge and discharge cycles), high efficiency (up to 95%), high current capacity, low environmental impact and low weight. With regards to their disadvantages, one can mention the relatively low operating voltage of a single cell (2-3 V) as well as the possibility of self-discharge (up to 25% in 48 hours) and also the large size in relation to chemical energy storages of a comparable capacity. The relatively low energy capacity of supercapacitors (in comparison to accumulators or batteries) does not allow for their common use in devices in lieu of accumulators or batteries (because of the necessity of frequent charging) (Jajczyk & Słomczyński 2019). Such a solution is inconvenient and limits the use of supercapacitors as a source of power for devices which are operated frequently, but for a short time, and which consume a relatively low amount of energy. Examples of devices used in such a manner include remote controls for radios or TV sets, keyless car keys, etc. These devices are usually put away in the same place after a short period of use. Sometimes, devices are equipped with a battery, which may be recharged (e.g. smartphones, toothbrushes). The replacement of a battery by a supercapacitor also results in an increase in the size of the device. As well as this, its mobility parameter will also be worse, as more frequent connection of the power (charging) cable will be required. This, as such, is inconvenient and limits the possibility of operating the device while it is charging, and in certain conditions, the galvanic connection is even dangerous (there is the possibility of short-circuits or dirtying the connector).

In the case of some devices, it is possible to stop using electric energy storages and, instead, use a wireless power supply which does not require the galvanic connection. Power may be supplied "through the enclosure"; it only suffices to place a device in the right location. In recent years, this method of supplying power has gained popularity owing to, among other things, the optimisation of devices, improvement of their performance and the introduction of standardisation. Owing to the implementation of a wireless power supply, in the case of devices operated continuously in the area of impact of the power supply system, it is possible to resign from energy storages completely. One example of such a device is a computer mouse, whose operating range is usually limited to the area of a mouse-pad.

2. Consumption of batteries and accumulators in Poland

Low power electrical devices, specifically portable devices, use a power source in the form of an electrochemical battery. Their biggest disadvantage during operation is the loss of their initial ability to discharge energy, which leads to the necessity of their replacement. Because many elements which are harmful to humans and the natural environment are used to construct them, they must necessarily be subjected to the recycling process (Legal act 2020, Nowacki & Mroziński 2012). Poisonous elements are released by waste batteries into the soil and ground waters which cause pollution of the natural environment. As a consequence of this – in the closed Earth's ecosystem – living organisms are poisoned leading to many diseases and illnesses.

Based on statistics, it is assumed that 1 tonne of batteries contains the following elements (Kozakiewicz 2009, 2010):

- manganese dioxide 270 kg (27%),
- iron 210 kg (21%),
- zinc 160 kg (16%),
- graphite 60 kg (6%),
- ammonium chloride 35 kg (3.5%),
- copper 20 kg (2%),
- potassium hydroxide 10 kg (1%),
- mercury (mercury oxide) 3 kg (0.3%),
- a few kilograms of nickel and lithium (0.4%),
- cadmium 0.5 kg (0.05%),
- silver (silver oxide) 0.3 kg (0.03%),
- small amounts of cobalt.

At present, due to the dynamically developing market of electrical vehicles, and thus, their accumulators, the percentage value of the elements used is changing (as more efficient and cheaper solutions are sought).

The Batteries and Accumulators Act adopted on 24.04.2009 (Legal act 2020) provided for an obligation to collect waste energy sources as described in art. 27 and art. 33. In accordance with the objectives, the required rate of collected batteries for the year 2016 was 45%. For the year 2016, the objectives of the Act were not accomplished. According to the reports of the Chief Inspectorate of Environmental Protection (CIEP), the actual battery collection rate on the Polish market in the year 2016 was only 39%, although nowadays, the situation has improved. According to the recent report of the CIEP for the year 2018 (Raporty GIOŚ 2019), the battery collection rate in Poland was 80% (Table 1).

The collection rate, increasing from year to year, has resulted in a decrease in the mass of recycled batteries and accumulators. An important aspect for the analysed level is also the organized process of collection and processing of end-of-life vehicles (Chamier-Gliszczyński 2011c), where the battery is an important element. Despite exceeding the collection threshold in the year 2017, which was at a level of 45%, and despite the achievement of a value of 80%, still a significant part (20% of batteries and accumulators) is not subject to processing, which constitutes a mass of over 2638 tonnes (Fig. 1).

Table 1. Batteries introduced into and collected from the Polish market in the years 2010-2018 (Raporty GIOŚ 2019)

Year	Mass of introduced portable batteries and accumulators [kg]	Mass of collected waste portable batteries and accumulators [kg]	Accom-plished collection rate [%]	Predicted collection rate [%]
2010	9 866 370.92	1 774 838.76	17.99	18.00
2011	9 818 740.44	2 230 889.23	22.72	22.00
2012	10 078 906.07	2 933 105.21	29.10	25.00
2013	10 544 747.99	3 170 109.92	30.06	30.00
2014	11 220 634.34	3 710 034.47	33.06	35.00
2015	11 755 981.53	4 508 589.04	38.35	40.00
2016	12 196 457.76	4 756 258.77	39.00	45.00
2017	12 795 706.75	8 411 931.21	65.74	45.00
2018	13 192 347.62	10 554 051.37	80.00	45.00

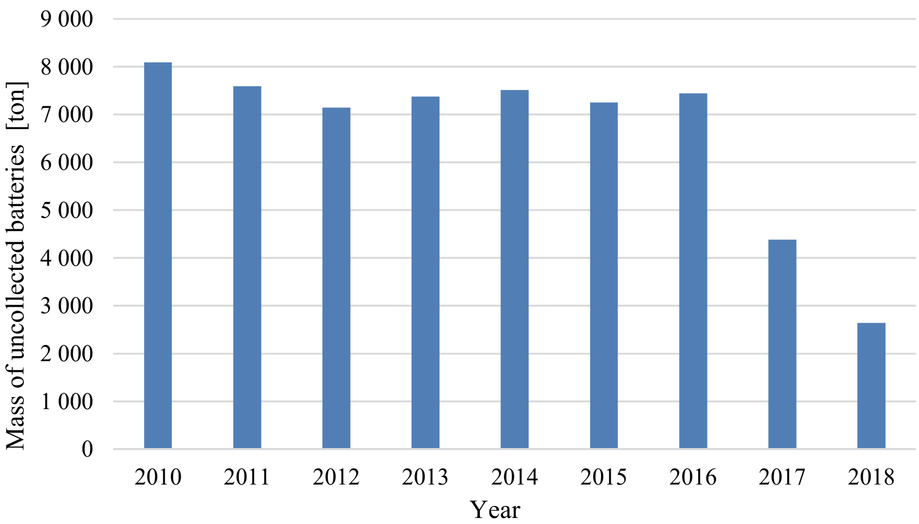

Fig. 1. Mass of uncollected waste portable batteries and accumulators in the years 2010-2018 (Raporty GIOŚ 2019)

A part of the mass of batteries and accumulators which were not subjected to recycling, includes batteries which were a source of power supply for electronic devices. A reduction in the number of batteries used is the simplest way to reduce the mass of batteries and accumulators which must be recycled.

3. A wireless power supply instead of electrochemical sources

The use of portable devices usually requires the use of energy sources such as batteries or accumulators to power these devices. Sometimes these sources can be replaced by capacitors. Specifically, this refers to devices which are characterised by low power consumption. These devices must be provided with the possibility of replenishing energy on a continuous basis, which creates certain inconveniences. However, it would then be possible to stop using energy storages owing to the use of wireless power supply systems.

Wireless power supply systems are based on the principle of electromagnetic induction. They transfer energy through the electromagnetic field just as is the case with transformers. The system consists of an energy transmitter and a receiver, that is, the primary winding side and the secondary winding side of the transformer. Unlike in transformers, the windings are separated (they are located in different devices). The transmitter may be provided with an air-core coil or coil wound onto a ferromagnetic core. However, on the side of the receiver, ferromagnetic core coils are implemented to avoid the accompanying increase in the mass of the powered device. With the assumption that the system is powered from a power network, the system comprises several converter blocks and a control system. At the input of each transmitter circuit, there is an AC/DC converter (rectifier), whose task is to convert the mains AC voltage into DC voltage. Then, there is the DC/AC converter, which converts DC voltage into high-frequency AC voltage (from several kHz to several MHz). The generated AC voltage is applied to the coil serially connected with the capacitor, with a capacity selected in such a way as to contribute to the occurrence of voltage resonance in the circuit. The receiver is provided with a passive power compensation system with a converter which converts AC voltage into DC voltage and a pulse system, used to power the receiver (Fig. 2).

The construction of a system which transmits energy in the form of an electromagnetic field is complicated, mainly due to the DC-AC converters used to match the appropriate operating frequency. To a great extent, the effective use of the wireless transmission of electricity depends on the performance of the circuit, i.e. the lowest possible energy losses. The greatest impact on losses is exerted by the stream of the dispersed electromagnetic field.

The year 2009 marked the development of the "Qi Wireless Charging" standard. This determined the parameters of devices which use a wireless power supply. Work on the standard was conducted by the Wireless Power Consortium, established by over one hundred companies interested in this technology. The first receiver which used the Qi Standard was presented in 2011.

Two groups of chargers were identified in the standard (Van Wageningen & Staring 2010, Hui 2013, Filipiak et al. 2019):

- the first one, low power – up to 5 W,
- the second one, medium power – up to 120 W.

In order to maintain maximum performance of the devices, the possibility of mechanical positioning of the receiver in relation to the base station was indicated, i.e. the use of a dock which enables the placement of the device only in one position. Another method is the automatic adaptation of the base station to the position of the mobile device, that is, the use of many coils in the transmitter which are switched on by the controller that searches for the configuration of the system that ensures its highest efficiency. The standard also determines the permissible frequency ranges for low power devices – from 110 to 205 kHz, and for medium power devices – from 80 to 300 kHz. The standard determines the maximum distance between the base device and the receiver, which is 40 mm. This means that the device is capable of transferring electricity to the receiver through an obstacle with a maximum thickness of 40 mm, if it is made of a material with relative magnetic permeability (Van Wageningen & Staring 2010, Hui 2013, Filipiak et al. 2019).

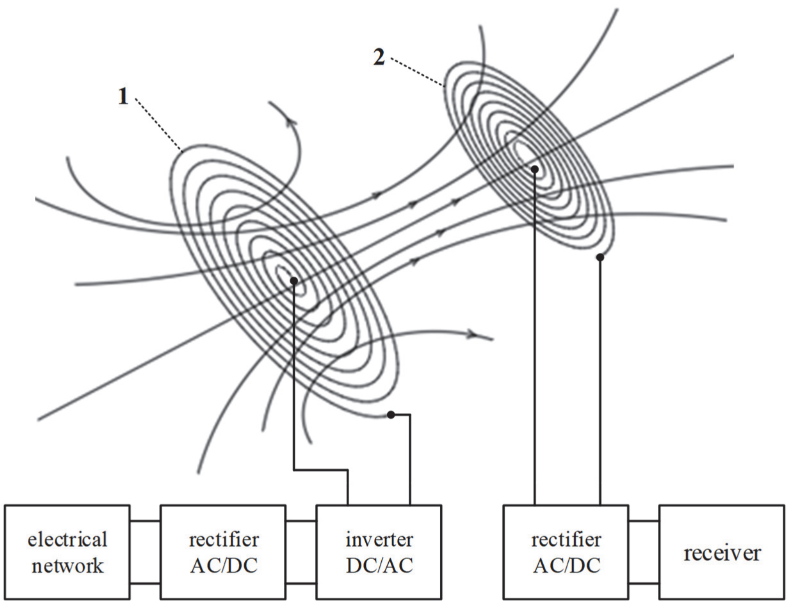

Fig. 2. Block diagram of the system for wireless energy transmission:
1 – coil of the transmitter of the power supply system, 2 – receiver inductor

4. An example of a device with a wireless power supply

Modern computer systems require the use of indicator systems such as e.g. a mouse. Among the offers presented by manufacturers of such equipment, we can distinguish trackball and optical devices, both wired and wireless. Out of those listed above, the most complicated devices, in terms of the processing of the real position into the virtual position on the computer screen, are the wireless mice. In most cases, they are powered with a battery (type: AA or AAA) with a 1.5 V rated voltage. It is also possible to encounter solutions which do not have their own power source, but use a wireless power supply. In this paper we tested an exemplary device which used a wireless power supply, that is, the A4Tech EVO Battery Free computer mouse (Fig. 3).

Fig. 3. Wireless mouse with a mouse pad for inductive power supply (A4Tech EVO Battery Free)

The tested device consists of an inductive pad and an optical mouse. The mouse pad is powered from a USB port (5 V DC). Transmission of power to the receiver is possible owing to the phenomenon of electromagnetic induction and the generation of electromotive force in the receiver coil (mouse) The electronic system located in the mouse pad converts the DC voltage coming from a USB port into AC voltage which allows for the induction of the alternating electromagnetic field with a frequency of approximately 122 kHz. A coil without a ferromagnetic core, in the shape of a rectangle measuring 14.5 cm by 18.5 cm, is mounted in the pad. There are 13 windings of copper wire on it. The mouse includes an air-core coil measuring 9.5 cm by 4.5 cm. The transmission of information about the position of the mouse cursor takes place through RFID technologies (Kostrzewski et al. 2019).

This paper verifies the practical aspects of the operation of such a type of power supply system. For this purpose, the value of the wirelessly induced voltage was measured depending on the position of the mouse on the power pad and the distance of the mouse from the pad. Fig. 4 presents the shape and position of the air-core coil in the mouse pad and the areas in which the tested receiver was placed during measurements. The transmitter coil consists of a wound copper wire, in the shape of a rectangle, and its intrinsic inductance amounts to 62 μH. The receiver coil is smaller, however, it has more windings. Its intrinsic inductance is 76.6 μH (inductances were measured with a METERMAN LCR55). The voltage signal generated in the transmitter and the one induced in the receiver coil have forms, which approximate those of sinusoidal waves and their frequency is about 122 kHz.

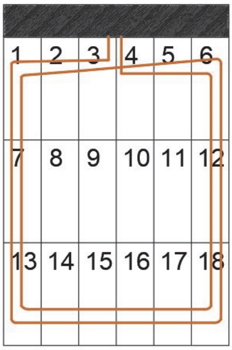

Fig. 4. Division of the power pad into sectors

During tests, the mouse (receiver) was placed in sectors defined in Fig. 4, and the effective value of the voltage induced on the receiver coil terminals was determined using the INSTEK GDS-82C oscilloscope. The values of the measured voltages are presented in Fig. 5. It was observed that the placement of the device powered in any place of the power pad ensures a voltage value that is sufficient for its correct operation.

It was verified in this paper whether the device met the requirements set by the Qi standard. For this purpose, the correctness of operation of the mouse was tested at a distance of 40 mm from the power pad. It was found that in each of 18 points (Fig. 4), the mouse works correctly after placing it 40 mm away from the power pad. The voltage measured at each point was less than 4 V.

5. Remarks and conclusions

This article has brought issues related to the use of electrochemical energy sources in mobile electrical devices to attention. Based on the reports of the Chief Inspectorate of Environmental Protection, the mass of portable batteries and accumulators introduced into the Polish market and collected from it in the years 2010-

2018 was analysed. It was demonstrated that the recycling system for this type of devices is more and more effective from year to year. However, attention has also been paid to the problem of energy sources which are still not collected. It was demonstrated that the batteries and accumulators which were not subjected to disposal because of their chemical composition are an environmental hazard.

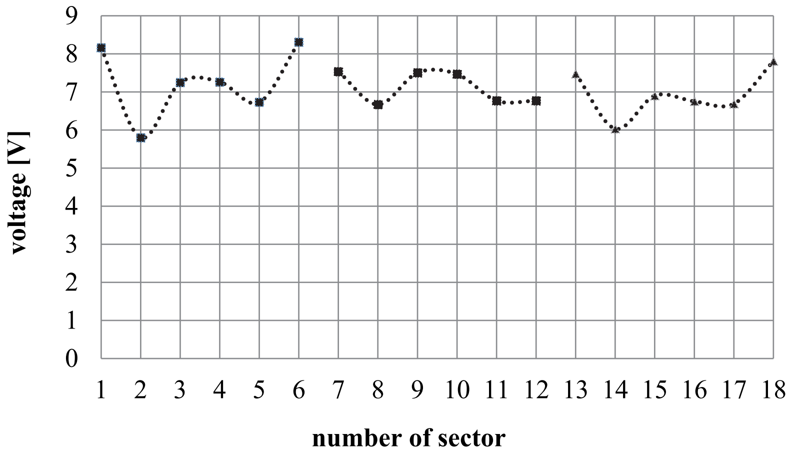

Fig. 5. Values of the induced voltage in the respective sectors of the power pad

The authors paid attention to the existing mobile solutions on the market, which do not require a power source in the form of a battery or accumulator. The paper discusses a wireless power supply system which takes advantage of the phenomenon of electromagnetic induction. A wireless mouse was given as an example of the device. The mouse uses an inductive power supply after it is placed on a special power pad and this mouse and power pad were subjected to insightful analysis with regards to their operation. As a result of the tests, it was found that the mouse works correctly irrespective of its place on the power pad. The tested device complies with the Qi Wireless Power standard and meets the requirements for operation set by this standard. It can be said that the wireless power supply successfully replaces a power supply obtained from batteries.

In devices which are used within a limited area (similarly to computer mice), it is possible to stop using power supplies dependent on batteries in order to switch to wireless inductive power supplies. As a solution which can help popularise this type of technology, there are suggestions to use inductive charging pads built into the table surface, with an area drawn to mark its location. The integration of a power supply system with a piece of office furniture will allow additional pads to be excluded, thus increasing the comfort of use of the mouse and the aesthetics of a computer workstation. The production of these devices can also be improved, e.g. by applying the methods presented in Szajna et al. (Szajna et al. 2020, 2018).

Owing to the continuous development of wireless power supply technologies, these systems are achieving ever better parameters (efficiency and range). In the case of certain devices and systems, in addition to ensuring similar mobility, the necessity of using power supplies based on batteries is eliminated, thus the number of batteries is reduced, which, in turn has a positive effect on environmental protection.

References

Burzyński, D., Pietracho, R.. Kasprzyk, L., Tomczewski, A. (2019). Analysis and Modeling of the Wear-Out Process of a Lithium-Nickel-Manganese-Cobalt Cell during Cycling Operation under Constant Load Conditions. *Energies*, *12*, 3899.

Chamier-Gliszczyński, N. (2010). Optimal Design for the Environment of the Means Transportation: a Case Study of Reuse and Recycling Materials. *Sold State Phenomena*, *165*, 244-249.

Chamier-Gliszczyński, N. (2011a). Recycling Aspect of End-of Life Vehicles. Recovery of Components and Materials from ELVs. *Key Engineering Materials*, *450*, 421-424.

Chamier-Gliszczyński, N. (2011b). Reuse, Recovery and Recycling System of End-of Life Vehicles. *Key Engineering Materials*, *450*, 425-428.

Chamier-Gliszczyński, N. (2011c). Environmental aspects of maintenance of transport means. End-of life stage of transport means. *Eksploatacja i Niezawodnosc-Maintenance and Reliability*, *2*, 59-71,

Filipiak, M., Głuchy, D., Godek, M. (2019). Wpływ technologii stosowanych w ładowarkach bezprzewodowych na proces ładowania urządzeń mobilnych. *Poznan University of Technology Academic Journals. Electrical Engineering*, *99*, 41-51.

Głuchy, D., Kasprzyk, L. (2017). Modelowanie pracy superkondensatora zasilającego układ poprawiający bezpieczeństwo drogowe. *Przegląd Elektrotechniczny*, *93*(12), 99-102.

Głuchy, D., Kasprzyk, L., Tomczewski, A. (2017). Modelowanie superkondensatorów na potrzeby współpracy z OZE. *Poznan University of Technology Academic Journals. Electrical Engineering*, *89*, 335-345.

Hui, S.Y. (2013). Planar wireless charging technology for portable electronic products and Qi. *Proceedings of the IEEE*, *101*(6), 1290-1301.

Jajczyk, J., Słomczynski, K. (2019). A dedicated battery for an electric bike. *ITM Web of Conferences. Computer Applications in Electrical Engineering, 28*, 01033.

Kasprzyk, L. (2019). Selected issues of modelling degradation of the lithium-ion batteries in electric vehicles, *Przegląd Elektrotechniczny*, *95*(3), 70-73.

Kostrzewski, M., Varjan, P., Gnap, J. (2020). *Solutions Dedicated to Internal Logistics 4.0.* In: Grzybowska K., Awasthi A., Sawhney R. (eds) Sustainable Logistics and Production in Industry 4.0. EcoProduction (Environmental Issues in Logistics and Manufacturing). Springer, Cham, 243-262.

Korkozowicz, M. (2010). Co dalej z recyklingiem baterii? *Odpady i Środowisko*, *5*, 63-65.
Korkozowicz, M. (2009). Baterie-nowe prawo i obowiązki. *Recykling*, *6*, 18-19.
Legal act, Act of April 24, 2009 on batteries and accumulators in Poland, Dz. U. 2009, 79.
Nowacki, M., Mroziński, A. (2012). Przykłady procesów recyklingu baterii w Polsce. *Inżynieria i Aparatura Chemiczna*, *51*(5), 239-241.
Raporty o funkcjonowaniu gospodarki bateriami i akumulatorami oraz zużytymi bateriami i zużytymi akumulatorami za lata 2010-2018 (2011-2019), *GIOŚ*.
Szajna, A., Stryjski, R., Woźniak, W., Chamier-Gliszczyński, N., Kostrzewski, M. (2020). Assessment of Augmented Reality in Manual Wiring Production Process with Use of Mobile AR Glasses. *Sensors, 20*(17)*,* 4755, 1-26.
Szajna, A., Szajna, J., Stryjski, R., Sąsiadek, M., Woźniak, W. (2019). *The Application of Augmented Reality Technology in the Production Processes, Intelligent Systems in Production Engineering and Maintenance: conference proceedings ISPEM 2018, 2019.* / eds. A. Burduk, E. Chlebus, T. Nowakowski, A. Tubis, Cham: Springer Nature Switzerland (Advances in Intelligent Systems and Computing 835), 316-324.
Van Wageningen, D., Staring, T. (2010). The Qi wireless power standard. In *Proceedings of 14th International Power Electronics and Motion Control Conference EPE-PEMC 2010,* 15-25).

Abstract

The paper discusses issues related to the recycling of electrochemical sources of electricity such as portable batteries and accumulators. Based on the reports of the Chief Inspectorate of Environmental Protection, the collection rate of waste batteries and accumulators in Poland for the years 2010-2018 was subjected to analysis. Despite the increasing year-to-year percentage value of the collection rate, it has been demonstrated that a significant mass of batteries and accumulators is still not recycled.

This article presents a method of reducing the amount of waste electrochemical energy storages, through the use of inductive power supplies. The idea of the operation of such circuits has been discussed and the Qi Wireless Charging standard, applicable since 2011, has been characterised. As an example of a device with wireless power supply, a computer indicator system has been provided. Tests have been carried out and the correctness of operation of this solution has been verified. It has been demonstrated that in some cases it is possible to resign from power supplies based on batteries or accumulators, and use wireless power supplies instead, without degrading the functional properties of devices. Solutions of this type may contribute to the protection of the natural environment.

Keywords:
electrochemical energy storages, recycling of batteries and accumulators,
wireless power supply, Qi Wireless Charging standard

Ograniczenie wykorzystania elektrochemicznych źródeł energii elektrycznej poprzez zastosowanie zasilania bezprzewodowego

Streszczenie

W pracy omówiono problematykę recyklingu elektrochemicznych źródeł energii elektrycznej takich jak baterie i akumulatory przenośnie. Na podstawie raportów Głównego Inspektoratu Ochrony Środowiska przeanalizowano zbieralność zużytych baterii i akumulatorów w Polsce w latach 2010-2018. Pomimo rosnącego z roku na rok procentowego wskaźnika zbieralności wykazano, że znaczna masa baterii i akumulatorów wciąż nie jest poddawana recyklingowi.

W artykule przedstawiono metodę ograniczenia ilości zużywanych elektrochemicznych zasobników energii elektrycznej poprzez zastosowanie zasilania indukcyjnego. Omówiono ideę działania tego typu układów oraz scharakteryzowano obowiązujący od 2011 roku standard Qi Wireless Charging. Jako przykład urządzenia zasilanego bezprzewodowo podano układ wskaźnika komputerowego. Wykonano badania i zweryfikowano poprawność działania tego rozwiązania. Wykazano, że w niektórych przypadkach możliwe jest zrezygnowanie z zasilania bateryjnego lub akumulatorowego na rzecz zasilania bezprzewodowego bez pogorszenia własności funkcjonalnych urządzeń. Rozwiązania tego typu mogą przysłużyć się ochronie środowiska.

Słowa kluczowe:
elektrochemiczne zasobniki energii, recykling baterii i akumulatorów,
zasilanie bezprzewodowe, standard Qi Wireless Charging