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A CONCEPT OF MINIMIZING AN ELECTRIC POWER SUPPLY SYSTEM FOR PORTABLE GEAR AND ARMS

ABSTRACT

Currently a much higher number of portable devices with improved functionality supporting our job-related and social activities require higher and higher capacity and power offered by sources of power supply. Theoretical analysis of the possibility to achieve exploitation features of currently known portable sources of electric current has led the author to a conclusion that even the best solutions will not meet the desired mass and volume magnitudes in relation to the energy supplied. Therefore, if the sources of energy have reached the physically and economically justified capability limits and they are characterized by significantly varied exploitation properties, a solution combining the advantages of various sources of energy through energy management seems to be sensible. In this connection this article presents the idea of a system of energy control, which using available cells will allow for reducing the weight of power supply systems. The considerations are based on defense-related applications, this, however, does not exclude applications for civilian purposes.

Key words:
portable energy source, power management.

INTRODUCTION

The future power of armed forces will be based on highly efficient individuals 'soldiers of the future'. The success of future warriors will depend not only on enhanced situational awareness, i.e. detailed knowledge on location and capabilities of enemy and friendly forces but also on employment of available armament

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and technologies. The demand for energy changes as fast as evolution processes in electronic devices. In connection with energy-intensive communication equipment and computers there appear a countless number of energy consuming receivers — laser pointers, biotechnical sensors, equipment used to maintain constant body temperature or systems of **exoskeleton**. An individual soldier acts both as an element receiving and transmitting information as well as an element of fire power. Electronic support enhances his/her situational awareness. Devices using infrared radiation increase the range of personal arms, displays show maps and positions of enemy and friendly forces, and communication equipment receives and transmits information on potential targets and available fire power beyond the range of personal arms. An appropriately equipped soldier has at his/her disposal information on the location of targets and practically limitless fire support. These kinds of technical capabilities were not available during the first conflict in Persian Golf in 1990. New and more advanced technical solutions cause electrical supplies to be essential in the proper working of systems that have not required electricity so far. It should be assumed that electrical equipment with a reliable power source is essential for effective actions performed by a soldier and transforming currently used equipment to the assumed level requires many innovations, and in this connection power sources are a common critical point. All electronic devices will require power sources providing continuous and undisturbed work in missions of up to 72 hours. This time-length was based on experience collected during operations carried out in military theatres during the last 3 decades. Providing enough electrical energy for soldiers on the battlefield is not a simple task and poses a substantial challenge for the engineers. It is a multidimensional task that requires considering all aspects of power systems, and power management. Companies developing equipment for soldiers are struggling with insufficient quantity of energy for designed electronic components as well as insufficiently advanced technology in certain areas of automation of the elements under consideration. Every device occupies space and constitutes an additional burden for the soldier. If a soldier is to act effectively, both the volume and weight of the elements has to be limited. The key criterion in optimization of systems supplying power for a soldier will be control of stocks and demand for energy as well as use of elements having minimum dimensions and weight. Personal gear, arms, food and other indispensable items can exceed 50 kg, and extra kilograms should be taken into account, stemming from specialized electronic equipment and power supplies needed. Such a payload significantly constrains effective actions by military personnel.

The present-day sources of power — batteries, satisfy the basic needs for energy, however, apart from the excessive weight, their acquisition, storage, and delivery pose an enormous logistic challenge, especially on the battlefield [5].

ANALYSIS OF EXPLOITATION PROPERTIES IN CURRENTLY EMPLOYED ELECTRIC CELLS

Currently employed electric cells can be divided into three fundamental groups:
– primary cells;
– secondary cells (rechargeable);
– fuel cells.

Most of the ideas in cell design used on a wide scale today originated over 100 years ago. These designs have been improved through the introduction of new materials and developing new technologies used to produce them. There exist a lot of criteria used to categorize the cells based on the material they are made of, electrolyte composition, shape, structure and designation.

The basis for the international system of marking primary cells is the division according to their shape and dimensions. [1, 4, 5, 8].

The enormous diversity of cells, which offer technical possibilities concerned with power supply for electronic objects, becomes an enormous burden for an operator. For example the most common battery AA weighs from 15 to even 30 grams, depending on manufacture technology. When used in an electric torch (torch for professional uses) containing from 2 to 8 batteries type AA the weight of the power supply cells can reach over 200 g. Each planned use requires spare batteries. Depending on the expected duration of use it is one or two sets, which gives another 400 g. Such weight constitutes significant load which could, instead, embrace, for example 4 dehydrated food rations (4 x 100 g) providing the operator with 1700 calories [9].

Since the 1990s the energetic capacity of primary batteries (e.g. one of the most common in the world alkaline batteries — type AA) has ceased to grow despite a lot of research and technology innovations. It seems that the maximum magnitude has been reached [1]. Progress in technology in the nearest future will include exclusively only some types of primary cells, especially lithium-magnesium (Li-Mn2O4), zinc-air ($Zn\text{-}O_2$) and lithium-air ($Li\text{-}O_2$) [7].

Use of the second type cells, for which development trends will be directed towards development of lithium-ionic-polymer ($Li\text{-}SO_2Cl_2$) technologies, nickel-zinc (Ni-Zn) technologies or lithium-metal (Li-Fe) technologies [7], eliminates the problem of the so called surplus, but generates another one, i.e. recharging batteries. Additionally, chargers themselves constitute load and another element which occupies already limited space.

Comparing the above mentioned types of fuel cells, the effect of weather conditions (temperature) on their performance must not be neglected. A drop in temperature below 0°C brings about a significant decrease in cell capacity, which in some cases may lead to inability to use the battery [3].

Special attention should be given to fuel cells whose principle of operation is oxidation (without burning) of externally, continuously supplied fuel. Theoretically there can exist chemical reactions whose result is generation by a cell of more energy than is contained in the fuel. The cell, then, takes heat energy from ambience and transforms it into electric energy. Oxidation of carbon into carbon oxide is such a reaction. Its theoretical efficiency is 124,2%. Fuel cells are not required to recharge just like the earlier mentioned secondary cells, and their operation duration is limited exclusively by the amount of fuel [1, 2, 6].

It follows from theoretical deliberations that fuel cells are at present the best source of electric energy, however, in order to provide for optimum operation of the pile a quite complex system is necessary. It must ensure appropriate proportions of pressure and reagents as well as management of the generated heat and water. They also require initial warming up to obtain rated parameters, however the available technical solutions solve this problem. Thanks to that the real parameters of complete systems significantly deviate from theoretical ones.

Performance characteristics of present-day electronic devices used on a battlefield, despite advanced technologies, still require large amounts of energy. It is commercially available cells or dedicated to military equipment cells that are the source of energy. A system used as an example, to maintain continuous work for 24 hrs requires as much as 596.98 Wh (tab. 1).

Table 1. Energy requirement resulted from using a conventional battery over 24 hrs of system operation [own work]

Battery type	Number of batteries required in 24 h	Energy from one battery [Wh]	Energy from the set of batteries of one kind [Wh]
AA	6	2.25	13.5
AAA	6	1.8	10.8
BB-2590	3	178.56	535.68
CR-123	10	3,7	37
		Energy from all used batteries [Wh]	596.98

The mission duration time is not without significance. If the necessity to replace power supply cells is not taken into account their weight might seem to be a negligible problem. However, during long-term operations the weight dramatically grows (tab. 2), which directly affects the effectiveness of performing tasks by an operator. Additional batteries also occupy heavily limited space.

Table 2. Weight of particular cells and total weight of conventional primary cells supplying power for the system [10–13, 15]

Battery type	Amount required in 72 h	Weight of one battery [kg]	Weight of battery set [kg]
AA	18	0,024	0,432
AAA	18	0,011	0,198
BB-2590	9	1,4	12,6
CR-123	30	0,017	0,51
		Total weight of battery [kg]	13,74

SUMMARY OF THE ANALYSES AND INDICATING THE AIM OF FUTURE INVESTIGATIONS

When analyzing the exploitation properties of available sources of energy, a conclusion can be drawn that the most important indicator of their real capabilities is comparing the increase in weight of cells in the work time-duration function (fig. 1). The comparison shows the advantage of fuel cells with regard to long-time work, but it also show the advantages of chemical cells used to supply power to devices which require short-time large-amount energy consumption.

Making a comparison of weight of primary cells with the combination of fuel cells and secondary cells needed to supply power to the modeled set during 72 hrs the difference of over 45% is obtained (tab. 3). These magnitudes were additionally presented in the graphical form (fig. 2), which illustrates the scale of the phenomenon. The employed configuration can be extended by other devices, depending on the operator’s needs. Extension of the number of devices and their energy consumption increases the difference in weight to the advantage of the solution based on systemic management of energy coming from different sources.

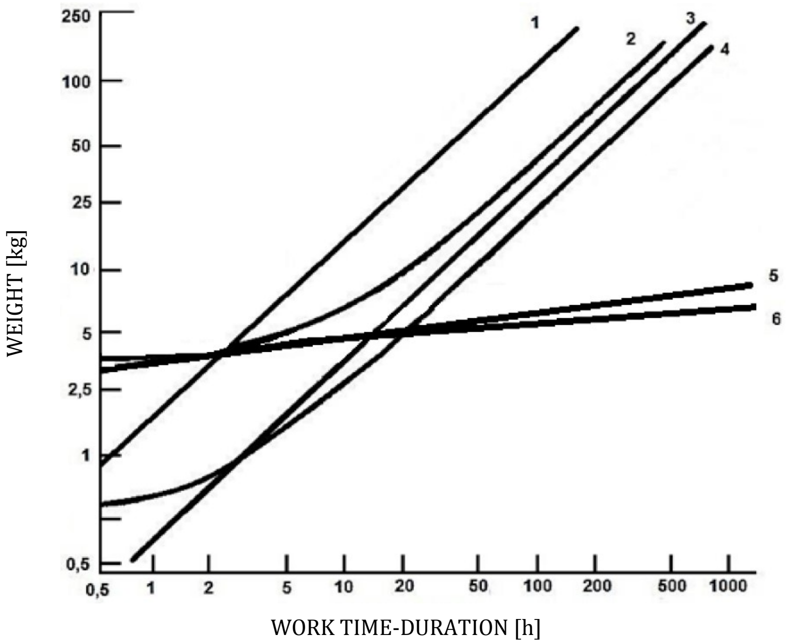

Fig. 1. Characteristics of primary, secondary and fuel cells in the work time-duration function and in the system weight function: 1— secondary cell 35 Wh/kg, 2 —primary cell 100 Wh/kg, 3 — secondary cell 150 Wh/kg, 4 — advanced primary cell 220 Wh/kg, 5 — fuel cell 400 Wh/kg, 6 — fuel cell 850 Wh/kg; assumed initial power level 50 W [4]

Table 3. Comparison of weight of supply cells in three configurations and comparison of their total weight [own work]

	Weight [kg]	Decrease in weight [kg]	Decrease in in weight [%]
Batteries			
24 h	4.58		
48 h	9.16		
72 h	13.47		
Fuel cell			
24 h	3.74	0.84	18.34
48 h	4.30	4.86	113.02
72 h	4.86	8.61	177.16
Fuel cell in combination with batteries			
24 h	5.19	–0.61	**–13.31**
48 h	5.75	3.41	**37.22**
72 h	6.13	7.34	**45.51**

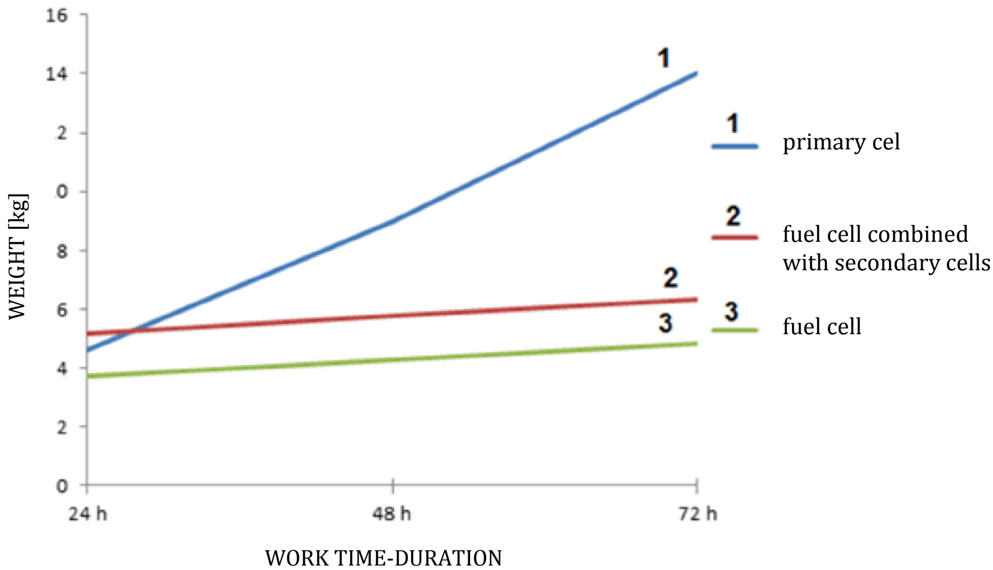

Fig. 2. Comparison of increase in weight of cells supplying power to the system investigated [own work]

Based on the previously described analyses a conclusion can be drawn that the best solution will be intelligent management of the energy of a fuel cell supported by other chemical cells. None of the currently available cells is a perfect source, and in their selection several factors must be taken into account. For this reason cooperation of cells of different types which constitute 'an energy bank' can increase the efficiency of the whole system, minimizing the weight at the same time. For the purposes of the investigations, a model of the system will be built. It will consist of seven (or more) receivers equipped with autonomous power supply sources, a main hybrid power supply source and a control system. The control system (fig. 3) will be based on algorithms allowing for maximum use the source of energy having the best energy properties for a given load in current environmental conditions (mainly air temperature and humidity). Obviously, it should also allow the operator to choose, out of available modes of operation, the mode appropriate for the task being performed. Additionally, the system can support decisions made by the user, e.g. owing to external sensors it will increase energy availability for selected devices (e.g. night-vision devices and lighting at night or in unlit compartments). The system should also use energy harvesting, i.e. processes in which energy is acquired from ambience (solar, heat, kinetic, as well as accidental and dedicated sources of energy). The combination of this type not only decreases the weight of the power supply system but also extends the longevity of the cells installed in it.

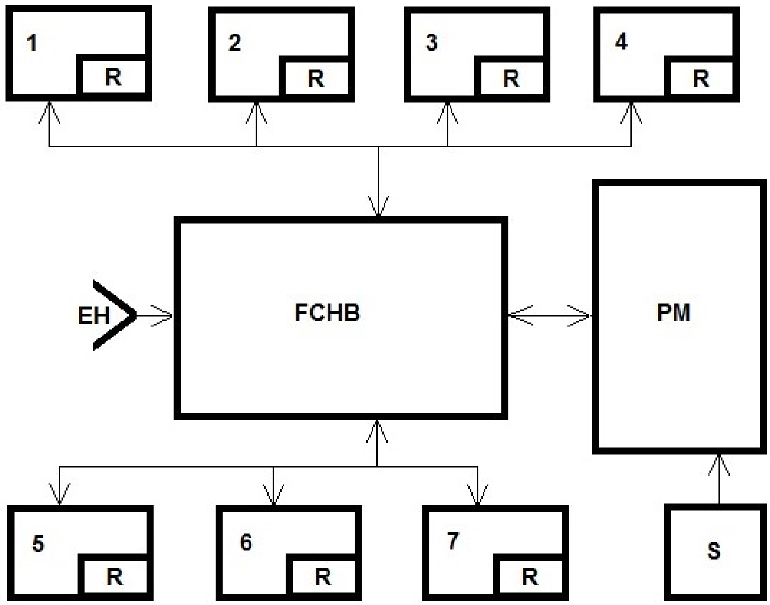

Fig. 3. Diagram of the system under consideration:
1–7 — receivers, R — secondary cells, FCHB — hybrid battery based on fuel cell, S — a system of sensors necessary for the system to work, PM — intelligent system for power management, EH — plug-in socket (energy acquisition) [own work]

CONCLUSIONS

The results of the analyses presented in the article justify decisions to carry out further investigations. Benefits from the proposed solutions are multidimensional and allow not only for a decrease in soldier's load but owing to minimizing of the number of types of necessary batteries will constitute a significantly relief for logistic services. The necessity to dispose of lower amounts of batteries containing chemical compounds harmful for the natural environment will significantly contribute to its protection. Another stage of actions taken by the author will be simulation-based investigations constituting the base for building and verifying a real system, allowing for verification of the adopted thesis. The simulation will involve modeling, in the Matlab environment, performance of a control system, using load profiles resulted from the use of different configurations of devices. The fact which has to be especially emphasized is that only the proposed systemic approach allows for real employment of energy acquired from reusable sources, which in turn offers new possibilities relating to further decrease in the weight of the whole system.

Detailed solutions of the presented concept will be the result of further research and they will be presented in future publications.

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KONCEPCJA MINIMALIZACJI SYSTEMU ZASILANIA ELEKTRYCZNEGO PRZENOŚNEGO SPRZĘTU I UZBROJENIA

STRESZCZENIE

Coraz większa liczba, funkcjonalność oraz niezbędność przenośnych urządzeń wspomagających nasze zawodowe i społeczne funkcjonowanie wymaga jeszcze większej pojemności oraz mocy ich źródeł zasilania. Analizując teoretycznie możliwe do osiągnięcia właściwości eksploatacyjne obecnie znanych mobilnych źródeł prądu, autor doszedł do wniosku, że nawet ich najdoskonalsze rozwiązania nie spełnią pożądanych wartości masy i objętości w stosunku do dysponowanej energii. Jeżeli więc źródła energii osiągnęły fizycznie i ekonomicznie uzasadnione granice swoich możliwości oraz charakteryzują się bardzo różnymi właściwościami eksploatacyjnymi, naturalnym wydaje się rozwiązanie łączące zalety różnych źródeł prądu poprzez system zarządzania energią. W związku z tym w artykule przedstawiono ideę systemu zarządzania energią, który na bazie dostępnych ogniw pozwoli zmniejszyć masę układów zasilania. Rozważania prowadzone są w oparciu o aplikacje militarne, co nie wyklucza jednak zastosowań cywilnych.

Słowa kluczowe:
przenośne źródło energii elektrycznej, zarządzanie energią.