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ENERGY PROFILES AS A METHOD FOR MINIMIZING WEIGHT OF HYBRID POWER SUPPLY SYSTEMS

ABSTRACT

This article presents an analysis of energy demand by a group of portable military use appliances. This analysis was used by the author to offer an solution aimed at reducing the weight of the power supply system. This solution is based on energy profiles which were derived from the analyses and measurements, and on applying appropriately modified hybrid supply sources. Catalogue data are often used in support of an analysis of performance of electronic appliances. For a user, documents prepared by a manufacturer are the main source of information concerned with the amount and quality of electric energy sources required for the appliance to work properly. Investigations carried out in real conditions often verify this data, which provides a base for seeking alternative solutions in the course of designing new sources of power, e.g. such as the ones proposed in the article.

Key words:
cell fuel, supercapacitor, battery, power management.

INTRODUCTION

Present day armed forces change as dynamically as the number and quality of electronic devices used by military personnel. Not so distant times when operations were carried out on front lines become history. Modern systems which support combat actions allow for increasing the distance from an enemy, and when using new generation of aerial and land unmanned vehicles, exposing people to risk

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can be almost eliminated. Such high advancements in technology have not eliminated a human being from the battlefield. Modern communication means and display systems are employed to ensure man-machine cooperation. Clandestine operations carried out by specialized troops generate problems for operators concerned with autonomous operations in areas of direct logistical support. A large number of electronic devices used by an operator requires power supply cells which ensure their proper performance throughout the whole mission. Depending on the specialty of an operator and related gear configuration, the weight of cells may be from a few to more than ten kilograms [1]. Such load, in addition to arms, ammunition, electronic appliances, clothing, and food, has become a serious problem. Limitations related to mobility, additional space, and replacing cells under different weather conditions are problems directly affecting an operator. When considered from the global point of view, this issue is an impediment in logistical support as it faces problems concerned with supplying, storing and disposing of batteries. A solution to this problem is using a power supply system which will ensure a sufficient amount of energy so that a set of devices in a particular configuration can operate. This set has a capability of acquiring energy from external sources, which, depending on the solutions, employed may significantly reduce the whole weight of the system [5]. Renewable energy sources and the generally understood notion of 'energy harvesting', i.e. a way of acquiring energy, require adequate energy management. This entails the necessity to solve several problems concerned with matching an energy source to a receiver, and controlling the flow of energy in a system [6, 7]. Such a large number of factors makes it necessary to employ support through decision making elements — intelligent systems. Logical systems deciding about energy distribution in the course of decision making have to be supplied with basic data on the system they support. The author offers an approach to be followed in order to calculate the total demand for energy and its planned distribution among devices. A decision making system designed in further stages of implementation will have a table of input data, further referred to as the energy profile. The data was determined on the basis of studies of the group of devices considered.

ENERGY PROFILES

In order to demonstrate the effect of use of energy profiles on the whole energy consumption in the system, the author chose, out of a large number of devices used in special operations, a group representative of the most important fields. The data used in measurements (tab. 1), comes from two sources. 'Catalogue data' is derived from the information supplied by the manufacturers and calculated on the basis of parameters of batteries dedicated to the considered device. 'Measured magnitudes' are supplied by the author, based on his own measurements carried out on real devices. Due to formal reasons names of devices producers and their symbols will not be given.

Tab. 1. Devices used in the experiment — measurement data compared with catalogue data [9, 12, 13, 15–20]

Name of device	Mode of operation	Input power of device — measured magnitudes [W]	Supply voltage during measurement [V]	Input power of device — catalogue magnitudes [W]	Type of cell used	Cell voltage [V]	Remarks
Personal radio	Standby Reception Transmission	3.24 5.4 23.76	10.8	4.3 4.3 43	12041-2200-02 (63 WHr)	10.8	Magnitudes taken from catalogue data calculated on the basis of capacities of batteries used and device performance time
Night-vision device	Display enhancement IR illumination	0.042 0.049	1.45	0.082 0.624	AA (1000mAh)	1.5	
Laser target indicator	Laser pointer (high) IR pointer (low)	0.0055 0.0041	3.06	1.5 0.9	CR 123A (1500mAh)	3	
Telescopic sight	On	0.0005	2.97	0.00078	DL 1/3 N (160mAh)	3	
GPS	Standby Detecting/tracking	0.0023 0.599	5.99	0.428 1	4 x AA (1000mAh)	6	
Data display	Display Standby	1.26 0.03	5	1.26 0.03	X8 (4,2V/ 3600mAh)	4.2	
Weapon mounted light	On	3.8	6	4.98	6	3	
Helmet mounted light	Color White	0.16 1.45	1.6	0.03 0.33	AA (1000mAh)	1.5	
Hearing protection devices	On	0.008	1.49	0.003	2 x AAA	1.5	

Developing the energy profile started with determining the total time used by a specific device during a mission. Each mission can be divided into two stages, which, due to the character of the mission, can differ in length of time and part of day. These differences directly affect the use of e.g. night vision devices. As can be noticed (tab. 2) the mission time was reduced to 72 hrs. This amount of time is a result of combat experience gained over the last decade in the international theater of operations [8]. The lengths of day and night adopted in the considerations, were simplified and made equal.

Based on the data included in tables 1–3 a simulation model was developed in Mat Lab environment (fig. 1). Simulation of various operation scenarios allowed determining the total demand for energy in a specific mission stage.

Tab. 2. Mission stages with percentage share of carried out activities (night activities are marked with grey color) [own work]

	Stage 1: Movement to point Alpha	Stage 2: Waiting at point Alfa	Stage 3: Movement to point Bravo	Stage 4: Waiting at point Bravo	Stage 5: Attack on object	Stage 6: Withdrawal to point Bravo	Stage 7: Movement to point Charlie		Stage 8: Breaking contact	Stage 9: Waiting at point Charlie	Stage 10: Evacuation
	12 h	12 h	6 h	6 h	2 h	3 h	7 h	6 h	2 h	4 h	12 h
Movement	70% 8 h 24'		70% 4 h 12'			100% 3 h	70% 4 h 54'	70% 4 h 12'			70% 8 h 24'
Waiting		50% 6 h		30% 1 h 48'						50% 2 h	
Rest	30% 3 h 36'	50% 6 h	30% 1 h 48'	30% 1 h 48'			30% 2 h 6'	30% 1 h 48'		50% 2 h	30% 3 h 36'
Reconnaissance				40% 2 h 24'							
Contact					100% 2 h				100% 2 h		

Tab. 3. Percentage share of use of devices in particular activities and modes of operation (deviced dedicated to operate at night are marked with grey color) [own work]

	Personal radio			Hearing protection devices	GPS		Smartphone		Telescopic sight	Lase target indicator		Weapon mounted light	Helemt mounted light	Night vision device	
	Standby	Reception	Transmission		Standby	Detecting	Standby	Display		Low	High			Enhancement	Illumination
Movement	60	30	10	100	5	95	80	20	100	100	0	0	0	100	0
Waiting	60	30	10	100	0	0	80	20	50	50	0	10	30	30	0
Rest	90	10	0	100	0	0	80	20	0	0	0	0	0	0	0
Reconnaissance	20	40	40	100	5	95	10	90	100	100	0	0	0	100	0
Contact	0	30	70	100	5	95	60	40	100	0	100	50	50	0	100

The sum of all loads presented in the diagram (fig. 2) constitutes the total energy demand at the mission stage being considered — energy profile. The difference between the profile derived from the catalogue data and the measurement based profile which can be seen in the diagram confirms the correctness of the adopted assumption. After presenting the other mission stages, in the same way information on the energy profile is obtained for the whole mission. In order to highlight the effect obtained in figure 2 presented is the stage characterized by the highest instantaneous power consumption from the source.

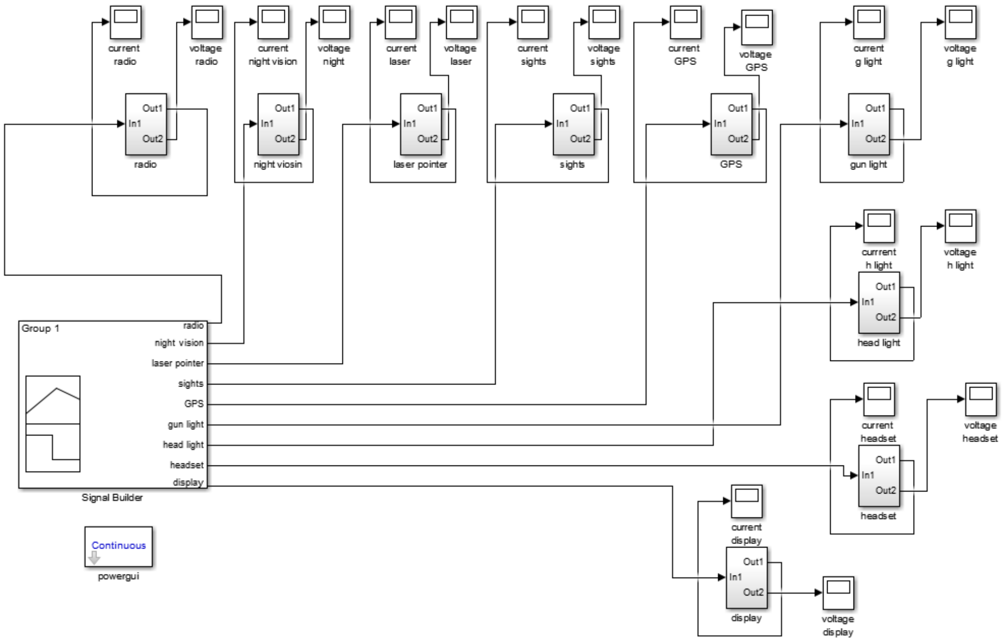

Fig. 1. Simulation model MatLab [own work]

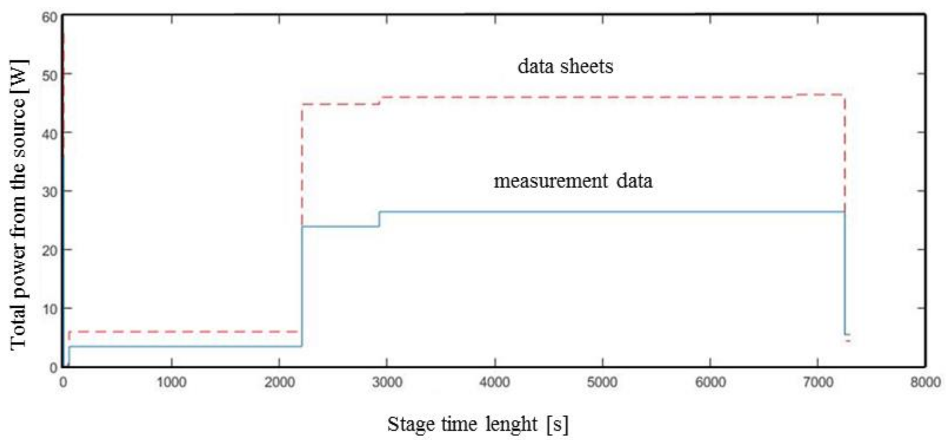

Fig. 2. Energy profile for the 5th stage of the mission [own work]

USE OF SUPERCAPACITATORS

The measurement results (fig. 2) unequivocally show that the catalogue data on energy parameters are much higher than those obtained in the measurements.

In civilian applications this can constitute a certain threshold of safety, however, for an operator this directly leads to added kilograms of batteries. Apart from the indicated differences between the catalogue data and real parameters, times of operation of the cells having the same parameters are of significance. They can differ from each other despite the same load parameters [2]. Changes in parameters of power supply cells when discharging a have significant effect on this phenomenon. Taking into consideration the results of the simulations and the physics of the phenomena related to power supply cell performance, it becomes obvious that the demand for energy should not be estimated on the basis of catalogue data. The total difference in energy derived from the calculations carried out and the analysis of the data supplied by the manufacturers can be calculated from the equation below:

$$E = \int_0^T P_1 dt - \int_0^T P_2 dt, \tag{1}$$

where:
P_1 — sum of power in investigated devices calculated on the basis of catalogue data;
P_2 — sum of power in investigated devices calculated on the basis of laboratory measurements.

In the case under consideration the difference is 29.96 Wh. It follows from the investigations on transient states [3] in devices and from the analysis of the catalogue data that high energy states given by manufacturers occur at very short time intervals or they do not occur at all. Performance of the energy management system, when hybrid power supply source is used, can be based on the effect referred to in literature as 'Peak Shaving' [4]. It is 'taking away' instantaneous loads from the main power supply source. Instantaneous power surges resulted from transient states or available modes of operation in a device may consume energy from a supercapacitator being an element in a hybrid cell. The supercapacitator, in this case, constitutes a storage of handy energy, which, owing to its properties, allows for multiple load and discharge cycles. The discharge time is a few hundred times shorter than in the case of secondary cells [10], which allows for its dynamic performance. The process of loading can be realized in an on-going manner from the main source or from available renewable energy sources.

Analyzing available modern secondary cells and supercapacitators [11, 14] for the assumptions:

$$\begin{aligned} P_p &\geq P_1; \\ U_p &\geq U_{max}, \end{aligned} \tag{2}$$

where:
P_p — peak power demand,
U_p — peak voltage demand

it is possible to determine physical dimensions of cells, and in consequence their proportions in a hybrid power supply system. When assumptions (2) are met, for the energy profile considered, three-time growth in weight occurs. This growth results from the relation of the supercapacitator weight to the weight of the secondary cell, for the assumption of three-time coverage of the same energy consumption. The weight saved in this way refers to the part of the secondary cell which secures the difference between the power of the investigated devices calculated on the basis of the catalogue and measurement data (1).

In order to use the solution described, it is necessary to use a power management system. Control algorithms in connection with a library of profiles derived from the analysis of the device set will allow for fast reaction of the whole system and effective distribution of power to particular devices attached to the system. The algorithms implemented in the system described will be the subject of further publications.

The system of energy management also has to manage the energy recovered from the broadly understood ambience — 'energy harvesting'. In this connection, matching the system work parameters is another function which has to be performed by the system mentioned. It must be remembered that advances in technology allow for more and more efficient energy recovery. Each amount of additionally obtained energy leads to diminished total cell weight. That is why it is important to take into account technological capabilities in the design process.

CONCLUSIONS

The results obtained on the basis of the investigations justify further analysis of the issue. Proper matching of algorithms in the power management system will allow for an effective use of available resources. The algorithms can also be used as a design tool in developing further concepts of hybrid cells. Appropriate selection of proportions between such elements as a supercapacitator and battery, will allow for additional savings in terms of weight of the whole system. Next stage of the investigations will be modelling a hybrid battery and developing a method for distribution of energy, ensuring uninterrupted performance of the system. It will be based, in whole, on the concept, presented in the article, of energy profiles and dynamics of phenomena resulted from them, occurring in a hybrid cell.

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PROFILE ENERGETYCZNE JAKO METODA ZMINIMALIZOWANIA CIĘŻARU HYBRYDOWYCH UKŁADÓW ZASILAJĄCYCH

STRESZCZENIE

Artykuł zawiera analizę zapotrzebowania energetycznego grupy urządzeń przenośnych zastosowania militarnego, na podstawie której autor zaproponował rozwiązanie mające na celu zmniejszenie masy systemu zasilającego. Rozwiązanie to bazuje na stworzonych na podstawie analiz i pomiarów profilach energetycznych oraz zastosowaniu odpowiednio zamodelowanych hybrydowych źródeł zasilania. Podczas analizy działania urządzeń elektronicznych często wspomagamy się ich danymi katalogowymi. Dokumenty przygotowane przez producenta są dla użytkownika podstawowym źródłem informacji na tematy związane z ilością i jakością źródeł energii elektrycznej wymaganej do poprawnej pracy urządzenia. Badania w warunkach rzeczywistych często weryfikują te dane, co daje podstawę do poszukiwania alternatywnych rozwiązań podczas projektowania nowych źródeł zasilania, na przykład takich jak zaproponowane w niniejszym artykule.

Słowa kluczowe:
paliwo ogniwowe, superkondensator, bateria, zarządzanie mocą.