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Examination of the electricity supply for land troops and options for the improvement

the author’s description and official reviews of the doctoral dissertation

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BUDAPEST, 2023.

Reasons of the thematic concept

It is a generally accepted fact for the society as a whole that modern civilisation is unthinkable without the widespread use of electricity. In 2019, the world consumed a total of 606 billion GJ of primary energy, of which about 30% was used as electricity.

There is a well-set infrastructure for the static civil use of electricity. Power plants and transmission lines will be able to serve power demand in the present and foreseeable future. However, military forces, including ground troops, cannot rely on civilian infrastructure for their own electricity supply for operational activities (missionary, border protection, disaster management and armed defence), as it is only available near the of transmission lines and is often damaged, destroyed or has limited capacity.

The availability of electricity is vital for the defence sector, including ground troops, as without it their capabilities would be significantly reduced. Modern military forces would probably not be able to operate at all if they lost their electricity-powered assets. Despite this, this area has been almost completely unexplored in Hungary and hardly researched internationally.

The scientific problem

The defence sector is also part of society, so its rules are mostly applied here, but it also has a number of specific features that are quite distinct from other segments of society. Despite lengthy research, I have not been able to find a comprehensive study of the role of electricity in land troops, or even in defence sector in general. I worked in the field of military technology research and development for eight years immediately prior to my current position and my experience is that the issue of electrification in the armed forces is examined still only at the level of equipment, without any examination of the significance of the technology or a deeper relationship between electrification and the capabilities of troops. Although I was the national coordinator of the NATO Paris-based research and development organisation STO from 2018 to 2021, I found no evidence of military technology developers looking for trends and complex solutions in this area, so the role of electricity is mostly examined from a point of view of a single development project.

In the STO, the focus is on tangible technologies and military equipment. Energy issues are not currently represented at panel level, but each panel has several working groups dealing with energy, possibly specifically on electricity.

However, the European Defence Agency, based on the needs of other CapTech (e.g. land-based technologies) in its Directorate for Research Technology and Innovation, discovered relatively early on that energy and environmental issues would largely determine future defence ambitions and capabilities, and in 2015 it set up the Energy and Environment Working Group, in which I represented Hungary from its inception until the end of 2022. The professional prestige of this group is also greatly enhanced by the fact that, although it was intended to be an ad-hoc working group when it was set up, it was transformed into a permanent working group, in European Defence Agency terminology, known as CapTech, from 2022. However, this group is also only concerned with a narrow segment of military applicationspeacetime energy infrastructure.

In addition to domestic activities, I have also noticed in international professional organisations that, although no one disputes the importance of electricity for the capabilities of ground troops, no one examines it in a complex way, exploring the deeper interrelationships. Recognising this gap, I began to research and publish on the subject, focusing on field electrical power applications associated with less studied military activities.

In peacetime, which in the case of Hungary is a period outside the special legal order under Articles 48-54 of the Basic Law, the activities of the land forces are relatively little different from those of the civilian sector in terms of energy. This is also true globally; in peacetime, military organisations rely heavily on civilian electrical energy infrastructure for their operations, primarily for cost-efficiency reasons. For geopolitical reasons (by which I mean mainly the relatively small size of the area and the topography and hydrography of Central Europe), the Hungarian Defence Forces in peacetime use almost 100% civilian electricity infrastructure, while in other countries' land forces typically use only 80-90%.

However, in special periods of order of law, whether in territorial defence, missionary tasks or disaster management, ground troops have to operate in a relatively autonomous way from an energy point of view. This is a specificity whose effects need to be examined, and energy supply under field conditions must be taken into account order to maintain and increase the capabilities of the troops. This activity should also include planning for the supply of electricity in the field, both now and in the future.

In order to maintain the capabilities of ground forces of HDF, and even more so to enhance their capabilities in the future, it is essential to understand the current state of battlefield electricity supply, the expected future prospects, and all the techniques and procedures that can be used in future military electrical power R&D.

Objectives of the dissertation

The aim of the research is to explore the role of electricity in the capabilities of land troops. In doing so, I examined both peacetime and operational use of electricity, both in generation, consumption and distribution. My research has examined in detail the electrical power activities in theatre of operations in three distinct segments: personal equipment, on-board systems of military and combat vehicles, and field accommodation equipment.

1. To analyse the relationship between electricity and the activities of ground troops in peacetime and operational conditions, focusing on the dependence of modern ground troops on electricity.
2. To examine the electrically powered military equipment of the present and near future, with particular attention to the production and consumption sides and the supply system. To esteem the current and projected electrical power requirements of ground forces.
3. To comparatively analyse the different types of applied field electrical power generation and distribution technologies and investigation of opportunities for efficiency improvements. To develop a framework for the evaluation of electrical energy systems.
4. To compare modern technologies and processes with conventional methods and to test and evaluate their applicability in the militaryenvironment. To identify alternatives to improve the efficiency of existing electrical systems and equipment.

Hypotheses of the dissertation

1. Electricity has a similar share in the energy baskets of each modern military force and national economies.
2. The demand for field electricity, essential for the operation of modern land forces, will continue to grow in the near and distant future due to trends in military technology development. In addition, this will threaten the combat capabilities of troops because of the vulnerable traditional supply model.
3. No single technology or process alone can address the above growing demand for electricity in the field. In order to meet the electrical energy needs all available technologies and a planned and complex application is required.

4. Hydrogen-based electricity storage technology has reached the stage where it is suitable for military use, thus expanding the technical options for providing electricity to troops on the ground.
5. Compared to conventional centralised aggregator-based field electricity supply systems, hybrid smart grids are operationally more advantageous for ground troops.

Research methods used

In my thesis I tried to use primary research methods where possible, but in many cases only secondary methods were applicable. Overall, I used the following research methods:

1. By applying the method of ***professional literature research*** and the ***method of primary data collection and analysis***, I explored the relationship between Hungarian and relevant international energy and environmental policy expectations and the national defence.
2. Using the ***method of professional literature research***, I examined - to the extent deemed necessary for the research - the operating principles, characteristics and analysis of the relevant energy technologies and evaluated their military applicability on the ***basis of my own development and engineering experience***. I examined the content of relevant military standards and regulations and assessed their applicability.
3. I estimated the current and projected electricity requirements of certain groups of land forces, equipment and parts of equipment and systems using the ***method of induction***, i.e. projecting the trends of individual electrical equipment and systems onto a whole group of equipment or systems.
4. Using the ***method of analysis-synthesis***, I determined the energy impact of the use of specific technologies and technical equipment. For some of the technologies relevant to military applications, I compared them by ***using radar charts***.
5. Using the ***data collection and comparison method***, I aggregated and evaluated the real-world performance of certain technical solutions and procedures under military operational conditions. This included my own ***laboratory and field measurements and tests***.

6. I have developed ***a system of criteria based on tables*** and evaluated the electrical energy installations in the military field and the impact of their possible improvements, acquisitions and implementation on security of supply.

Obstacles during the research

Special mention should be made of the factors that have greatly hindered a detailed, scientific study of the area.

1. The field has a large overlap with civil electricital technologies and methods, where is a generally a large and high level literature available. At the same time, there are only a few relevant publications available on the application of these techniques for specifically military purposes, most of which cover only a very narrow area, mostly at the equipment level. For some smaller but relevant sub-areas, no literature could be found at all.
2. Military standards, regulations and technical instructions were also of limited use. Most of these are very outdated and do not cover many modern techniques already in use. Another problem was the low level of detail in military documents, which in most cases only contain specifications of the most important parameters.
3. The collection of primary sources was also difficult. The Hungarian Defence Forces have insufficient technical facilities for monitoring and collecting data on electricity consumption in the case of stationary installations and none at all for field installations.
4. The importance of electricity is undisputed, but it is still a very poorly managed area within the armed forces, including the Hungarian Defence Forces. In the case of the Hungarian Defence Forces, not only are there no appropriate documents (e.g. energy strategy), but there is also a lack of responsible organisational elements at doctrinal and coordination level.

The structure of the dissertation

The thesis is structured as follows:

1. In the **Introduction**, I formulated the scientific problem on which the thesis is based, set out the objectives and hypotheses. I have described the methods used in the research and provided a literature review.

2. **In the first chapter** I discussed the role of electricity in peacetime activities of ground troops. As a part of this, I collected energy macro data of the Hungarian Army, compiled its energy basket and compared it with the energy baskets of other armed forces and the national energy mix. I described the documents defining the peacetime electrical energy activity, the budgetary implications of the activity, and the objectives and methods of peacetime energy management.
3. **In the second chapter**, I analysed the purpose of onshore troop electricity generation, use and distribution. I have examined in detail the methods and means of electric power generation in the field. I identified the electrical assets that determine the capabilities of ground troops and the impact of their absence on the capabilities of the troops.
4. **In the third chapter**, I determined the nominal amount of electricity used in the field, within the constraints of the possibilities, both for individual equipment, on-board combat and vehicle systems, and for camp accommodation equipment. Separately, I examined the known devices that set the trends and determined trends in future usage.
5. **In the fourth chapter**, I have collected and analysed all the methods and technologies that can be applied theoretically to increase the efficiency of field electricity generation, distribution and use, and then identified the methods and techniques whose optimisation will contribute most to maintaining or increasing the capabilities of the ground troops.
6. **In the fifth chapter**, I detail the techniques that offer the greatest potential benefit to the capabilities of ground troops in terms of personal equipment, combat and vehicle on-board systems, and fielding. As part of this, I will also present my own technical ideas.
7. **In the summary**, I concluded summarising my conclusions and new scientific findings that have emerged from the scientific work. I made suggestions for the use of the thesis and for further research, and finally I described my publications and the sources used in the research.

Summarised conclusions

In the first chapter of the thesis, since for technical reasons it was not possible to collect data only for ground troops, I examined the peacetime energy consumption patterns of the Hungarian Defence Forces as a whole. In doing so, I first collected the aggregated energy data of the Hungarian Defence Forces and compiled its energy basket.

I found that the advanced defence sector is a very significant energy consumer within the national economy. Depending on the level of development and ambition of each army, defence activities can account for around 1% of the total energy consumed by the state, even in peacetime. This makes militaries themselves very important energy market players. The share of the Hungarian Defence Forces in the energy market within the national economy is around 0.2%, but this is commensurate with the level of ambition level of the country.

At the same time, the energy basket of the forces studied corresponded to the energy basket of the country concerned with minimal variation, since in peacetime, for economic reasons, the defence sector also relies primarily on civilian energy infrastructure. Thus, if a high proportion of electricity within the energy basket of a state indicates a developed economy, then a high proportion of electricity within the energy basket of a military force indicates a developed defence sector. Since the use of electricity within the energy basket is the least dependent on perodac effects, it is also the best energy indicator of the development of the economy, or even the defence sector.

I have found that in peacetime, the energy management objectives of the defence sector, including the Hungarian Defence Forces, are the same as those of other state actors, i.e. primarily driven by financial considerations, but also include energy security and climate protection. In order to achieve the above objectives, the most important means of increasing energy efficiency in peacetime are improving the energy efficiency of installations, including the modernisation of lighting and building services in terms of electricity. In peacetime, increasing energy awareness and, increasing the energy independence of military installations from civilian infrastructure, in particular through the use of solar panels.

In the second chapter of the thesis, I examined in detail the current widespread field power supply architecture for ground troops. I found that power supply depends almost entirely on the operation of field aggregators. Because larger aggregators are more efficient and easier to install and operate than several smaller units, they are essentially the only units in use, typically larger than 100 kW. The only exceptions to this are dedicated aggregators in high-priority infocommunication centres and installations located at a greater distance from the camp core, e.g. fuel stations.

However, this highly centralised structure has several dangers. As large aggregators are generally very reliable but also expensive, they have no warm backup, so a possible failure, or enemy strike or sabotage, could compromise the combat capabilities of the entire formation. Since logistic forces do not have medium voltage equipment, electrical power cannot be manoeuvred, and during supply difficulties, prioritised disconnection of consumers can only be carried out by manpower.

Depending on the activity, the on-site electricity network is responsible for 20-60% of the fuel consumption of a ground unit. Servicing the field electrical infrastructure should not, however, take priority over the operation of military vehicles and combat vehicles. In addition, maintaining fuel supply lines is costly in theatre of military operations and particularly risky in armed conflict.

I have also looked in detail at the electrical equipment used in the field and found that some of the accommodation facilities (housing, catering, entertainment) could be replaced by other forms of energy, but the logistics of supplying and operating this would be extremely difficult.Their loss would slowly erode morale in the long term, leading to a loss of skills. The situation is similar for field operation and maintenance assets, but their loss would be felt in a shorter timeframe. The loss of tactical reconnaissance and electronic warfare assets would already greatly reduce the capabilities of troops, while there are no alternative options for maintaining info-communication, i.e. command and control, and its loss would cause an immediate and radical reduction in the capabilities of troops.

Megállapítottam, hogy műveleti területen is nagyon fontos az energiagazdálkodás, de céljait tekintve alapvetően eltér a béke idejű tevékenységtől. Terepen nem elsődleges a költséghatékonyság, vagy a klímavédelem, a villamos energia minél hatékonyabb felhasználásnak elsődleges célja a műveleti célok elérése, ennek érdekében a csapatok autonóm működési képességeinek fenntartása, vagy lehetőség szerinti növelése.

In the third chapter of this thesis, despite the difficulties mentioned earlier, I have assessed the extent of, and expected trends in, the use of electricity by ground troops in the field. By using indirect methods, through the increasing penetration of electrically powered devices in the field and the number of new devices that are expected to emerge in the near future, I have demonstrated that the dependence of ground troops on electricity will increase for the foreseeable future in all three segments under study, in the areas of personal equipment, on-board equipment for military vehicles and combat vehicles, and also in the area of field accommodation.

The extent of this varies in the three segments and the rapidity is debatable depending on the proliferation of provisoric new devices, but the growth itself is not in question, while the land forces' own electricity generation infrastructure has not changed for about 50 years because oft the technical barriers. Putting these two facts together, I have concluded that the current electricity supply model is not only vulnerable due to its centralised nature, but is steadily increasing the pressure on logistical support forces.

The electricity demand of field assets is difficult to quantify, but will definitely increase due to the relatively rapid proliferation of tactical and logistics drones, as well as land-based driverless assets, and due to the emergence of 3D printing in logistics.

The electrical power on-board military vehicles is also growing, but only a small part of which is due to the proliferation of electronic control systems from the civilian automotive industry. Much larger power loads are coming from specifically military equipment, e.g. by Active Protection Systems (APS) and Counter Improvised Explosive Device Disruptors (RCIED). Additionally partially or fully electric powertrains have also appeared in ground troop vehicles, which could lead to a further radical increase in electrical power demand.

Of particular importance is the power supply of electrically powered equipment as part of personal equipment, which, with current battery technology, could radically increase the load on soldiers, assuming increasing demand, thus causing degradation in other capabilities.

In all three segments, infocommunications activities are becoming increasingly important, with electronic equipment as the only modern way. As a result, although modern digital devices provide the same computing power as before, the demand for computing power is constantly increasing, thus offsetting the impact of more modern devices. Artificial intelligence already plays a role in the strategic systems of the leading military powers, but there is no doubt that it will soon appear in tactical systems, again leading to a further large increase in electric power demand.

In the fourth chapter of the thesis, I first systematically examined the technical and administrative procedures that can reduce dependence on fuel supply for the supply of electricity to ground troops in theatre of operations. In doing so, I have sought to be comprehensive and to assess all the methods involved. I have devised an intentionally simple spreadsheet-analytical method for evaluating those applicability in the field.

I took a row in the various options for increasing the energy density of energy storage, standardisation, reducing the energy use of electricity consumers, increasing the efficiency of electricity generation, the applicability of new generation devices, and energy management and selected those that are inherently suitable for field implementation and offer the best opportunity to reduce fuel dependency in the field of electricity generation.

Based on the analysis, I found that the most suitable methods to improve the field electricity balance are the the modernisation of lighting, the introduction of hydrogen-based energy systems, the energy management and the in-situ use of renewable energy sources, with a special focus on solar energy in Hungary. However, I have also found that none of the above methods alone can improve the electricity balance of land-based troops to the extent that it can meaningfully reduce the need to operate conventional aggregators. To this end, all available innovative techniques and the optimisation of existing techniques must be applied in a planned and coordinated manner in the future.

In the fifth chapter of the thesis, I have identified promising directions for improvement in the electricity efficiency of land-based troops, based on the previous work. As part of this, I also compared emerging new technologies with current solutions. I have also presented my own ideas in this domain.

I have demonstrated that energy storage solutions based on hydrogen fuel cells, both as part of personal equipment and for large-scale applications, are ripe for use in the military, including in the operational domain. The energy storage solutions that can be implemented with hydrogen-based equipment already available are capable of performance comparable to current battery-powered devices. At the same time, their application is no less safe than Li-ion technology, and they have considerable potential for further development.

I have also demonstrated that smart hybrid systems are competitive with conventional aggregators. The purchase price of a smart hybrid system is significantly higher than that of a simple aggregator, but it is cheaper to operate in the long term, while offering much higher operational safety. The expected increase in fossil fuel prices and the focus on operational safety in the longer term clearly favour smart hybrid equipment.

I have found that the architecture of the military smart hybrid systems that have been made publicly available so far is fixed, and thus does not sufficiently exploit the variation possibilities that arise from more complex architectures. As a result, I have introduced the concept of modular smart hybrid grids, where interchangeable modules can be used to build the grid configuration best suited to the needs of a given military operation. An additional advantage of the modular system is the possibility of cheaper production and cheaper further development.

I have also criticised the concept of the limited number of tactical charge-distribution units currently available, which do not fully exploit the potential of the multiple energy sources available. The system based on a supercapacitor I envisage would be able to aggregate the power of several electricity sources, thus fully exploiting all the energy currently available.

The new scientific results

1. First time I collected and analysed the energy macro data of the Hungarian Defence Forces. I proved that the energy basket of a state and of its defence sector is the same with a little variation.
2. I have established and demonstrated that the amount of electricity required by ground troops in theatre of operations will continue to increase in the near and far foreseeable future, creating new demands for logistical support.
3. First time I analysed the theories and methods for mitigating the logistical support needs generated by the electricity demands in theatre of operations in their entirety and found that there is no technology or process that is a solution in itself. Only a complex and planned application of existing and innovative new solutions can meet the growing electrical demands of ground troop capabilities in the future.
4. Among other things, I have demonstrated with a first-of-its-kind test firing in Hungary that hydrogen-based energy storage technology is already sufficiently advanced for military applications. I have demonstrated that the use of hydrogen in the field and the application of PEM cells built on it can extend the time of autonomous operations, thus increasing the survivability of troops.
5. I have set up a generative model of battlefield power systems and demonstrated that using systems that incorporate renewable energy sources, storage cells and advanced control systems (hybrid smart grids) is a more efficient and secure way of providing electricity for ground troops than the traditional aggregator-based model.

Recommendations

I recommend the topic and the results of the thesis for the development of the energy policy of the Hungarian Defence Forces and the Ministry of Defence, as well as for the procurement and R&D activities of military equipment, primarily for the definition of technical requirements and the operational environment. The thesis provides a good horizontal overview of the activities and specificities of military electrical energy particularly of the electrical energy of ground troops in the field of operations, but for reasons of scope it was not able to go into its depth. Whether in domestic form or in international cooperation, I recommend the following as further research topics related to the subject of this thesis:

- Development of the energy policy and/or energy strategy of the Ministry of Defence and/or the Hungarian Defence Forces;
- Renewal and development of regulations for the supply of electricity to ground troops;
- The military applicability of hydrogen technology in the system of collective electricity supply at personnel or small unit level and as part of the military operational field electricity supply infrastructure;
- Investigation of operational models for smart-grids in military environments;
- Systematic investigation of the electrical energy issues of the digital soldier concept.

I also recommend the thesis for the teaching activities at the Faculty of Military Science and Military Officer Training of the National University of Public Service. As part of this, I highlight the following, which are currently missing from the themes of all forms of training:

- The thesis explores the peacetime energy operations of the Hungarian Defence Forces, presents its energy basket and evaluates that in international comparison;
- The thesis describes the differences between the peacetime and military operations of the ground troops in the field of electrical energy management and the different objectives of the operations;
- The thesis introduces electrically powered military devices as part of personal equipment, on board vehicles and combat vehicles and during field deployment, discussing their basic operation and main characteristics;
- The thesis presents electrical power technologies and processes suitable for field use and evaluating their impact;

- The thesis introduces and describes in detail the advanced electrical power technologies that will determine certain capabilities of the future Army.
- The thesis introduces the applicability of artificial intelligence to military electrical power.

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In 2011: Graduated in Dobó István Gimnázium as a military cadet.

1991-1995: He studied at Bolyai János Military Technology College and graduated as a Bachelor of Electrical Engineering.

1996-1999: He studied at Technical University of Budapest and graduated as a Master of Electrical Engineering.

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2004-2008: He attended a self-financed correspondence course at the University of Óbuda, and obtained a pre-degree certificate in Computer Engineering.

2014-2022: He worked for the defence research and development organisations of the Hungarian Defence Forces and the Ministry of Defence. In these positions, he represented the Hungarian Defence Forces in several Hungarian and international professional organisations, He was Hungarian the national coordinator of the NATO Scientific Technology Organisation and the Hungarian representative in several working groups of the European Defence Agency.

In 2015: He started his studies at the Military Doctoral School of Engineering and in 2018 he obtained a pre-degree certificate.

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Other scientific activities: He is a member of the Hungarian Society of Defence Science, the Hungarian Electrotechnical Association, the Association of Information Technology and the Scientific Journalists' Club. Since 2015, he is the head of the Hungarian delegation to the Sustainable Energy in Defence and Security Sector conference series organised by the European Commission and the European Defence Agency. Since 2021, he is the editor-in-charge of the technical-scientific journal of Hungarian Defence Forces, Military Technology.

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