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Minimum Threshold for Energy Harvesting

Alexandra M. Baker and Gregory Bew

United States Military Academy

Department of Systems Engineering

Corresponding author's Email: Alexandra.Baker@usma.edu and Gregory.Bew@usma.edu

Author Note: Cadet Alexandra Baker is a First-Class cadet at the United States Military Academy at West Point, where she majors in Systems Engineering. The author would like to greatly thank her Honors Advisor, MAJ Gregory Bew, and the Systems Department for their support and guidance.

Abstract: With increasing technology demands at the small unit level, there are increasing energy demands. In order to fill a capability gap that the armed forces has coined "soldier power on the move," research efforts should first assess the amount of energy a warfighter needs to complete a mission. Power sources, primarily batteries, take up valuable room in a warfighter's rucksack and add encumbering weight to a combat load. Converting a warfighter's movement to a usable energy source that could power his/her equipment could greatly decrease the weight of a combat load. Ideally, the warfighters' movements can be used to charge the power sources a soldier carries. In developing the technologies to harness the energy of this movement, efforts must first establish a minimum acceptable generation level. This study will analyze the power and energy characteristics for dismounted warfighters to establish the minimum threshold value for energy harvesting technologies. Establishing this threshold will establish a criteria to screen for feasibility of energy harvesting alternatives. Currently such a measurement does not exist, so researches do not have a goal they are trying to achieve when maturing this technology.

Keywords: Energy harvesting, Soldier power on the move, Capability development

1.2 Literature Review

1.2.1 Proof of Concept

The concept of power scavenging or power harvesting has been in literature since at least 1984 when E. Häusler, L. Stein, and G. Harbauer first published the results of an experiment designed to convert the movement of the rib cage during natural respirations into electric energy to provide power to implants that require a permanent power source. This experiment where a prototype device was implanted into a dog served as a proof of concept, with the experimenters theorizing that a device weighing a few grams could provide up to 1mW of power.

1.2.2 Riemer and Shapiro Study

To reduce the weight of batteries carried, energy harvesting is taken into account. Starner looks at the energy that humans naturally generate as a byproduct due to other actions such as the force generated from walking and the heat lost to the environment. While this energy is generated naturally, it is not harnessed. Riemer and Shapiro published an experiment mainly focusing on the negative work phase since the positive work phase increases metabolic cost of actions.

The Riemer and Shapiro study looks at the trade off in weight, between the weight of the device and the battery weight. Lowering the metabolic cost of a mission will enable soldiers to carry less weight in terms of food. They determined that using the movement of the human body when walking can produce energy that can be used to recharge batteries. The center of mass relative to the ground has a 40 percent efficiency for energy produced compared to metabolic cost.

1.2.3 Knowledge of Soldiers

Some soldiers would argue that they would rather just carry the extra weight in batteries because that is what they are used to. This reaction is also due in part to the poor performance of energy harvesting alternatives in the past that weighed more than the weight of batteries they would replace. Add that to the resistance to change of the average soldier and you have a culture that is hard to affect. Hence, switching to different energy harvesting technologies may frustrate and discourage the soldiers. This behavior and attitude of the soldiers should be taken into consideration. However, this can be fixed. Soldiers are not knowledgeable on power and batteries. They do not understand the tools and technology that can be used to make their lives easier. Soldiers can be educated about power and how batteries work. If they understand why they are using this new type of technology and how it is harvesting energy, soldiers would be more inclined to use and take advantage of them.

2. Methodology

The purpose of this project is to determine the minimum power generation threshold required for a technology to be feasible for use by a dismounted soldier. Meeting with the client, Program Executive Office (PEO) Soldier, a problem statement was developed, which is to establish the minimum threshold value for energy harvesting technologies. During this meeting, experts from Soldier power also provided the tools needed to help determine this capability gap.

One of the tools used was an excel spreadsheet that laid out the three mission types and information about each. This information included a timeline of movements, what hours solar panels can be used, data about the platoon generator, and squad movements. Additionally, this tool included information about each type of device a platoon uses on a 72 hour mission. The equipment includes four types of radios: rifleman radio, MBITR, ASIP, and SATCOM. For each of these radios, the battery weight, energy per battery, required watts her hour, the usage time, etc. were provided. The first step was to determine how much the power the platoon needs on a 72 hour mission. Using the total power needed, the radios were prioritized by what radio needs the most power, which is the rifleman radio. The rifleman radio is issued throughout the organization, which is why it required the most power.

In order to determine the calculations, some assumptions were made. The first assumption is that there is a power reservoir, such as a conformal battery, that will be attached to the radio. In Figure 1 below, the picture shows a Rifleman radio connected to a conformal battery. The power coming from the power reservoir is being supplied by a “hub.” In Figure 1 below, it shows how the rifleman radio is powered.

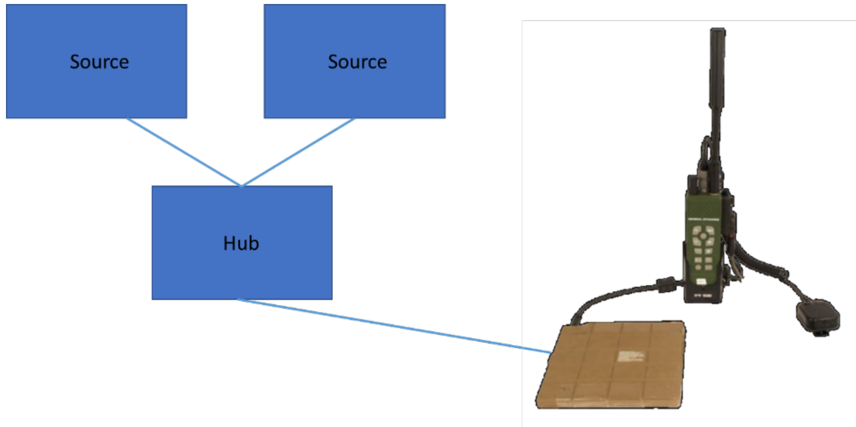

Figure 1. Sources connected to the hub connected to a conformal battery with constant watts connected to a rifleman radio.

Another assumption made was that the results are based on energy harvesting. Possible energy harvesting solutions are kinetic harvesters such as energy harvesting rucks sacks and knee braces, or photovoltaic alternatives such as solar blankets. The results do not take into account generator or scavenging capabilities, as seen in Figure 2 below.

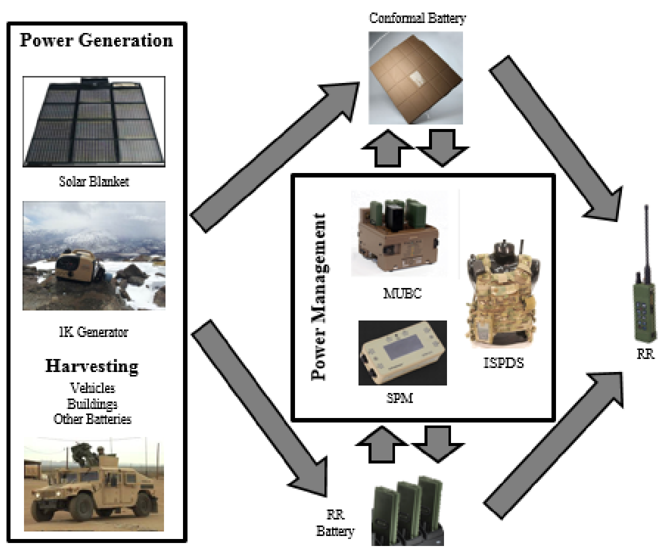

Figure 2. Operational view of how where the power comes from to charge the batteries (Aten et al).

Another tool used was a graph of the theoretical hours needed to provide 52Wh of charge at 12 volts DC, seen below in Figure 3. This study used the graph as a supplement to determine this capability gap.

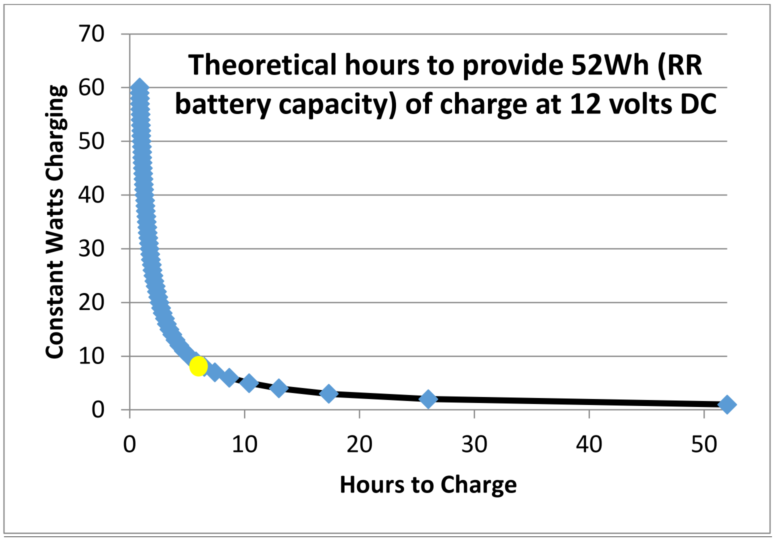

Figure 3. Theoretical hours to provide 52Wh of charge at 12 volts DC.

By using the data above, the rate of charge was determined by finding the point of interest in the curve where there was a most significant change, which is 7.75 W/hr, represented by the yellow dot. This gap was determined by averaging out the points on the curve.

2.1 Power and Energy Characteristics for Dismounted Soldiers

Based on stakeholder analysis and soldier input, four mission profiles were created, including the timelines of the different missions a dismounted warfighter conducts. A typical mission for a soldier is 72 hours. However, depending on the type of mission, different amounts of energy are produced due to movement. The missions are broken down into three types of missions: sustainability, offensive, and defensive. Depending on the type of mission, kinetic and/or potential energy harvesters are possible. For example, on an offensive mission, the squad is moving the majority of the time, making it ideal for kinetic energy harvesters. The actual energy output is dependent on the terrain since a warfighter moves at different speeds when engaging various terrain. Weather also plays a factor since a soldier will move slower and take more rests in the heat than in cooler weather. However, 72 hour missions cannot be conducted in extreme heat due to the lack of water nor can they be conducted in extreme cold due to exposure. Additionally, the sunnier it is, the more solar availability, increasing photovoltaic energy harvesting. Therefore, different terrain and weather have a significant impact on the power usage and energy harvesting, which was taken into account.

Soldiers were interviewed on equipment usage to verify that the equipment load for a squad was correct. The equipment load included equipment necessary for each mission and mission-specific equipment. The usage of each type of device was then determined in hours, which was then used to determine the number of batteries for each device is required for a 72 hour mission. The weight and energy per battery was also recorded. Using this information, an average demand for energy was determined for a dismounted infantry platoon. The weight of the radios for a 72 hour mission was determine, which was used to determine the platoon power per hour and the platoon power per 72 hour mission. Once the platoon power per 72 hour mission was determined, the percentage of power for each of the devices were found. The table 1 below shows the power and percentage for each device. Since the Rifleman Radio and MBITR (Multiband Intra Team Radio) consumed the majority of the platoon's power (approximately 92 percent), the analysis is focused on these two devices.

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Table 1. Platoon Power per Device

Device	Platoon Power / 72 Hour Mission (Watts)	Percentage of Platoon Power (%)
Rifleman Radio	22,680	74.896
MBITR	5292	17.476
ASIP	785.455	2.594
SATCOM	1524.71	5.035
TOTAL	30,282.2	

3. Results

3.1 Minimum Threshold for Energy Harvesting Technologies

Using the energy gap and comparing it to different technologies, a projected amount of power that will need to be supplied to a hub, regardless of the technology providing the power can be determined. This amount of power required to erase the calculated gap over the time available is how the minimum threshold was generated.

The amount of power generated has a non-linear relationship to the amount of time it takes to charge a battery. Using the standard of a conformal battery as the baseline, it would take significantly longer to charge a battery at 2 watts continuously that it would at 10 watts continuously. In fact, at 2 watts, the battery would never reach a usable charge in time for use before other power supplies were exhausted. At 7.75 watts however, you could self-sustain a Soldier's Nett Warrior system by switching conformal batteries between charging and use, referring back to Figure 3. While there are many other considerations to determine if alternatives are feasible, identifying the power requirements by itself so it can be used to specify what benchmarks emerging technologies must achieve is useful.

Additionally, the demand was calculated based on the assumption that on a 72 hour mission, only 36 hours will be beneficial to energy harvesting due to daylight and soldiers' movement. The demand was found by multiplying the required watts per hour by 72 hours since the usage of the radios is 72 hours on the mission. In order to find the demand, the energy per battery was subtracted from the overall demand since the mission will start with full batteries, 63WH (the energy per battery), is not included in the actual demand. The demand was then compared with the 72 hour supply needed for the mission, which was determined by the attained constant watts multiplied by the useful hours, 36 hours. The constant watts were then altered to see how many watts made the ratio equal to one. The results were plotted below in Figure 4.

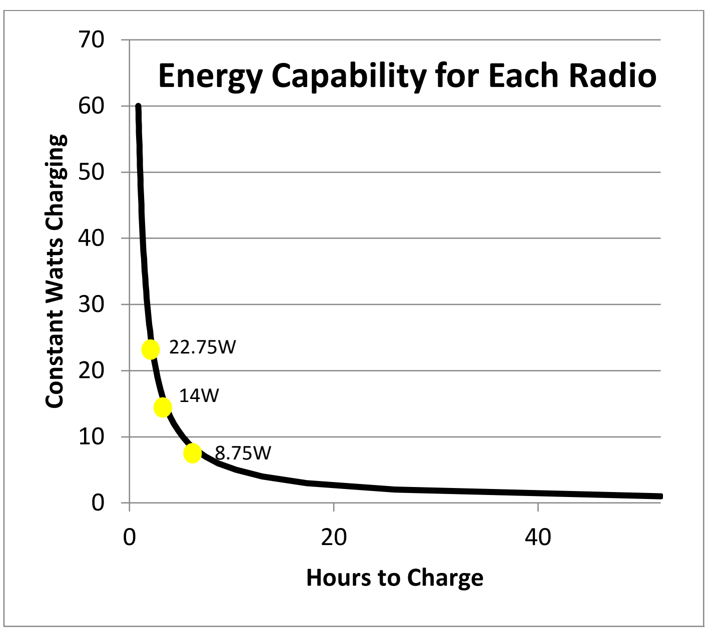

Figure 4. Time to charge each radio based on watts provided.

The rifleman radio needs 14 constant watts from an energy source in order to conserve approximately 75 percent of the platoon's power. The MBITR requires 8.75 constant watts. Finally, when both the rifleman radio and MBITR are charging together, they require 22.75 constant watts, shown in Figure 5 below.

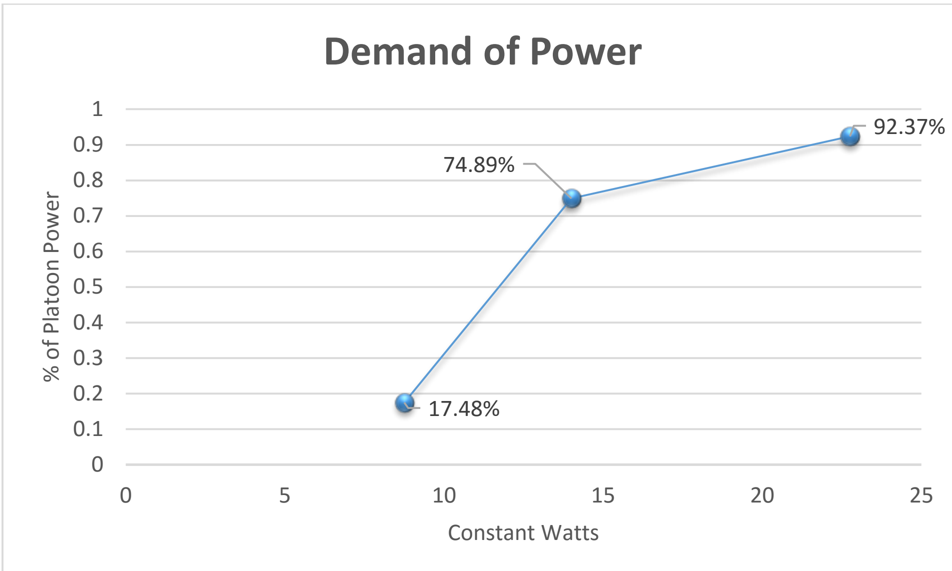

Figure 5. The demand of power for the rifleman radio (75%), MBITR (17%), and both together (92%).

Furthermore, assuming each mission has the same 72 hour power supply, each type of mission produces different amounts of energy based on how much movement occurs. An offensive mission produces more energy since the warfighters are moving much more. Table 2 below shows the approximate hours of movement for each type of mission and how much energy is needed each hour of movement to achieve the supply.

Table 2. Approximate hours of movement for each type of mission (Aviles).

Type of Mission	Hours of Movement	72 Power Supply (WH)	Energy Needed Per Hour
Sustainment	39	819	21
Offensive	27	819	30.3
Defensive	20	819	41

4. Conclusion

By using a warfighter's movement to produce a usable energy source that could power his/her equipment could greatly decrease the weight of a combat load. Knowing the minimum threshold for energy harvesting technologies for each of the radios will allow soldiers to adjust how many batteries are necessary for their mission. By carrying less batteries, the warfighter has less weight and/or more room for other mission-essential items. A recommendation of the minimum threshold that an alternative should produce is 15 watts. Since the demand of power shows how significant the rifleman radio is to the platoon at a constant 14 watts, it has a power drain of approximately 75 percent of the platoon's power. Thus, with an alternative at 15 constant watts, the platoon weight of batteries would be slightly under 300 pounds. Moreover, depending on the mission, the platoon leader can adjust the battery and solar weight based on how much movement occurs on the mission.

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