

Optimal Power Management of Vehicle Sourced Military Outposts

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ABSTRACT

This paper considers optimal power management during the establishment of an expeditionary outpost using battery and vehicle assets for electrical generation. The first step in creating a new outpost is implementing the physical protection and barrier system. Afterwards, facilities that provide communications, fires, meals, and moral boosts are implemented that steadily increase the electrical load while dynamic events, such as patrols, can cause abrupt changes in the electrical load profile. Being able to create a fully functioning outpost within 72 hours is a typical objective where the electrical power generation starts with batteries, transitions to gasoline generators and is eventually replaced by diesel generators as the outpost matures. Vehicles with power export capability are an attractive supplement to this electrical power evolution since they are usually on site, would reduce the amount of material for outpost creation, and provide a modular approach to outpost build-up. Military vehicles have the attributes of a microgrid and when connected produce a scalable power generation capability [1]. For example, each vehicle could power a subset of the outpost's build-up and when connected form a networked microgrid topology. However, vehicles must be available to disconnect dynamically for mobility-centric mission requirements. When this happens, there will likely be a shortage of electrical power requiring prioritized load shedding. Alternatively, excess generation will occur at times motivating an optimal solution to efficiently utilize the generation assets and minimize fuel consumption. An optimal, power management and control scheme is described using a notional 72-hour outpost evolution scenario to illustrate the approach. Particular attention is given to competing objectives such as minimizing fuel consumption while maintaining portable battery state-of-charge for equipment used during patrols. Using an optimal power flow and power coordination controller, vehicle centric microgrid architectures were constructed and simulated. For the uninterrupted outpost construction, the scheduled generation and storage were sufficient to supply all prioritized loads. Conversely, for the interrupted outpost construction, vehicle availability dictated which prioritized loads could be satisfied when unexpected power deficits arise.

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INTRODUCTION

Ad-hoc military outpost are constructed in response to military operations and contain multiple generation, storage, vehicle, and load assets. Initially, a mix of disposable and rechargeable batteries in conjunction with vehicles are used to power most communication systems, while small portable fossil fuel generators aid in establishment of a combat operations center (COC) and other ancillary components critical to the mission at hand. As the storage is depleted during the initial stages of an outpost's deployment, gasoline generators are used to aid in the construction. Sometime thereafter, primary power sources (stationary diesel generators) are brought online to charge the energy storage units and provide the outpost with reliable electrical power. When systems such as the COC or communication array become fully operational they are connected to the primary electrical grid. At this point, the military outpost has a

base electrical load, and very limited functionality. As time progresses, additional assets are bought online to increase the outpost's functionality, ultimately resulting in a fully functional installation capable of providing force amplification and support.

In this paper, the first 72 hours of the outpost refers to the first 72 hours where electrical generation is required. Electrical generation resources are brought online as needed, which could lead to inefficient operation of the microgrid. Additionally, not all of the military components are utilized throughout the construction of the outpost. In a kinetic environment, a mounted infantry patrol is more likely to successfully complete the route from the rear to the new outpost location than a mounted infantry patrol with logistics vehicles carrying several fossil fuel generators. Furthermore, a mounted patrol without logistics vehicles is a smaller and less attractive target. Military vehicles may

possess the ability to export electrical power or contain vast reserves of energy storage, making the military vehicle a microgrid which has the potential to provide electrical resource sharing using either vehicle-to-grid (V2G) or vehicle-to-vehicle (V2V) architectures [1]. Using standard grid tied electrical resources in addition to military vehicles, it may be possible to (1) reduce the number of military assets required to establish a military installation, and (2) allow V2V or V2G networked microgrid architectures to be constructed, resulting in more efficient operation of the military microgrid.

Several studies have been conducted which identify potential V2G applications including power management stability and control and experimental studies. In [2], the authors proposed a distributed V2G power management control strategy based on droop control to maintain frequency accomplished through use to power electronic circuits. In [3], an optimal energy management control strategy is proposed as it pertains to aggregate small electric energy systems (SEESs) including microgrids. In [4], coordinated V2G control is considered as it pertains to microgrid which contain wind power generation. The authors propose a robust conventional load frequency control (LFC) in addition to battery state-of-charge (SOC) deviation control, enhanced performance and robust stability is achieved by optimizing both control strategies using particle swarm modeling techniques coupled with H_2/H_∞ . In [5] plugin-hybrid-electric-vehicles (PHEVs) bidirectional charger systems are identified as critical components which facilitate voltage regulation, aggregate power peak shaving and reactive power compensation for various charging modes of the PHEV. The study found that reactive power compensation is possible under level one charging. In [6], intelligent solutions used to monitor and control of electrical grids are considered which contain plug-in electric vehicles (PEV). The proposed integrant controllers include fuzzy load and fuzzy voltage controllers optimized for grid stability of load and voltage resulting in increased reliability and efficiency of an electrical grid.

Several studies have been conducted which identify military vehicles as viable electrical generation and storage resources, which could be used for V2G and V2V applications including [1], [7], [8], [9], and [10]. In [1], an optimal power management schema was considered for hybrid military vehicles. The single vehicle provided a base framework for fuel optimization, but provided insight into extending the optimal power management to multiple military vehicles. In [7], an optimal energy management strategy was postulated for a microgrid which utilized both distributed generation and energy storage. In [8], the use of renewable sources and military vehicles were considered for frequency and voltage regulation for a military microgrid. In [9], coordinated multi-microgrid optimal control algorithms were postulated to form a smart decentralized distribution management system. While the study was conducted on a civilian microgrid, the control methodology provides a base framework which could be extended for military applications. In [10], a simulation was constructed capable of modeling a V2G microgrid, the goal of the research effort was to evaluate the reliability of the microgrid which utilized various electrical assets. It also provided control methodology, which identified acceptable times to charge/discharge the vehicles to provide peak power shaving and smooth the grid load during islanded operation.

The majority of the studies described thus far have identified potential power management control schemas as they pertain V2G application within simulations, some studies have been conducted based on experimental results. In [11], the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) project was presented. The SPIDERS initiative main goal was to identify the potential to use tactical microgrids to provide greater control and stability for military electrical networks. Within the project, military vehicles were identified as viable assets which could be used to provide added reliability and functionality to military microgrid. In [12], implementation of systems that facilitate frequency control using a web-centric communication. The main research effort was to test the system response in terms of latency, precision and stability of the microgrid.

In this paper, an optimal power management and control strategy is described as it pertains to a notional 72-hour evolution of a military outpost. After describing the notational evolution of a military outpost, individual components which make up the microgrid are described in greater detail. Additionally, an optimal power apportionment strategy is considered. Using a MATLAB/Simulink simulation, the optimal power apportionment strategy's performance is analyzed and evaluated.

PROBLEM DESCRIPTION

The military outpost used for the simulation studies is assumed to be operated by a battalion reinforce (eight hundred to a thousand) soldiers separated into six companies; each company is made up of 150-200 service members. Each military vehicle requires a minimum of four soldiers to operate and maintain the vehicles' functionality while the vehicles are out on patrol or responding to a reported contact. The six companies are broken down into squads A through F. Under normal operations, companies A and B are responsible for providing base security for the military installation, companies C and D are responsible for conducting patrols until the outpost is operational, and companies E and F are responsible for constructing the outpost's infrastructure. Under abnormal operations (patrol comes under fire, or contact is reported), a quick reaction force (QRF) from companies A and B depart friendly lines using the military vehicles to assist the patrol that has called for assistance, simultaneously companies E and F stop construction of the outpost, shut down systems which have not been configured to work with the primary grid assets, and assist in defense of the outpost. After the QRF returns to the outpost, abnormal operation is suspended and normal operations resume shortly thereafter. The total load for the simulation, which includes the prioritized loads have been provided in [Figure 1](#), while the individual squads E and F milestone loads have been provided in [Figure 2](#). Each individual squad milestone loads can be attributed to providing some kind of additional functionality to the military outpost. Each additional functionality increases the total load for the military outpost.

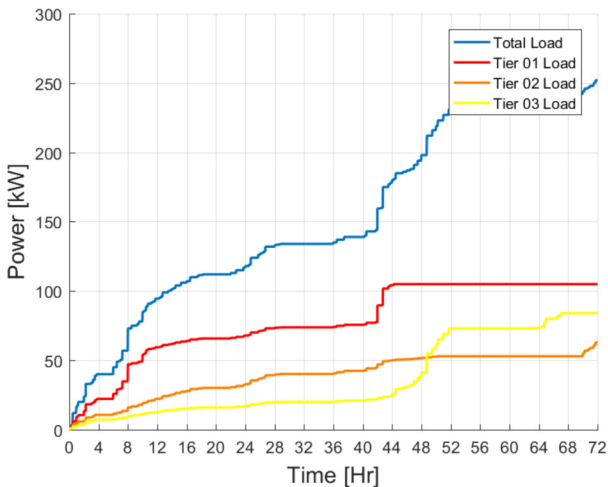


Figure 1. The outpost’s total electrical load for the first 72-hour buildup, after which point the military outpost will be fully manned and operated. As time progresses the outposts load increases in response to the increased functionality available for use within the military installation.

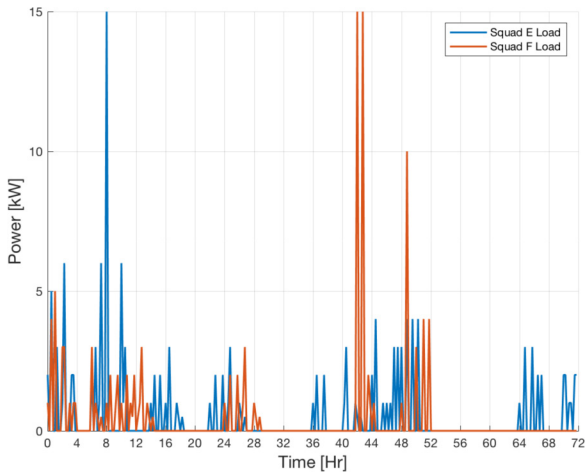


Figure 2. The individual loads attributed to the two squads responsible for bringing the outpost’s functionality online. Each spike of load is attributed to milestone completed as the bases functionality is increased.

The networked microgrid identified for the simulation studies has four military vehicles, which make up the primary grid assets. The secondary grid assets include two gasoline generators, and to electrical storage units. The secondary grid assets are used to provide power, prior to turning on primary grid assets. The secondary grid assets act like temporary power units, which are used during the construction phase of the outpost. All simulation studies presented are for vehicle centric microgrids, and can be separated into two separate scenarios, (1) uninterrupted outpost construction, and (2) interrupted outpost construction due to a security threat. The presence of a security threat will cause an interruption of the outpost construction, and potentially a loss of primary grid assets, resulting in load deficits, which will require

tired loads to be shed. The two separate event schedules, which dictate the operational load profile and dynamic events for the simulation studies, as shown in Figure 3 and Figure 4.

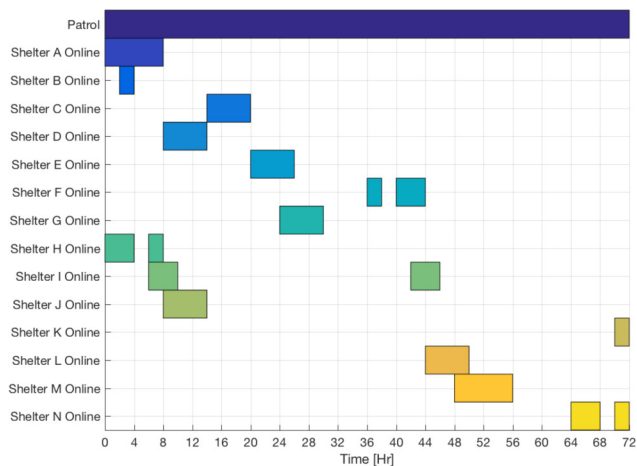


Figure 3. The uninterrupted outpost construction event schedule. This event schedule lacks events, which would cause the base’s security level to increasing.

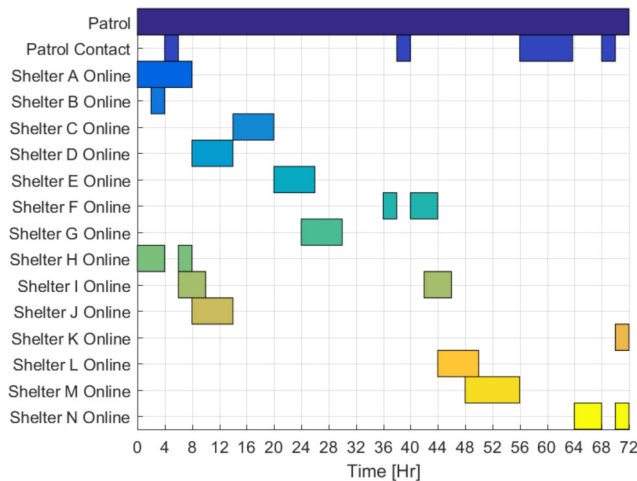


Figure 4. The interrupted outpost construction event schedule. This event schedule includes events where the continuous patrols report a contact, which causes the base to enter a heightened state of security, which leads to an interruption of construction.

Generic shelter names have replaced technical shelter names, for a list of technical shelter names, refer to Table 1. The final piece of information required for the simulation studies includes the vehicle Squad A and B’s planned vehicle usage. It is assumed that the four primary grid assets (military vehicles) are heavily armored, as such these vehicles will be used for assisting patrols when patrols encounter contacts. The vehicle usage for the interrupted outpost construction has been provided in Figure 5. For the uninterrupted outpost construction, scenario does not have a planned vehicle usage indicating the military vehicles are available for use throughout the entire simulation epoch.

Table 1. Generic shelter designation to technical shelter designations.

Generic Shelter Designation	Technical Shelter Designation
Shelter A	BN COC
Shelter B	Fires
Shelter C	Co HQ COC
Shelter D	Co A COC
Shelter E	Co B COC
Shelter F	Co C COC
Shelter G	Co Weapons COC
Shelter H	COM Shak
Shelter I	Motor Pool
Shelter J	LOGs
Shelter K	BC SGT M OPsO Offices
Shelter L	Chow Hall
Shelter M	Enlisted Quarters
Shelter N	Office Quarters

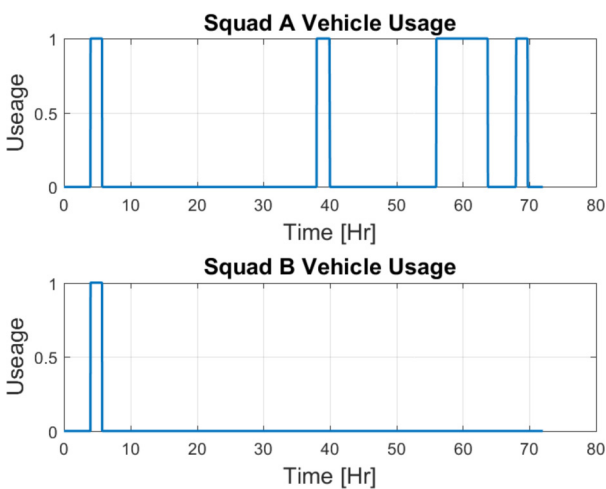


Figure 5. Planned vehicle usage for squad A and squad B. The planned vehicle usage for squad A and B are only used for the interrupted outpost construction scenario. If the usage is high than the vehicle is in use, if low the vehicle is not in use. The vehicle usage refers to the vehicle being unavailable to provide electrical power to the networked microgrid.

Tactical military microgrids are constructed using modular components. When a military outpost is established, various portable storage units, gasoline engines, and commercial off the shelf diesel generators are transported to the site in addition to loads and vehicles, which have exportable power capabilities and large battery storage capacity. Initially the outpost will have limited functionality since the majority of outpost components are not yet assembled or operational. As time progresses and the outpost's functionality and electrical load characteristics increase in both magnitude and complexity. The grid architecture used for the simulation studies is provided in Figure 6. The grid architecture can be subdivided to form five separate microgrids consisting of four primary microgrids and one secondary microgrid. Each primary microgrid, labeled 1-4, contains a single military vehicle and multiple, prioritized electrical loads. The secondary microgrid, labeled as 5, contains two gasoline generators and two Li-Ion battery packs. A single control architecture will be simulated including a vehicle centric microgrid subject to two separate event scenarios. The first scenario is uninterrupted construction of the outpost and the second scenario is interrupted construction due heightened security threats. For both simulation

studies it is assumed that the military vehicles are the primary grid assets, while the secondary grid assets include the gasoline generators and the energy storage units. In both scenarios the gasoline generators are continually used by the engineers to bring new loads online. The batteries remain operational for a short period of time when the load power P_{load} is less than 35kW. When higher loads are encountered, additional generation assets are brought online increasing the power generation capacity. If the generation capacity is sufficiently larger than the load demand, batteries may be charged. The loads are separated into three tiers. The first tier contains all critical loads. These are loads that must be operational at all times such as Combat Operations Centers (COCs), medical equipment, and critical communications equipment. The second tier contains noncritical loads. These are loads that are required for extended operations such as motor pools (vehicle repair shops) and mess halls. The third tier contains comfort loads such as lighting, non-critical communications, and moral boosting devices. loads as well as the added charging load. Additionally, if the generation capacity is significantly reduced (vehicles become inoperable or are unavailable) the batteries will be brought online and allowed to discharge to achieve the maximum power generation capacity. Once the maximum power generation capacity is achieved, and the total tiered load for the networked microgrid exceeds the total power generation capacity, the lowest priority loads are shed until the power generation exceeds the total microgrid load. This deficit could be either planned (long term) or transient. In the transient case, rapid charge/discharge of the battery occurs which aids in stability.

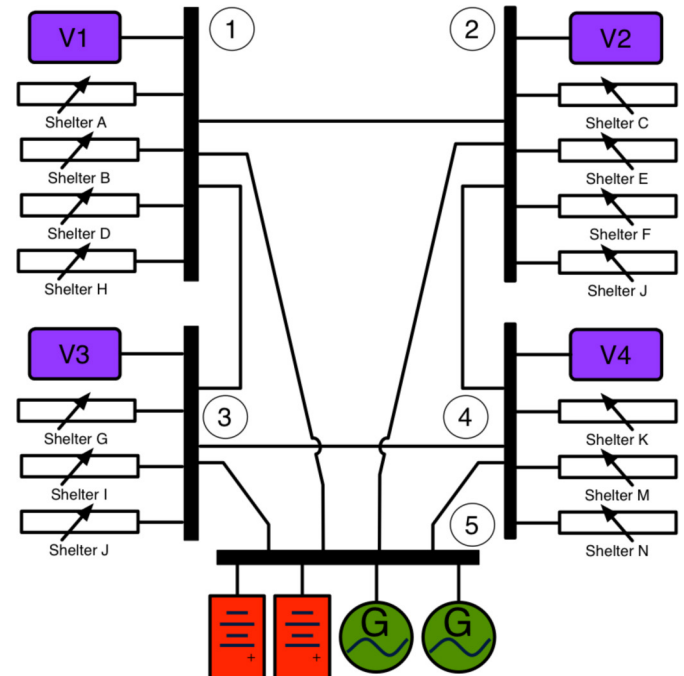


Figure 6. The networked microgrid architecture.

The system is modeled using MATLAB\Simulink using both AC and DC power sources. Since power transfer is done via DC transmission lines, the AC sources are rectified. The simulation is made up of six components including - (1) electrical storage (battery) model, (2) vehicle models, (3) gasoline generator models, (4) a grid model, (5) an optimal power flow controller, and (6) a power-coordination controller.