E700XD Portable Doppler Radar Energy Systems Analysis

Brandon M. Bailey
Department of Engineering Physics, Air Force Institute of Technology, WPAFB, USA
Email: Brandon.Bailey@afit.edu

Torrey J. Wagner and Jada B. Williams
Department of Systems Engineering & Management, Air Force Institute of Technology, WPAFB, USA
Email: {Torrey.Wagner, Jada.Williams.ctr}@afit.edu

***Abstract*—Occurring in industrialized nations, inexpensive and abundantly available power is routinely taken for granted. However, energy resilience and to a lesser extent price are key concerns when considering potential solutions for disaster response, disaster relief, or military operations. The Department of Defense (DoD) currently uses a 5 kW generator to power the E700XD portable Doppler radar system when grid power is unavailable [1]. While the radar has an approximate power consumption of 2.5 kW, there is a potential for higher demand due to weather conditions [2]. This paper examines the cost of operating a currently installed generator, compared to the cost for an optimized hybrid generator and battery system. The optimized energy system design includes a 2.75 kW generator, 3 kWh battery and inverter/charger. This design reduces the annual cost by nearly 50% when considering the component cost and the cost of fuel. In addition, the battery allows for an hour of operation in the event of a disruption to the primary generator solution, increasing the resiliency of the system.**

***Index Terms*—energy resiliency, hybrid energy system, weather radar**

I. Introduction

Attaining peak efficiency is important in austere locations where fuel availability is not always a certainty and fuel resupply can be difficult or dangerous. One such situation occurred in the aftermath of Hurricane Maria in Puerto Rico, where weather acted as a catalyst to compel a military relief operation [3].

Weather is a major factor in planning and operations. Predicting wind levels and directions as well as cloud heights, thunderstorms, extreme temperatures or other parameters assist in determining the optimal modes of transportation, deciding strategies, necessary equipment, and energy and safety requirements. Atmospheric conditions can also determine fuel consumption rates due to air conditioning and impact human rest-work cycles. Due to the variability of these factors, it is vital to monitor changing weather conditions. In the case of precipitation, wind and convective weather such as thunderstorms, radio detection and ranging (radar) is an effective tool to predict and monitor impending weather conditions and therefore mitigate their effect on operations.

According to recent estimates, there are over 270 EWR radars currently deployed worldwide [2]. The radars are portable and require only a small footprint for deployment in austere locations. After Hurricane Maria in 2017, two DoD radars were deployed and their data was released publicly to the National Weather Service to promote public safety throughout Puerto Rico [3]. Radar capability increases the warning time for severe weather, providing sufficient time for commanders to communicate the impact to personnel and to secure key assets. However, this capability requires a reliable supply of power, which can be a considerable challenge in remote locations.

Deployed radar systems use technology to increase radar efficiency and minimize the amount of energy used within the system. Fluctuations in energy use can be caused by the operating radar's environmental conditions; understanding the nature of these fluctuations can help to design an optimal energy solution.

II. Literature Review

As the majority of military operations have some degree of weather sensitivity, portable radars can mitigate their impact. Adverse weather conditions can occur at any time of day, however not all phenomena require the same amount of radar coverage. In some situations, the operators may be able to run the system intermittently, depending on the sensitivity of the mission, for the observed weather conditions. Energy requirements for the radar system must be able to support standard operations in addition to long duration demands that result from extreme weather conditions.

A. Radar

This research develops a model to examine the unique energy requirements for the EWR700 portable radar system, which is shown in Fig. 1. Following model development, this study compares the cost of the current technology with the cost of an optimally-sized generator and battery in order to examine potential savings and energy resiliency benefits.

Manuscript received July 30, 2019; revised November 12, 2019.

doi: 10.18178/ijoee.7.2.62-66

Radars emit a pulse of electromagnetic radiation at a known wavelength and frequency that varies by radar system. The radar then receives the energy that reflects from an object [4]. This backscattered radiation gives the position of a target based on the time it took to return back to the radar. The amount of the returned signal is then expressed as a magnitude at that given position.

Figure 1. EWR700XD Radar [1].

While emitting energy, some radars cannot simultaneously receive energy. Wavelength and pulse repetition frequency among other factors determine the maximum effective range of the radar, and the size of the objects the radar can discriminate. Backscattered radiation behaves in predictable ways based on the relationship of the frequency, the power of emitted energy and the size of the target [4], [5]. A simple radar system has the following components: the transmitter to create the specific characteristics of energy to be sent out, the antenna which emits and receives the signal, the receiver which amplifies the returning echo and performs signal processing, and an interface to display the radar data on a human-readable display [4], [6]. Fig. 2 shows the components in a simple radar system.

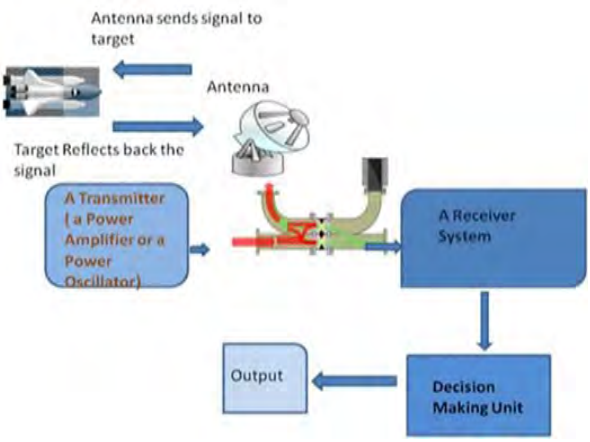


Figure 2. Depiction of a simple radar system [6].

The primary energy requirement is driven by the transmitter, and a typical energy requirement during transmission can range between 10 and 12 kW [4], [5]. Some radars use a solid state transmitter to reduce the energy requirement. The EWR700 uses a solid state transmitter and wave compression technology to attain a relatively low power requirement between 1.8-2.5 kW [7], depending on weather conditions [2].

The energy requirement includes variability the results from the need to maintain a set temperature for the transmitter's power conditioning unit [8]. For the purposes of this examination, the primary energy variation is due to temperature and relative humidity fluctuations, which change the cooling requirements for the power conditioning unit.

B. Diesel Generator

The baseline EWR700 system uses the Cummins Commercial Series QD5000 5 kW diesel mobile generator. Table I describes the generator performance parameters that are used to establish the baseline costs [7], [8].

TABLE I. GENERATOR PERFORMANCE PARAMETERS

Generator fuel burn rate (gal/hr)	.39 (half load) [12] .60 (full load) [12]
Fuel energy content, including efficiency (kWh/gal)	13.7 [10]
Generator power output (kW)	2.5 (half load) [12] 5.0 (full load) [12]

In this study, a hybrid energy system is designed to prevent the inefficiency of operating a generator at less than peak load, which is highlighted by Fig. 3.

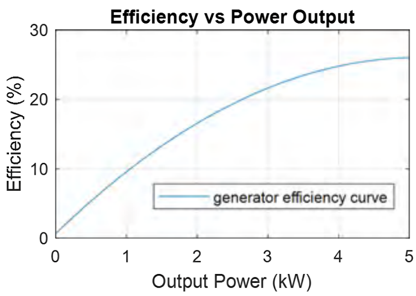


Figure 3. Generator efficiency plot.

C. Batteries

Lithium ion batteries were selected for their depth of discharge, lifespan, and energy density, as certain lead acid batteries can be a liability in extreme conditions below 5 degrees F, and discharging lead acid batteries in these conditions could cause permanent damage to the batteries [9]. A representative Lithium ion battery was designed to sustain a 100% depth of discharge for over 600 cycles [10]. For some battery technologies, charging is not possible when temperatures fall below freezing [9], to resolve this it is assumed that the battery location is maintained above freezing due to proximity to the generator. This battery technology can maintain its charge and discharge rates at high temperatures, at an expense of battery life [9]. For the temperature profile used in this scenario, the impact of these extreme temperature considerations are assumed to be negligible.

D. Baseline Costs

The current energy system has a 5 kW generator with the capability to reduce power output to 2.5 kW when the load is below 2.5 kW. When the generator load is at or above 2.5 kW, the fuel burn rate is 0.60 gallons per hour, and when the load is at or below half load the fuel burn rate is 0.39. The fully burdened cost of fuel in an austere location was assumed to be $10/gallon [8].

Under these conditions the cost of fuel for the year is $36000, the energy system including component costs is $5600, resulting in a total system cost of $41600 for 1 year. The model for the one-year scenario output of a generator is illustrated in Fig. 4, this component's output exceeds the "half load" limit about 15% of the time, most often during the day in the summer months.

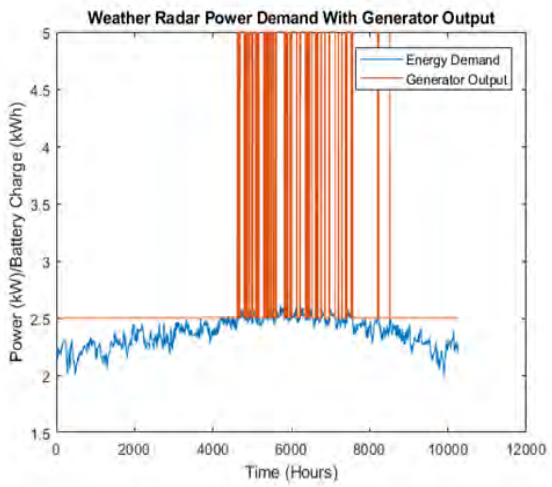


Figure 4. Total annual energy requirement overlaid with the baseline technology generator output.

III. Method

Hybrid energy system model development is discussed in this section, including assumptions, deployment considerations, energy requirements and optimization. The cost and performance parameters for each component are defined in Table II [8].

TABLE II. Component Cost and Performance Model Parameters

	Generator	Battery	Inverter Charger
Component Cost	$1,120/kW [5]	$490/kWh [6]	$900 [10]
Replacement	-	600 Cycles [12], [13]	-
Weight (lbs)	800 [5]	300 [6]	100 [10]
Fuel Cost ($/gal)	10 [8]	-	-
Peak Efficiency	26%	-	-
Power Output (steady state/max)	5 kW / 5 kW [5]	4 kW / 4 kW [6]	6 kW/ 6 kW [10]

A. Assumptions

The power consumption of the radar is relatively consistent with variations due to the air conditioning systems that maintain temperature stability in the power conditioning unit. Both ambient air temperature and moisture impact the efficiency of the air conditioning system [14]. Wind resistance to radar rotation is assumed negligible because of the protective dome around the rotating portion of the radar system.

The average radar-only power requirement under ideal conditions is 1.8 kW [7]. An average of 0.25 kW is added for additional energy loads to support computing needs and facilities essential to the personnel operating the radar. According to EWR, the maximum power draw is 2.5 kW, however extreme temperatures can increase the power demand over 2.5 kW. We calculate that environmental conditions such as temperature and relative humidity result in an additional 0 - 0.65 kW power draw. Although weather conditions such as ice and wet snow can attenuate a radar signal, we assume a negligible effect on the energy draw of the system beyond the temperature and relative humidity (RH) contributions of the system.

The weather observation data includes both scheduled and unscheduled observations, causing a varied time in between sampling. This is considered negligible because the temperature and RH change relatively smoothly and sharp discontinuities are uncommon. In analyzing the intermittent time periods of the observed data in 2016, we assume a data frequency period of 0.85 hours so that the 10260 observations match the 8760 hours in a year.

B. Deployment Considerations

Radar systems are typically deployed in semi-permanent and relatively stable locations that contain substantial air traffic. When access to local power grids are unavailable, generators supply the primary electric power, and require a dedicated supply chain to deliver diesel fuel. The intermittent nature of solar and wind increases the complexity for acquiring reliable sources of energy, and they were not considered. System replacement procedures, including transportation costs, are not accounted for within the model.

C. Energy Requirement

The meteorological terminal air reports (METARs) and special weather reports (SPECIs) collected from Des Moines, Iowa in 2016 depict the temperature and RH profiles used in this analysis. The kW contribution for each time step of 0.85 hours was calculated by setting a percentage weight to observed RH and temperature values with the maximum values given at 100% RH and 93-degrees Fahrenheit respectively. The contribution for each parameter was assigned a linear relationship based on percentage of the maximum observed values for each parameter during each hour. The fluctuation due to RH and temperature subsequently determine the fluctuation in energy required for the system. A summary of this information is presented in Fig. 5.

Using the contributions shown in Fig. 5, over the course of one year the radar averaged a daily demand of 2.37 kW with a maximum value of 2.60 kW during the hottest day of the year, and a minimum of 1.98 kW during the coldest day of the year. It is important to note that air conditioning for human operators was disregarded; the only air conditioning considered is associated with cooling the system using the power conditioning unit. The resulting power requirement is shown in Fig. 6.

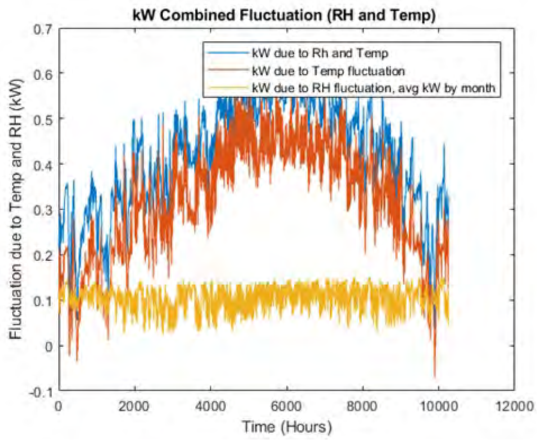


Figure 5. Sources of power requirement variability.

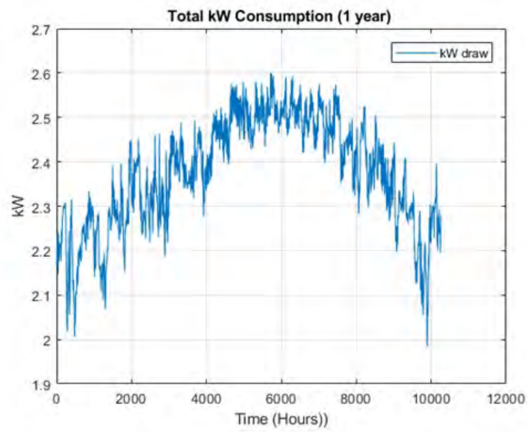


Figure 6. Total power demand including baseline, temperature, and relative humidity fluctuations.

IV. Analysis

A. Battery and Generator Single-Variable Optimization

Initially, a one variable sweep for both the generator and battery size was conducted to understand their contribution to system dynamics, using the energy requirement represented in Fig. 6. As depicted in Fig. 7 and Fig. 8, the generator and battery costs rise linearly with increasing generator and battery sizes, respectively. In Fig. 7, below 2.6 kW the cost of fuel decreases because the energy requirement is not being met. When the generator reaches the average power demand, the cost drops due to the benefits of operating the generator at peak efficiency.

B. Two-Variable Optimization

A two-variable sweep while varying the sizes of a generator and battery from 1-4 kW and 1-6 kWh, respectively, is now performed. The results of this sweep are presented in Fig. 9. Using this analysis, the optimal generator size for the load, while operating the generator at peak efficiency, is 2.75 kW. A generator of this size offers several options for battery sizes depending on mission requirements. We selected a 3 kWh battery to provide an hour of backup, therefore increasing the resiliency of the proposed system. The system resiliency could be extended with a larger battery or by operating the radar intermittently to run periodic volume scans. In locations where energy is stable and available, if the designed system is selected, the installed battery can be smaller than the proposed 3 kWh.

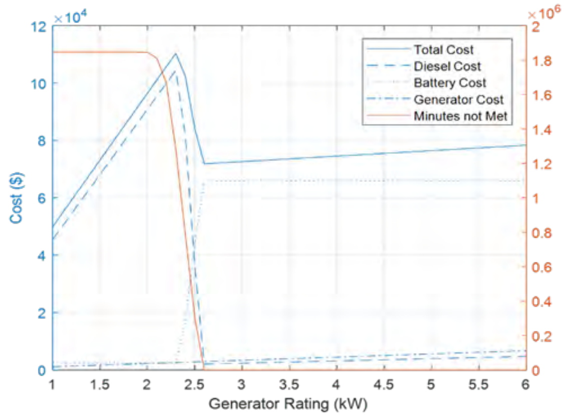


Figure 7. One-variable optimization for the generator.

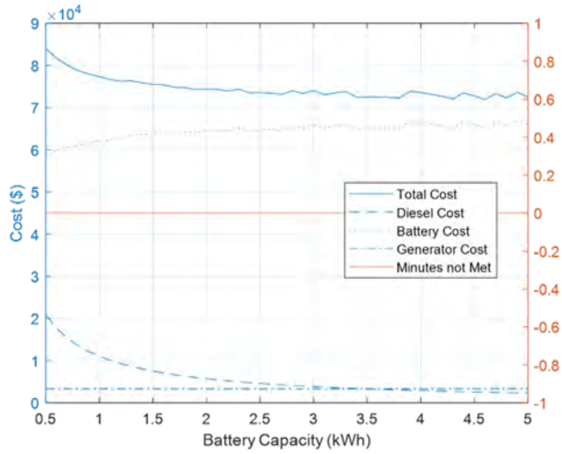


Figure 8. One-variable optimization for the battery.

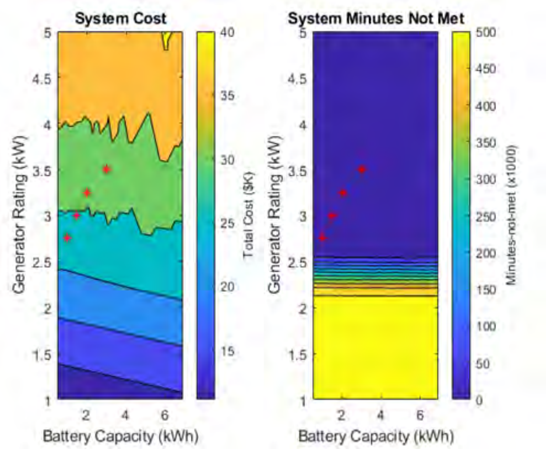


Figure 9. Total system Cost (left) and Performance (right). Optimal design points are shown in red.

An installed battery increased the overall efficiency of the generator due to operating the generator at peak efficiency as shown in Fig. 3. Fig. 10 presents a time-series history of the optimal solution, which shows the times the generator is operated, the state of charge of the battery, and the energy requirement.

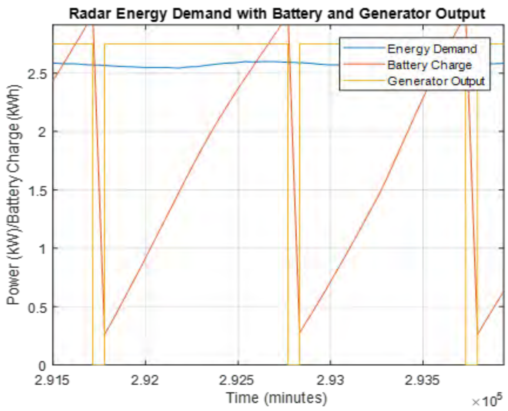


Figure 10. Time-series history of the energy requirement, battery state of charge and generator output.

V. Conclusions

We present an optimized solution of a 2.75 kW generator and 3 kWh battery system whose one-year operation costs total $28,500. This cost is significantly reduced from the baseline cost of $41,600. The 2.75 kW generator operates at peak efficiency, while storing any unused power in the battery. When the battery is fully charged, the generator turns off. The 3 kWh battery can provide an hour of standalone operation, providing resiliency during disruptions in fuel supply or generator outages. Although smaller batteries are cost effective, we propose that improvements in energy resiliency with a larger battery is worth the cost.

This study can be performed in any climate, provided a dataset of weather observations. For future work, refining the parameters for extreme temperatures could increase model accuracy.

Acknowledgment

Authors' Note: The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof. Reference to specific commercial products does not constitute or imply its endorsement, recommendation, or favoring by the U.S. Government. The authors declare this is a work of the U.S. Government and is not subject to copyright protections in the United States. This article was cleared with case number 88ABW-2019-1277.

References

[1] EWR Radar Systems. (2018). E700XD data page. *EWR Radar Systems*. [Online]. Available: http://ewradar.com/product/e700xd/

[2] M. Gabella, R. Notarpietro, S. Bertoldo, A. Prato, C. Lucianaz, O. Rorato, M. Allegrett, and G. Perona, "A network of portable, low-cost, X-band radars," *InTech*, pp. 175-202, 2012.

[3] National Oceanic and Atmospheric Administration, "Federal collaboration yields radar coverage for Puerto Rico, USVI in wake of Hurricane Maria," NOAA Media Release, no. 31, October 2017.

[4] C. Wolff. (2018). Radar Tutorial. Radartutorial. [Online]. Available: http://www.radartutorial.eu/07.waves/Waves%20and%20Frequency%20Ranges.en.html

[5] D. C. Herbster. (September 2018). *Radar Types and Components*. [Online]. Available: http://opwx.db.erau.edu/faculty/mullerb/Wx365/Radar_components/radar_components.html

[6] Electronics Projects Focus (ELPROCUS). (December 2018). *RADAR- Basics, Types & Applications*. [Online]. Available: https://www.elprocus.com/radar-basics-types-and-applications/

[7] EWR Weather Systems, "E700 power consumption generator," *EWR Radar Systems*, 2018.

[8] J. Chester, T. Wagner, and D. Dudis, "36% reduction in FOB generator fuel use with optimized energy storage," *Marine Corps Gazette*, 2019.

[9] *BU-410: Charging at High and Low Temperatures*, Battery University Group, 2017.

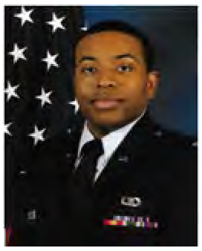
[10] *BU-808: How to Prolong Lithium-based Batteries*, Battery University Group, 2018.

[11] EWR Weather Systems. (2018). About EWR. *EWR Radar Systems*. [Online]. Available: http://ewradar.com/about/

[12] *Advanced Medium Mobile Power Sources Brochure*, Cummins Inc., 2017.

[13] S. R. Dubbs, *Estimating the Fully Burdened Cost of Fuel Using an Input-Output Model - A Micro-Level Analysis*, Naval Post Graduate School, 2011.

[14] Northern Arizona University. (December 2018). Thermal Comfort (Relative Humidity (RH) and Air). [Online]. Available: https://www7.nau.edu/itep/main/eeop/docs/airqlty/AkIAQ_ThermalComfort.pdf



Brandon Bailey was born in Georgia, USA in 1991. He received a B.S. degree in Meteorology from the University of Oklahoma, Norman, Oklahoma, in 2013. He has served as a warning coordination meteorologist, lead meteorologist, and meteorological consultant for two strategic headquarters. In 2018 he started a Master's degree in Atmospheric Science from the Air Force Institute of Technology, Dayton, Ohio, USA.

His main research interests include utility of meteorological forecasts in industry and operations, as well as meteorology in emergency management and defense support of civil authorities.

Torrey Wagner was born in Minnesota, USA in 1977. He received the B.S. degree in electrical engineering from the University of Minnesota, Minneapolis, Minnesota, in 1995, and the Ph.D. degree in electrical engineering from the Air Force Institute of Technology, Dayton, Ohio, USA in 2010.

Since 2017, he has been with the Faculty of the Department of Systems Engineering & Management, Air Force Institute of Technology, where he is currently an Assistant Professor. His main research interests include energy systems engineering and agile software systems engineering.

Jada Williams was born in the District of Columbia, USA in 1989. She received the B.S. degree in geoenvironmental studies from Shippensburg University, Shippensburg, Pennsylvania, in 2012, and an M.S degree in renewable and clean energy from the University of Dayton, Dayton, Ohio, USA in 2015. Since 2018, she has been with the Staff of the Department of Systems Engineering & Management, Air Force Institute of Technology, where she is currently a Systems Engineering Research Assistant. Her main research interests include renewable energy systems engineering and model based systems engineering.