

# **INTEGRATION OF SOLAR MICROGRIDS**

by

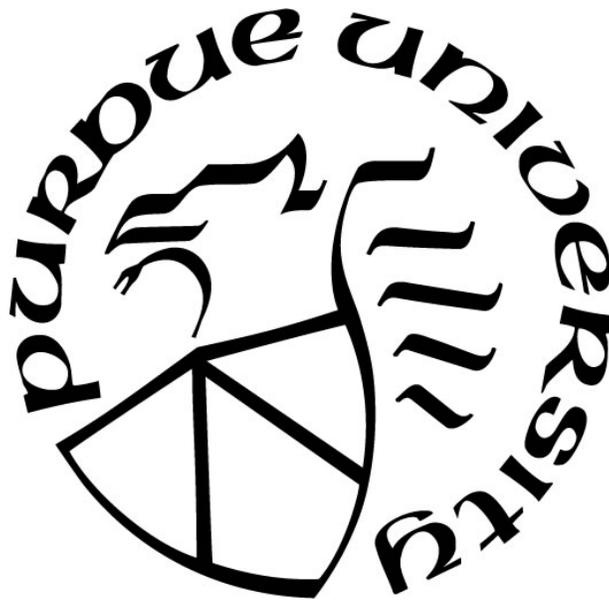
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*Dedication*

*John Axelberg CEO & President, General Stamping & Metalworks Inc. without your vision and support, this project would not be possible, thank you!*

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## LIST OF ABBREVIATIONS

Ah: Ampere Hour

BMID: Battery Monitoring Identification Device

CO<sub>2</sub>: Carbon Dioxide

DC: Direct Current

DER: Distributed Energy Resources

ESS: Energy Storage Systems

GW: Gigawatt

GWdc: Gigawatt Direct Current

ITC: Federal Investment Tax Credit

IRR: Internal Rate of Return

kW: Kilowatt

kWh: Kilowatt Hour

MW: Megawatt

MWh: Megawatt Hour

MWdc: Megawatt Direct Current

NPV: Net Present Value

NZEB: Net-Zero Energy Building

PV: Photovoltaic

ROI: Return on Investment

VPN: Virtual Private Network

ZEB: Zero Energy Building

## GLOSSARY

**Greenhouse Gases:** Gases in Earth's atmosphere (carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (NO), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs), Sulphur hexafluoride (SF<sub>6</sub>), and water vapor (H<sub>2</sub>O)) that absorb part of the solar radiation reflected from the Earth's surface and trap the heat in the atmosphere; this is referred to as the greenhouse effect. An increase in the concentration of greenhouse gases is likely to result in rising average temperature of the Earth, or global warming(Black, Hashimzade, & Myles, 2017).

**Hydrocarbon:** A naturally occurring compound of hydrogen and carbon. There are many different types of hydrocarbon, which can take the form of a gas, liquid, or solid; examples include natural gas, bitumen, and petroleum. A conventional or criteria pollutant(Park & Allaby, 2017)

**Microgrid:** a small network of electricity users with a local source of supply that is usually attached to a centralized national grid but is able to function independently (Stevenson & Lindberg, 2011).

**Renewable Energy:** Energy obtained from naturally-occurring renewable-energy sources (renewables) such as the sun (solar power), tides and ocean waves, hot rocks (geothermal), and wind. It may also include biomass and biofuels (Atkins & Escudier, 2013).

**Zero-Energy Building:** a zero energy building produces enough renewable energy to meet its own annual energy consumption requirements, thereby reducing the use of nonrenewable energy in the building sector (Peterson, Torcellini, Taylor, & Grant, 2016).

**Internal Rate of Return:** The discount rate that makes the net present value (NPV) of a project zero. In other words, it is the expected compound annual rate of return that will be earned on a project or investment("Internal Rate of Return (IRR) - A Guide for Financial Analysts," 2019).

## ABSTRACT

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The hydrocarbon combustion process used to generate electricity releases harmful levels of Carbon, Sulfur and Nitrogen Oxides into the atmosphere. The alternative to environmentally toxic hydrocarbon based fuel, is electricity generated from solar powered microgrids. Solar photovoltaic microgrids represent a clean, renewable and economically viable energy alternative to hydrocarbon based fuel. The microgrid project outlined the specifications required to charge the battery powered material handling vehicles at General Stamping & Metalworks. The project was designed to replace utility supplied electrical power with a solar microgrid to charge three lead acid type batteries. The solar microgrid project specifies the system requirements, equipment selection and installation methodology. Operational strategies for additional photovoltaic applications within the organization are discussed. Outlined in the report are the costs of installation and return on investment. The project was designed to demonstrate a practical application of microgrids within a manufacturing environment. The goal of the project was to design and build a small scale installation to provide a proof of concept. The overarching goal was to reduce the toxic emissions produced by utility supplied electrical power by installing a solar powered microgrid. The end result of the analysis was that photovoltaic powered microgrids represent a viable energy generating system for battery powered applications. However, based on the regional utility price of .092 \$/kWh, the solar installation did not meet the organizations investment acceptance criteria.

## CHAPTER 1. INTRODUCTION

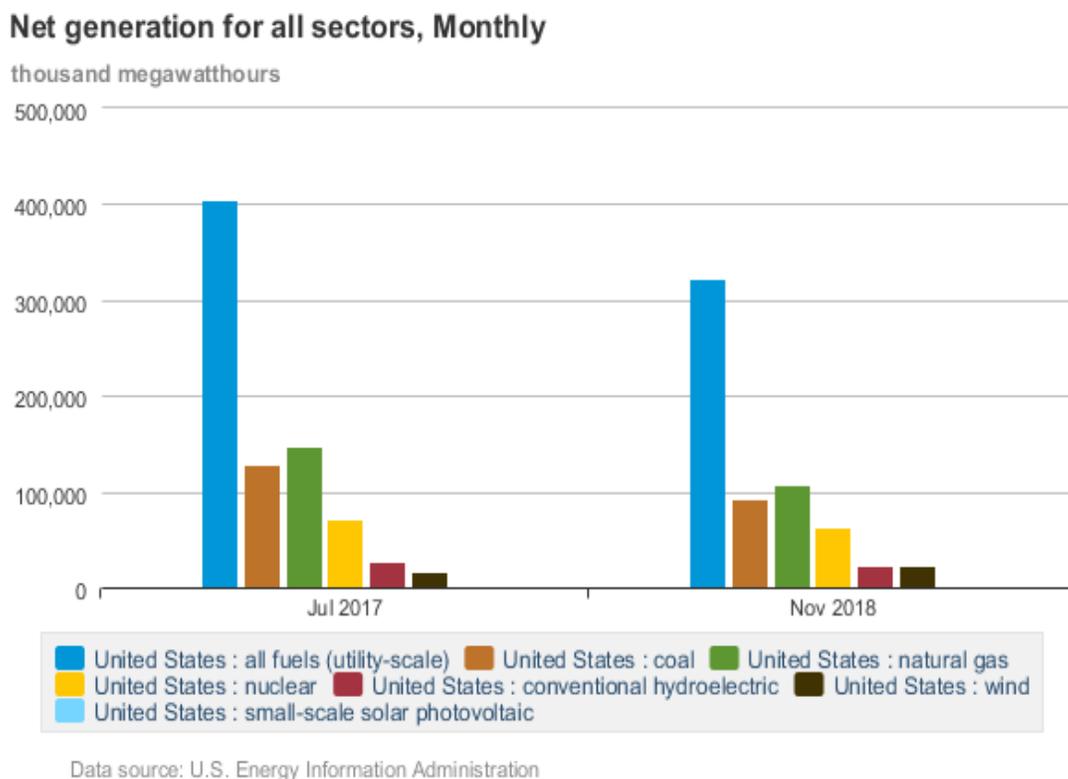
### 1.1 Microgrid Solar Installation

Businesses and private citizens rely on municipally operated power grids for the safe delivery of clean uninterrupted electrical power. Municipally owned infrastructure provides the framework for both the transmission and distribution of electrical power. The scale and complexity of the infrastructure required to meet the electrical demand across the United States is staggering. “The U.S. electrical grid, the largest and most complex man-made system in the world today, is an interconnected network for delivering electricity from generally centralized suppliers to distributed consumers”(Prehoda, Schelly, & Pearce, 2017). Retail electricity is produced by regional utility companies using multiple fuel sources. The primary fuel sources used to produce electricity include fossil fuels (hydrocarbons), nuclear power and renewable resources (wind, hydroelectric and solar). Renewable energy sources however, make up only a small percentage of the energy used to produce utility scale electricity. Bulk electrical power in the United States, is generated from the burning of hydrocarbon based fuels, specifically coal and natural gas.

“In 2017, about 4,034 billion kilowatt-hours (kWh) (or 4.03 trillion kWh) of electricity were generated at utility-scale facilities in the United States. About 63% of this electricity generation was from fossil fuels (coal, natural gas, petroleum, and other gases). About 20% was from nuclear energy, and about 17% was from renewable energy sources. The U.S. Energy Information Administration estimates that an additional 24 billion kWh of electricity generation was from small-scale solar photovoltaic systems in 2017” (“EIA - Electricity Data,” 2019)

The graph shown in (Figure1) illustrates the annual net generation of utility scale electricity by fuel source for the years 2017 and 2018. Nonrenewable fuel sources (Hydrocarbons) represent the largest percentage of fuel used to generate retail electricity.

Figure 1 EIA, Independent Statistics &amp; Analysis, 2019



Coal and natural gas represent the largest share of fuels. Combined, coal and natural gas make up 62 percent of the fuel used to power utility scale electricity. The combustion process used to generate electricity releases harmful levels of Carbon, Sulfur and Nitrogen Oxides into the atmosphere. The alternative to environmentally toxic hydrocarbon based fuel, is electricity generated from carbon neutral photovoltaic powered microgrids. The United States Department of Energy, describes a microgrid as, “A localized grid that can disconnect from the traditional grid to operate autonomously...Microgrids support a flexible and efficient electric grid by enabling the integration of growing deployments of distributed energy resources such as renewables like solar”(“Office of Electricity (OE),” 2019). Microgrids that operate using clean, renewable energy sources have the potential to replace hydrocarbon based electricity.

Photovoltaic (PV) powered microgrids represent a viable electrical generation alternative with the potential to provide the clean, uninterrupted electrical energy. Installing and implementing independent photovoltaic microgrids decreases reliance on municipal power grids while reducing the emission of toxic hydrocarbon byproducts. The microgrid project outlines the design and equipment specifications required to support the electrical charging needs of General Stamping & Metalworks. The specified PV array was designed to provide the electrical energy required to charge the fleet of material handling vehicles. The project concept was to replace utility supplied electrical power with a PV installation to charge three lead acid type batteries. The success of the project served as the justification for future scalable solar infrastructure applications. The project was designed to record the electrical discharge rate measured in amperes hours used during normal operations. The evaluation period served to measure the output required of the proposed solar installation. The recommended system made adequate allowances for power loss inherent in electrical installations.

The solar microgrid project specifies the system requirements, equipment selection and installation methodology. Operational strategies for additional photovoltaic applications within the organization are discussed. Outlined in the report are the costs of installation per Watt and the return on investment. The project was designed to demonstrate a practical application of microgrids within a manufacturing environment. The goal of the project was to design and build a small scale installation to provide a proof of concept. The overarching goal was to reduce the toxic emissions produced by utility supplied electrical power by installing a solar powered microgrid. The project seeks provide clear evidence that photovoltaic solar microgrids are a viable power source for battery charging applications.

## 1.2 System Requirements

Specified in chapter four are the types, electrical capacity and discharge rates for each battery used in the study. Chapter four tabulates the charging frequency, duration and capacity returned for each charging event. Listed in chapter five are the recommended photovoltaic performance requirements based on results of the data compiled in chapter four. Tables and graphical information presented in chapter four list the charging data recorded at the charging station during daily production activities.

### 1.3 Equipment Selection

Equipment selection includes the specifications for solar modules (solar panels) used to generate the required output detailed in chapter four. Included in the chapter five are the size, type, manufacturer and electrical output strength of the specified array. Listed are the number of modules required to meet the charging requirements for both the TSP-7000 and SP-4000 vehicles. The array type and pitch angle used to maximize output strength are outlined in chapter five. Photovoltaic type and projected lifespan of the installation was calculated using manufacturer's warranty information. Practical lifespan and technology improvements are discussed.

### 1.4 Operational Strategy

The operational strategy describes the overall philosophy of microgrid installations. Chapter five details the charging application in its current configuration and introduces the scalability of futures solar applications within the facility. Detailed is General Stamping & Metalworks philosophy on solar energy participation and its commitment to renewable energy. Described is the organizational participation in the solar energy sector and its ongoing efforts to reduce costs for utility scale solar customers. A brief discussion with the Chief Operating Officer outlines plans for future charging installations within General Stamping & Metal Works Inc.

### 1.5 Photovoltaic Installation Costs

Outlines the cost of installation per Kilowatt hour, and cost of operation. Detailed output of the installation, the electrical cost savings and return on investment scenarios are also detailed. Tax deductions for solar installations are calculated and discussed in chapter five. Applied in the calculation are the Federal Investment Tax Credit (ITC) for consumers purchasing and installing solar panels. The tax credit ranges from 10-30% of the installation costs. Potential for grants along with state and federal incentive programs to offset the initial construction costs are discussed. Outlined in Chapter five is the estimated payback period.

## 1.6 Problem Statement

A world free from the hazardous byproducts of Hydrocarbon combustion is possible. The use of Hydrocarbon combustion for electrical energy is drowning Earth's atmosphere in dangerous levels of Carbon, Sulfur and Nitrogen Oxides. The safe, free and unlimited alternative to Hydrocarbon fuel lies in solar energy. According to the U.S. Department of Energy, "solar energy is the most abundant energy resource on earth, 173,000 terawatts of solar energy strikes the Earth continuously. That's more than 10,000 times the world's total energy use" (Pierce, 2019). The National Academy of Engineering *Grand Challenges for Engineering* also recognizes the environmental and economic impact of solar energy. "For a long-term, sustainable energy source, solar power offers an attractive alternative. Its availability far exceeds any conceivable future energy demands. It is environmentally clean, and its energy is transmitted from the sun to the Earth free of charge."(NAE, 2018). The demand for clean energy continues to grow while fossil fuel sources are being slowly depleted. "Growing electricity demand in the modern and developing world, coupled with the looming danger of climate change, means that it is becoming more and more imperative for cleaner renewable energy technologies to replace traditional fossil-fueled generators" (Neill, Stapleton, & Martell, 2017). Photovoltaic electrical energy generation is the sustainable alternative to hydrocarbon based fuels.

## 1.7 Summary

The key to eliminating dependency on hazardous Hydrocarbon based fuel is to make solar more economical for all users. Solar photovoltaic microgrids represent a clean, renewable and economically viable energy alternative to hydrocarbon based fuel. The journal article *How Batteries and Solar Power are Disrupting Electricity Markets*, describes the economic case for solar photovoltaic (PV) power generation. "World retail power prices are rising and the cost of PV-generated and stored electricity is declining, creating potential savings for consumers and small businesses. As companies and consumers adopt these new technologies, they are unlocking billions of dollars in potential value"(Rubel, Pieper, Zenneck, & Sunak, 2017). Generating electrical energy using photovoltaic systems represents a practical and economically viable alternative to hydrocarbon based fuel sources. Photovoltaic powered microgrids are an environmentally and economically sound application of renewable electrical energy.

## CHAPTER 2. REVIEW OF LITERATURE

### 2.1 Environmental Damage from Hydrocarbons.

The combustion process used to generate utility scale electricity releases toxic chemical compounds into earth's atmosphere. The effects are felt across the planet in the form of reduced air quality, environmental degradation and detrimental impacts on human health. The bulk of electrical power generation in the United States is derived from coal and natural gas. The toxic byproducts produced from hydrocarbon based fuels has detrimental long term effects on the planet. The harmful effects on humans and plant life is explained in the 2018 article *Effects of Hydrocarbons on the Environment*.

“The planet's atmosphere and climate have been changing for decades, and hydrocarbons are one of main culprits. These are a class of compounds primarily composed of carbon and hydrogen. As major components of oil, natural gas and pesticides, these substances contribute to the greenhouse effect and climate change, deplete the ozone, reduce photosynthetic ability of plants, and increase occurrences of cancer and respiratory disorders in humans. Methane and chlorofluorocarbons are two hydrocarbons that can drastically alter the atmosphere. Methane oxidizes into carbon dioxide (CO<sub>2</sub>), increasing the amount of CO<sub>2</sub> in the atmosphere and adding to the greenhouse effect and global warming. Aromatic hydrocarbons come from the combustion of coal, oil, tar and plant material. Benzene is a common hydrocarbon used as a solvent and in fuel. It's been found to deplete red blood cells, cause cancer in mammals and damage bone marrow. Polynuclear aromatic compounds are hydrocarbons with two or more benzene molecules. They've been shown to cause cancer. Alkyl nitrates are products of hydrocarbons that chemically react with molecules in the atmosphere. They can chemically react again to produce nitrous oxide, which can affect blood vessels, the liver, the kidneys and the nervous system” (Schab, 2018)

The clean renewable alternatives to hydrocarbon based fuels are solar energy, wind energy and biochemical hybrid systems. Photovoltaic solar arrays are the singular technology with the highest potential to replace hydrocarbon based fuels for utility scale production.

## 2.2 Practical Applications of Microgrid Solar Installations

Successful solar applications incorporate the capacity to store surplus electricity generated during high solar activity for use when solar activity is low. Modern solar microgrid applications take advantage of high capacity batteries to store captured electricity. Typical battery applications include charging stations, lighting, and water heating. As battery storage capacity grows, solar microgrids become more economically viable. Santa Rita Jail in Dublin, California is a successful case study of a photovoltaic solar (PV) battery based microgrid system.

“Santa Rita Jail is a 4,500 inmate facility located in Dublin CA, approximately 40 miles east of San Francisco. Over the past decade, a series of Distributed Energy Resources (DER) installations and efficiency measures have been undertaken to transform the 3MW facility into a "Green Jail". These include a 1.2MW rated rooftop PV system installed in 2002...The battery is the only truly dispatchable DER at the jail. Utilizing Distributed Energy Resources Customer Adoption Model (DER-CAM) optimal battery scheduling is determined for several scenario-weeks. This has been conducted for an operational fuel cell (Scenario 1) and, a short fuel cell outage (Scenario 2). The higher capacity of Battery A allows it to reduce max-peak power demand charges more than Battery B. A is also capable of islanding for longer durations than B, which is of value to microgrid applications. Despite its lower capacity, B still captures a significant portion of potential demand charge savings. B can allow for short periods of islanding. The installation of a large-scale battery at Santa Rita Jail provides added reliability, plus the potential to shift electricity purchase to less expensive off-peak times” (Lai, Mendes, Marnay, & Donadee, 2011)

Microgrid implementation projects similar to the Santa Rita Jail have been successful worldwide. Examples in practice include installations in Europe and Japan. The deployment of photovoltaic microgrid technology allows nations and regions with limited natural resources to generate electrical power from sunlight. “Japan is one of current world leaders in microgrid demonstration projects. Motivated by its limited natural resources, the Japanese government set ambitious targets for utilizing more renewable energy resources.”(Lee & Wetz, 2013a, p. 13).

The European Union (EU) is also pursuing large scale microgrid installations to reduce greenhouse emissions and increase system reliability. Renewable powered electricity generation is vital to the EU Agenda 2030 for Sustainable Development. “Renewable energy is a focal point of discussion in the European Union, as clean production technologies contribute to all three aims of energy policy security, competitiveness, and sustainability”( Atkins Cabeza-García, & Soares, 2018). The implementation of solar powered microgrids helps the EU to meet its goal to increase the use of renewable energy.

“From the EU international level, there are two major microgrid research projects. The first project funded by EU was the ‘Microgrids: Large Scale Integration of MicroGeneration to Low Voltage Grids’ which was undertaken by a consortium led by National Technical University of Athens (NTUA) and included 14 partners from seven EU countries, including utilities such as EdF (France), PPC (Greece), and EdP (Portugal); manufacturers SMA, GERMANOS, and URENCO; and research institutions and universities such as Labein, the University of Manchester, and ISET Kassel. With a €4.5 million grant, this project was designed to investigate the dynamics of DGs in a microgrid”(Lee & Wetz, 2013, p. 12)

Industrialized nations have vested interests in reducing greenhouse gases that contribute to global climate change and reduced living standards. Solar powered installations worldwide are increasing in frequency and efficiency. Photovoltaic installations have the ability to bring electrical power to regions that lack complex and expensive infrastructure. Stand-alone microgrids eliminate the need to install large scale electrical grids for power distribution. Specifically, battery powered microgrids system are the least complex and most cost effective solution for electrical generation.

### 2.3 Net Zero Energy Buildings

The ultimate goal of a completed microgrid installation is a one hundred percent self-contained energy producing system. Ideally, during peak energy production, microgrids will generate surplus capacity that can be transferred to the local municipal grid for credit. The United States Department of Energy describes Energy Neutral or Zero Energy Building as;

“A zero energy building (ZEB) produces enough renewable energy to meet its own annual energy consumption requirements, thereby reducing the use of non-renewable energy in the building sector. ZEBs use all cost-effective measures to reduce energy usage through energy efficiency and include renewable energy systems that produce enough energy to meet remaining energy needs. There are a number of long-term advantages of moving toward ZEBs, including lower environmental impacts, lower operating and maintenance costs, better resiliency to power outages and natural disasters, and improved energy security”(Peterson et al., 2016 p.5).

Achieving Net Energy Zero for existing or legacy structures is not economically possible. However, all structures can benefit from technology designed to supplement energy needs using renewable energy systems. As energy prices continue to rise and fossil fuel sources rapidly deplete, renewable energy sources become necessary to sustain business operations. Solar microgrid installations provide a buffer for unstable power networks and add a layer of reliability during severe weather events. Successful microgrid applications are self-sustaining and add economic value to building systems.

“Zero net energy policy goals for buildings in the United States and across the world imply a high penetration of distributed renewable energy resources and a substantial increase in energy efficiency. According to the National Science and Technology Council, aggressive adoption of energy efficiency technologies will reduce building energy consumption by 60%–70%. The remaining 30%–40% of energy must come from onsite generation to achieve zero net site energy. Distributed renewable energy will be deployed on a large scale only when its assets provide attractive returns to owners and enable utilities and grid operators to safely and reliably mitigate the impact of renewables’ intermittency on the electricity distribution infrastructure”(Fregosi et al., 2015 p.3).

Increasing the portion of electricity produced using solar photovoltaic systems ultimately reduces the environmental impact of coal and natural gas. Providing a lower cost, highly efficient alternative to fossil fuel moves utility scale energy producers to switch to renewable fuel sources. Incorporating energy capturing technologies (PV installations, wind energy) into

new building design is the most cost effective method of implementation. The state of California has recognized the need to implement renewable energy systems for residential and commercial construction. “The California Energy Commission approved a mandate that residential buildings up to three stories high, including single-family homes and condos, be built with solar installations starting in 2020”(Ailworth, 2018).

The California mandate is intended reduce reliance on fossil fuels and decrease carbon dioxide emissions while mitigating costs of electrical production. Solar photovoltaic microgrids are leading the way in replacing hydrocarbon based fuels. “The mandate is part of California's goal to slash greenhouse gas emissions 40% below 1990 levels by 2030 and 80% by 2050...the state seeks to achieve net-zero energy in new residential buildings by 2020 and new commercial buildings by 2030”(Hering, 2018). The photovoltaic battery charging application is designed to provide a practical application of renewable energy generation.

“The commercial building sector presents approximately 37% of the electricity currently used within the United States, and electric energy consumption in the commercial building sector will be expected to increase until high performance buildings can be effectively designed to reduce building energy consumption. With the rapid growth in renewables, the net-zero energy building (NZEB) concept has been considered as one of the remedies to reduce electric energy usages and achieve increased energy efficiency in buildings. The Energy Independence and Security Act of 2007 (EISA 2007) authorizes the net-zero energy commercial building initiative to support the goal of net-zero energy for all new commercial buildings by 2030. It further specifies a net-zero target for 50% of the U.S. commercial buildings by 2040 and net-zero for all the U.S. commercial buildings by 2050”.(Kim, Cho, & Luck, 2019 p.1)

Implementing photovoltaic electrical systems is a viable application of using renewable energy sources to achieve a net-neutral, or net-zero buildings. Future increases in photovoltaic technology will only help to increase implementation. Achieving net-zero commercial buildings is a major step in reducing environmental impacts of fossil fuels

## CHAPTER 3. RESEARCH METHODOLOGY

### 3.1 Introduction

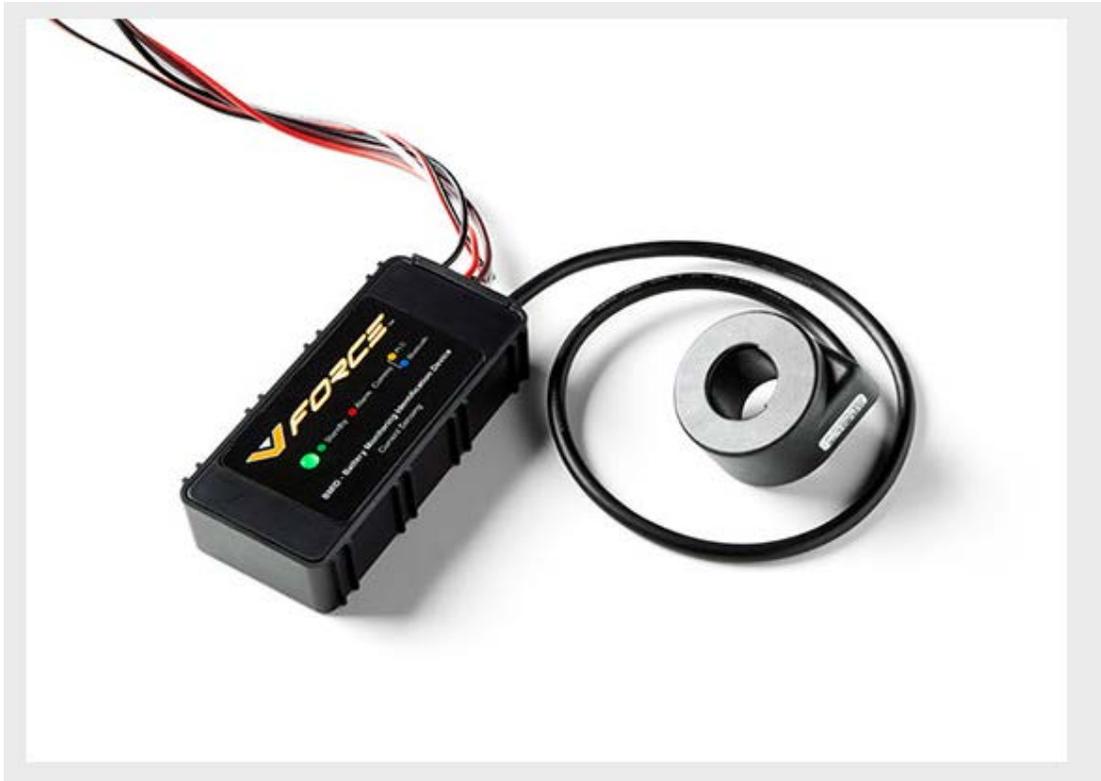
The safe, free and unlimited alternative to Hydrocarbon fuel lies in solar energy generation. Converting sunlight into electricity using photovoltaic materials is the key to eliminating the world's hazardous dependency on hydrocarbons. The photovoltaic solar microgrid integration project was designed to use solar energy to charge batteries used in material handling vehicles. "Photovoltaic installations with batteries are expected to be one of effective systems to cope with energy issues... batteries improve the utilization rate of power supplied from PVs and batteries to on premise loads." (Endo et al., 2018) Installing a rooftop photovoltaic microgrid will replace the municipal utility as the power source battery charging. The microgrid system is comprised of a south facing fixed type rooftop photovoltaic array. The array is used to charge two 48 volt, and one 36 volt direct current (DC) batteries. The research portion of the project establishes the daily battery usage measured in Amp-Hours (Ah). Battery discharge rates are captured and recorded by installing a battery monitoring and identification device (BMID). The BMID recording device was installed on the TSP-7000 and SP-4000 stock trucks ("Crown Equipment," 2019). The BMID device continuously monitors and records battery discharge data during normal production operations. Battery charging rates and charging duration are measured and recorded at the charging station.

### 3.2 Research Methodology

The solar integration project was designed to use a solar photovoltaic microgrid to replace utility supplied electricity in a battery charging application. The batteries in the project are used to power a fleet of material handling vehicles. The vehicles operate in a narrow aisle, high density manufacturing warehouse. The vehicles used in the project are manufactured and serviced by Crown Equipment Corporation, New Bremen Ohio. The specific vehicle models include one Turret Stock Picking vehicle (TSP-7000) and one SP-4000 Series lift truck (SP 4000). The project was designed to capture, record and analyze battery discharge rates. Electrical discharge was measured and recorded in Amperes Hours (Ah) from each battery under normal operating conditions.

The electrical discharge rates captured during the study period were used to provide the requirements for a solar powered photovoltaic microgrid. The electrical discharge data is captured by installing a battery monitoring identification device (BMID) directly to each battery, shown in (Figure 2).

Figure 2 Battery Monitoring Identification Device BMID



*Photo Courtesy of, Crown Equipment (“Crown Equipment,” 2019)*

The batteries used in the project, include two, 48 Volt 1250 Ah. (60 Kilowatt Hour) and one 36 Volt, 750 Ah. (27.0 Kilowatt Hour) units. The battery charging system consists of a centralized charging station where depleted batteries are exchanged for fully charged units. The station was designed to continuously charge batteries when not in use.

The station was equipped with one (Crown Equipment V-HFM) FS3-MP330-3 and two FS5-MP330-4 charge control units (Figure 2). The charge control units receive discharge data from the BMID and output the data via *V-Force* software interface (“V-Force | 24, 36, 48V HFM High Frequency Forklift Chargers | Crown Equipment,” 2019). The charging stations use three phase 480 Volts, 16.1 A at 60 Hertz. The electricity was delivered from regional utility supplier Indiana Electrical Power,(AEP, 2019).

Figure 3 V-HFM Charge Control Units



### FS3

A 46-pound single or three phase charger with a charge current up to 180 amps. The V-HFM FS3 charger can be used for conventional, opportunity or fast applications.



### FS5

A 95-pound three phase charger with a charge current up to 300 amps. The V-HFM FS5 can be used for conventional, opportunity or fast applications.

*Photo Courtesy of, Crown Equipment*(“Crown Equipment,” 2019)

Optimal photovoltaic array size was determined by the charging requirements established during the study period. The results from the study was used to specify the array to charge the single 36 Volt, 750 Ah battery. Successful completion of the 750Ah system will provide proof of concept for a larger array to charge the complete six battery system. The six battery, photovoltaic charging system represents a solar powered microgrid. The photovoltaic powered array was designed to replace environmentally toxic utility supplied electrical power

### 3.3 Data Capturing Timing

The battery charging/discharge rate analysis period begins on Tuesday February 12<sup>th</sup> 2019. The BMID device was installed and calibrated by Crown Field Service Manager (Andy Haluda). Charging data was recorded continuously for the subsequent 30 consecutive days. The electrical performance data was available for analysis on a daily basis via the V-Force software report. Charging data was recorded during normal (2) shift production operations. The first production shift was scheduled from 5:00am to 3:00pm and the second shift was scheduled from 3:00pm to 1:00am. The two shifts operate six days a week, Monday through Saturday. The V-Force software records date/time of charging events, charge duration, temperature of battery and capacity returned in Ah. The daily Ah total was used to determine the electrical demand required to effectively power the fleet of material handling vehicles. The data collected during the analysis period reflects typical stock picking operations during a peak business season. Stock picking operators have received Crown factory training and are certified to GSMW safety protocols.

### 3.4 Data Capture Locations

Electrical charging data was transmitted from the batteries to the FS3 and FS5 charge controls via the BMID communication device. The data was stored on the FS3 and FS5 charge controller units, where it was available for download during the study period. The electrical charging data was downloaded via a Universal Service Bus (USB) cable to a Dell 7000 series laptop computer (Dell Precision, 2019). The charge controllers and station are located on the manufacturing floor at General Stamping & Metalworks, 25101 Cleveland Road, South Bend Indiana. Transmission of data from the FS3 and FS5 controller takes place at the charging station using the Dell 7000 series laptop. The data transfer from the FS3 and FS5 units will take place on Monday February 18<sup>th</sup> and 22<sup>nd</sup>, 2019. Data transfer will be supervised by a certified Crown technician. The two 48 Volt 1250 Ah and one 36 Volt, 750 Ah batteries are labeled for study identification using yellow/black decals. Charge control units are programmed onsite to receive data collected from BMID devices. The batteries and charge control units used in the study are paired, and are used with specified (TSP-7000) and (SP-4000) trucks.

Battery charging data was captured using the BMID units and transmitted to the FS3 and FS5 charge control units. The BMID units were designed to stay on the batteries for future evaluation and historical charging pattern data analysis. The charging data was retrieved from the charge control units by connecting the Dell 7000 series laptop. The V-Force battery maintenance software compiles the data and outputs a detailed report. The data was transferred to a Microsoft Excel spreadsheet and sent to project manager (Matthew Wilfing) at regularly scheduled intervals. The data was categorized by:

1. Date/time of Charging Event
2. Nominal Voltage (Volts)
3. Battery Capacity (Ah)
4. Capacity Returned (Ah)

Amperes per hour discharge rate was converted to Kilowatt Hours using the formula:

$$\text{Watt Hour} = \text{Ampere Hour} * \text{Voltage} \quad (Wh = Ah * V)$$

$$1000 \text{ Watt Hours} = 1 \text{ Kilowatt Hour}$$

$$\text{Example: } 100Ah * 36V = 3600Wh \text{ or } 3.6kWh$$

### 3.5 Data Storage

The Crown Equipment V-Force software generates an electronic report that was sent to the Project Engineer (Matt Wilfing). The report and categorized data was stored on General Stamping & Metalworks network server located at Union Station Data Center, South Bend IN.(Union Station, 2019). The data was available for analysis 24 hours a day 7 days a week via Virtual Private Network (VPN). The weekly V-Force generated report was backed-up onto the Purdue University, office 360 Cloud Drive account for the Project Engineer, Matt Wilfing. Historical battery charging and discharge information was held on GSMW servers in perpetuity for future comparative studies.

### 3.6 Research Instruments

The instruments used in the Solar Integration Project include two, 48 Volt 1250 Ah. (60 Kilowatt Hour) and one 36 Volt, 750 Ah. (27.0 Kilowatt Hour) batteries. The batteries are used to power a TSP-7000 Stock and a SP-4000 Turret Stock Picking vehicles. Statistical data was derived from the run data captured from the each battery used in the study. Statistical analysis was compiled using Microsoft excel(Microsoft, 2019). The three batteries used in the system are designed to provide the electrical energy for ten hours of continuous use. The batteries used in the charging system are lead acid type.

### 3.7 Procedures for Data Gathering

Battery discharge data was collected using the BMID recording device in conjunction with the FS3 and FS5 charge control units. The period of study began for the TSP-7000 began on February 11<sup>th</sup>, 2019 and concluded on March 11<sup>th</sup>, 2019. Electrical discharge information was recorded at the charging station. The data analysis period for the SP-4000 began February 22<sup>nd</sup> 2018 and concluded on February 20<sup>th</sup> 2019. The data collected for analysis are the total Ah returned per charging event. Photovoltaic output ranges are estimated using manufactures supplied data.

### 3.8 System Inputs

The photovoltaic solar microgrid was a fixed rooftop array designed to replace the current central battery charging station. The array was designed to meet the battery charging needs specified in chapter four. The system output was based on the requirements recommended from the Nation Renewable Energy Laboratory, PV Watts's calculations(NREL, 2019). The battery requirement in this project was two: 48 Volt 1250 Ah. (60 Kilowatt Hour) and one 36 Volt, 750 Ah. (27.0 Kilowatt Hour) batteries. The estimated electrical load was based on the electrical power formula  $kWh = Ah \times (Voltage \div 1000 \text{ Watts})$  Example:  $60 \text{ kWh} = 1250Ah \times (48Volts \div 1000Watts)$

### 3.9 Summary

The goal of the solar integration data collect plan was to accurately determine the electrical demand of the battery charging system. The project used electrical discharge data recorded during normal production operations to determine the total electrical demand of the material handling vehicles. The electrical demand (measured in Ah) during the study was used to specify the requirements of the proposed photovoltaic array. Electrical charge and discharge rates were captured by installing an electric monitoring device (BMID) directly onto the batteries used in the study. The BMID device were used with the charge controllers to precisely measure the electrical demand used by the material handling vehicles. The data was compiled and transferred into Crown Equipment's V-Force software where it was analyzed by category. The total electrical demand measured during the data capture period established the requirements of the photovoltaic microgrid. The goal of the microgrid project was to provide an infinitely renewable alternative to utility supplied electricity. Replacing utility supplied electrical power with the photovoltaic microgrid reduces the toxic byproducts produced by fossil fuel generated electricity. The photovoltaic microgrid project was one step in the process to achieve a net-zero manufacturing operation. The economic advantage of operating net-zero operation was energy cost control and reliability.

## CHAPTER 4. RESULTS

### 4.1 Introduction

The use of hydrocarbon based fuel to generate electricity has long term detrimental impacts on the planet. Reducing toxic byproducts generated during the combustion process requires a viable renewable energy alternative. The aim of the solar microgrid project was to replace utility electrical power for battery charging applications at General Stamping & Metalworks. The photovoltaic microgrid project was designed to record the electrical discharge rates used by the TSP-7000 and SP-4000 material handling vehicles. Battery monitoring devices (BMID's) were installed to record the battery capacity returned during each charging event. Charging events represent normal intermittent battery charging activity. The objective of the study was to define the size of the photovoltaic array by tracking battery discharge rates. The rate of electrical demand was determined by the capacity returned to each battery during the study period. The electrical discharge output was based on amperes hours (Ah) returned to the batteries during the study. The data collection results were the recorded charging events, duration of charge time and ampere hours returned to the batteries.

### 4.2 TSP-7000 Charging Data

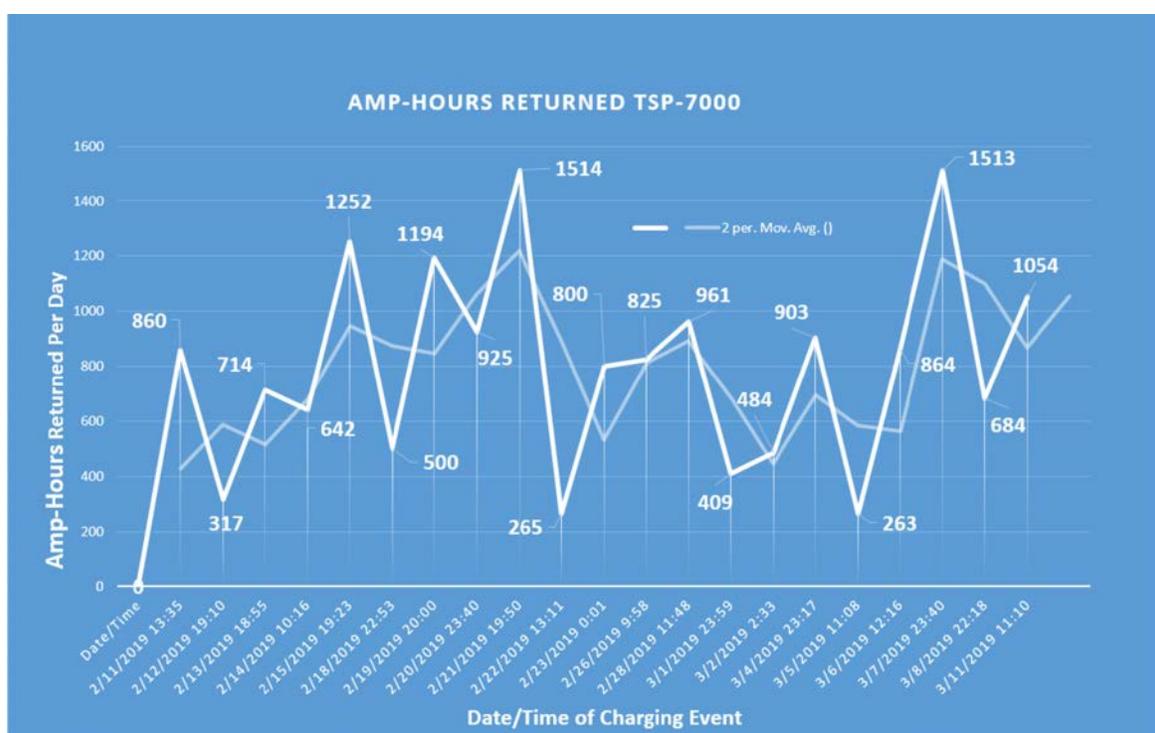
Charging data collected for TSP-7000 was recorded using the BMID and FS5 charge control units. The period used for analysis began on February 11<sup>th</sup> 2019 and concluded on March 11<sup>th</sup> 2019. The charging data was tabulated and exported into a Microsoft Excel spreadsheet using the V-Force suite of software. Voltage and battery capacity were held constant while charging time and capacity returned were the variables tracked. Amp-Hours returned during each charging event was recorded by the FS5 charge controller. Converting Ah to Kilowatt-Hours (kWh), used the formula:  $kWh = (\text{Voltage} \times \text{Amp-Hours}) \div 1000$ . The Turret Stock Picking vehicle was a high daily use vehicle. Standard weekly shifts operate from 5:00am to 3:30pm and 3:30pm to 2:00am Monday thru Friday. Weekend shifts operate from 5:00am to 1:30pm and from 1:30pm to 10:00pm. Charging opportunities are available during each shifts 30 minute break periods. Battery discharge data for the TSP-7000 is presented in Table 1.0.

Table 1 Battery Discharge Data TSP-7000

<i>Date/Time</i>	<i>Nominal Voltage (Volts)</i>	<i>Max. Battery Capacity Amp.Hours</i>	<i>Charge Time (Hrs/Min/Sec)</i>	<i>Capacity Returned (Ah)</i>	<i>Capacity Returned (kWh)</i>
3/12/2019 14:53	48	1250	5:21:45	705	33.8
3/11/2019 11:10	48	1250	11:44:55	1054	50.6
3/8/2019 22:18	48	1250	5:02:37	684	32.8
3/7/2019 23:40	48	1250	5:50:21	829	39.8
3/7/2019 8:54	48	1250	5:40:41	793	38.1
3/6/2019 12:16	48	1250	6:30:04	864	41.5
3/5/2019 11:08	48	1250	2:51:23	263	12.6
3/5/2019 2:23	48	1250	2:59:29	598	28.7
3/4/2019 23:17	48	1250	0:13:56	42	2.0
3/4/2019 23:03	48	1250	2:37:25	524	25.2
3/4/2019 20:26	48	1250	9:22:38	522	25.1
3/2/2019 2:33	48	1250	2:25:32	484	23.2
3/1/2019 23:59	48	1250	6:10:24	409	19.6
2/28/2019 11:48	48	1250	2:45:53	552	26.5
2/28/2019 9:02	48	1250	4:26:59	316	15.2
2/26/2019 9:58	48	1250	2:32:59	509	24.4
2/26/2019 7:25	48	1250	11:12:30	903	43.3
2/23/2019 0:01	48	1250	5:36:05	800	38.4
2/22/2019 13:11	48	1250	2:54:21	265	12.7
2/21/2019 19:50	48	1250	2:15:02	449	21.6
2/21/2019 17:31	48	1250	2:39:34	240	11.5
2/21/2019 1:50	48	1250	2:04:01	413	19.8
2/20/2019 23:40	48	1250	2:58:49	272	13.1
2/20/2019 14:30	48	1250	2:28:58	496	23.8
2/20/2019 12:01	48	1250	2:54:38	256	12.3
2/19/2019 20:00	48	1250	2:12:49	442	21.2
2/19/2019 17:40	48	1250	5:38:04	833	40.0
2/19/2019 6:08	48	1250	3:24:12	306	14.7
2/19/2019 1:25	48	1250	2:32:22	507	24.3
2/18/2019 22:53	48	1250	9:15:53	500	24.0
2/15/2019 19:23	48	1250	1:13:42	245	11.8
2/15/2019 18:02	48	1250	5:20:14	748	35.9
2/15/2019 8:23	48	1250	3:08:26	279	13.4
2/14/2019 10:16	48	1250	1:49:09	363	17.4
2/14/2019 8:27	48	1250	2:51:06	258	12.4
2/13/2019 18:55	48	1250	2:16:58	456	21.9
2/13/2019 16:38	48	1250	0:25:20	25	1.2
2/12/2019 19:10	48	1250	0:34:23	34	1.6
2/12/2019 15:36	48	1250	0:14:54	18	0.9
2/12/2019 14:43	48	1250	2:48:39	294	14.1
2/11/2019 13:35	48	1250	2:35:41	566	27.2
2/11/2019 10:59	48	1250	2:37:26	275	13.2

The data captured in (Table 1) illustrates typical charging duration and electrical capacity returned per charging event for the TSP-7000. The tabular charging data was used to graph and plot each charging events shown in Figure 4. Date, time, charging duration and capacity returned are plotted to create a rolling average for returned electrical capacity. The rolling average is plotted along the actual capacity returned during charging activity. The TSP-7000 was equipped with a battery power level display that indicates when charging was recommended. The average charging duration during the study period was three hours and 18 minutes, while the average capacity returned per day was 806.8 Ah or, 38.5 kWh.

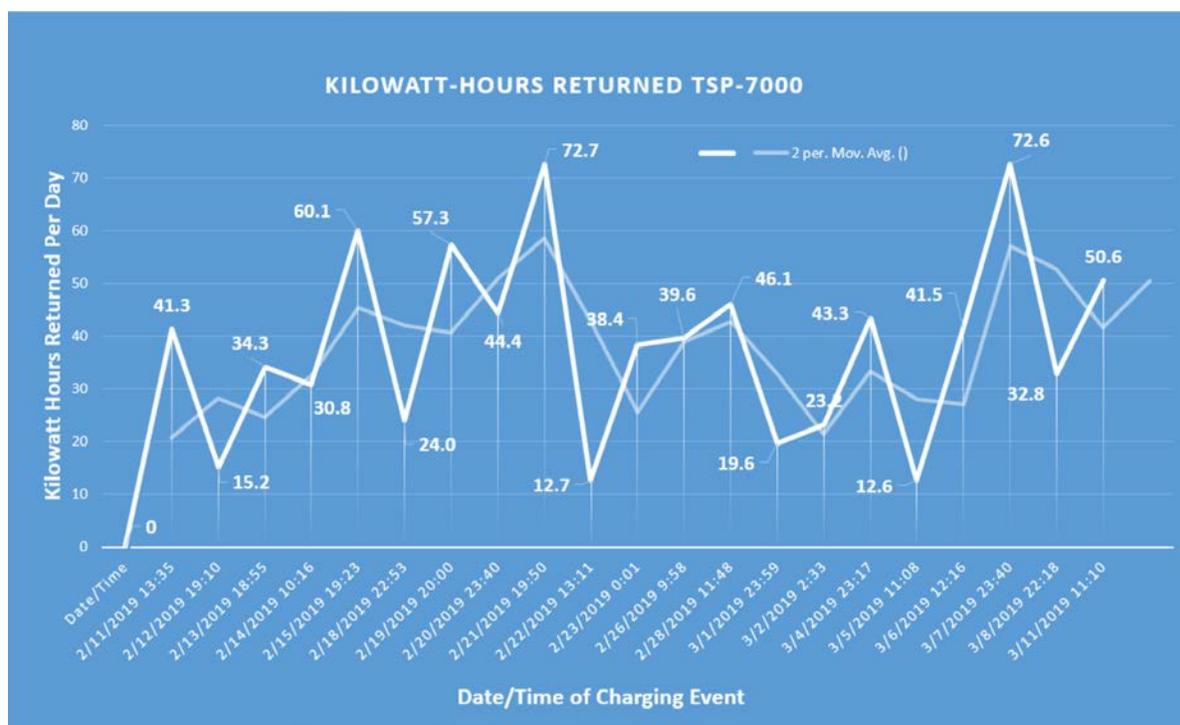
Figure 4 Capacity returned per charging event for the TSP-7000 Amp-Hours



The average daily hours of effective sunlight for PV electric generation hours for South Bend Indiana, (Latitude: 41.73, Longitude: -86.34) range was 3.8 to 4.1 hours per day (“Solar Maps Geospatial Data Science NREL,” 2019). The solar range used to define array power in this project was 4.0 hours per day. Figure 5, graphs the average daily kWh returned during the study period. The graph shows the typical daily charging pattern and kWh returned to the battery system during the study period. Charging times reflect the charging events taking place on both day and night shifts. Feedback from the first shift operator Damian Harmon was that battery life

under normal working conditions was approximately 10 hours (Harmon, 2019). Damian expressed that battery life was affected by operator workload and level of aggressive driving. Operators on the first shift experienced higher Ah battery draw due to higher volume production levels. He described that speed, both rate of lift and travel, greatly effect battery life. Conservative driving habits expanded the period between required charging.

Figure 5 Capacity returned per charging event for TSP-7000 Kilowatt Hours

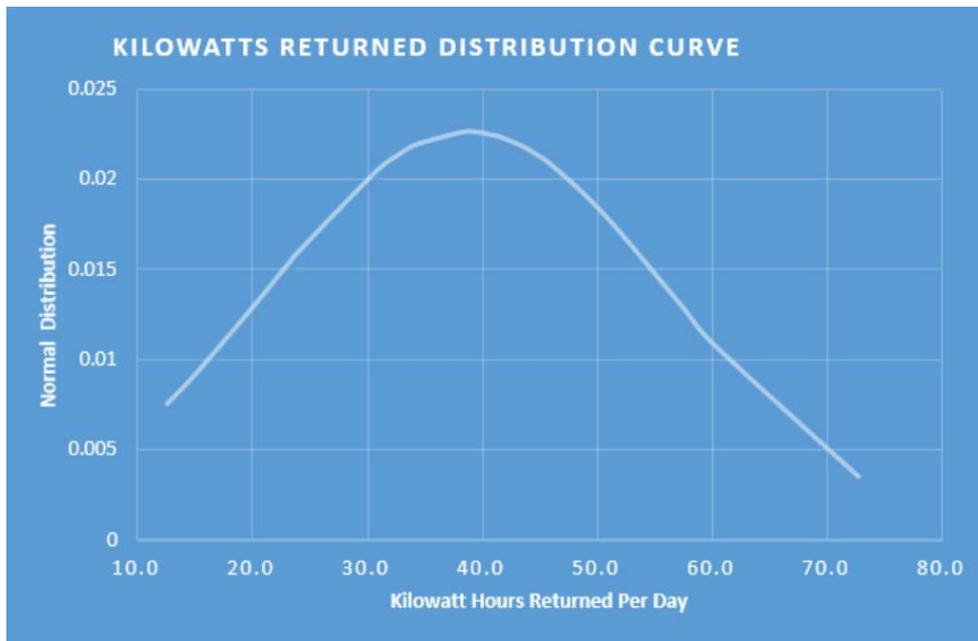


The mean kilowatts hours returned per day during the study period was 38.7 kWh. The mean was then divided by the number of hours of sunlight per day to provide an average daily kWh rate. Based on the data collected during the study period, a 15 kWh installation meets the full charging requirements of the system. Shown in Figure 6, is the normal distribution plot of the kilowatts returned during the study period. Using Panasonic Corporation VBHN325SJ47,325 Watt Solar Modules (Panasonic Corporation, 2019). The system will require 46 modules to meet charging requirements for the TSP-7000. The calculation used to determine the number of modules:

$$\begin{aligned} \text{Maximum kWh} &= 60 \text{ (Full Battery)} \\ (1250 \text{ Ah} \times 48 \text{ V}) &= 60,000 \text{ Watts, or } 60 \text{ kW.} \end{aligned}$$

The 60 kW was then divided by the hours of solar activity in South Bend IN. ( $60 \text{ kW} \div 4 \text{ Hours of Sunlight} = 15 \text{ kW}$  installation (W. Hutzler, personal communication, March 26, 2019). Shown in Figure 6 is the distribution curve for the kilowatts returned per day during the study period. The graph describes how the kWh returned was closely distributed about the mean of 38.7 kWh returned per day.

Figure 6 Kilowatt Distribution Curve TSP-7000



Based on output power of the solar modules, a 15 kW array will return 60 kWh to the system per day. The 15 kW installation meets 82.5% of all charging event requirements. Since the battery charging system was a paired system, the likely hood of depleting both batteries was minimal. The kWh returned was balanced between two batteries, allowing one battery to be in a constant charging state.

#### 4.3 SP-4000 Charging Data

The SP-4000 was a specialized stock picking vehicle used in kitting operations at General Stamping & Metalworks Inc. The SP-4000 was used infrequently in comparison to the TSP-7000. When compared, the SP-4000 used only 2% of the average daily Ah used by the TSP-7000.

Table 2 details the charging data collected for the SP-4000 Stock Picker. The data capture period began on February 22nd, 2018 and recorded charging activity through February 20<sup>th</sup> 2019.

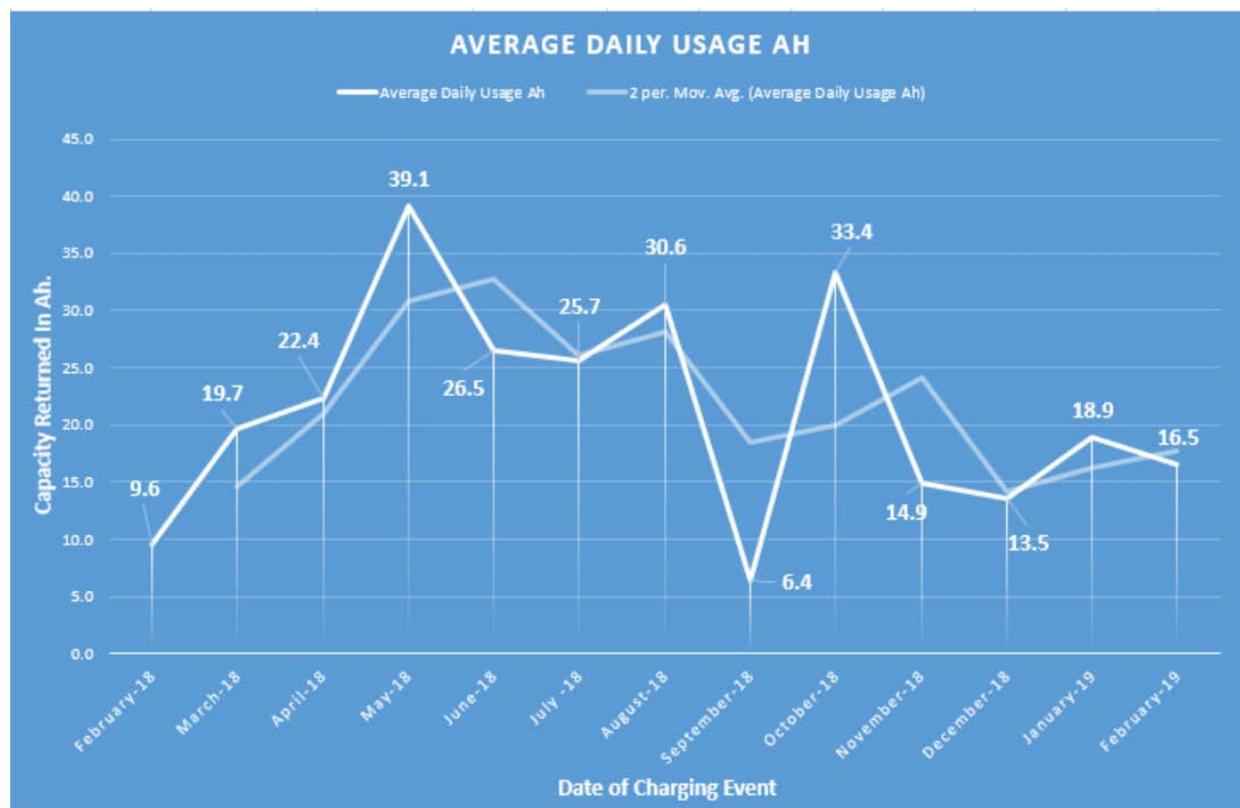
Table 2 Battery Discharge Data SP-4000

<i>Date/Time</i>	<i>Nominal Voltage</i>	<i>Capacity (Ah)</i>	<i>Charge Time (Days/Hrs/Min/Sec)</i>	<i>Capacity Returned (Ah)</i>	<i>Capacity Returned (kWh)</i>
2/22/2018 11:42	36	750	3:37:39	269	9.68
3/9/2018 10:44	36	750	3:22:20	236	8.50
3/26/2018 8:38	36	750	4:10:16	375	13.50
4/11/2018 12:08	36	750	0:19:06	57	2.05
4/12/2018 5:57	36	750	3:42:33	306	11.02
4/13/2018 14:21	36	750	1:07:24	66	2.38
4/22/2018 11:28	36	750	2:06:30	128	4.61
4/26/2018 12:45	36	750	1:44:16	112	4.03
5/2/2018 5:06	36	750	1:50:52	119	4.28
5/16/2018 8:43	36	750	14:23:40	623	22.43
5/21/2018 12:20	36	750	1:45:49	101	3.64
5/22/2018 1:58	36	750	2:02:47	367	13.21
6/4/2018 9:17	36	750	1:46:15	148	5.33
6/5/2018 0:52	36	750	2:16:45	121	4.36
6/13/2018 10:03	36	750	0:09:21	27	0.97
6/19/2018 12:07	36	750	2:08:32:38	217	7.81
6/30/2018 8:05	36	750	4:10:15	278	10.01
7/11/2018 5:01	36	750	8:58:47	397	14.29
7/28/2018 1:08	36	750	4:03:28	259	9.32
8/14/2018 5:04	36	750	2:05:48:20	202	7.26
8/23/2018 11:17	36	750	16:11:09	746	26.86
9/4/2018 8:33	36	750	2:02:49:36	198	7.12
10/3/2018 4:58	36	750	6:05:31	404	14.54
10/25/2018 12:55	36	750	3:22:57	202	7.27
10/31/2018 8:16	36	750	10:36:07	428	15.41
11/14/2018 9:23	36	750	3:39:51	221	7.96
11/29/2018 7:57	36	750	2:23:13	144	5.18
11/30/2018 7:56	36	750	1:23:13	83	2.99
12/8/2018 6:00	36	750	1:07:34:36	114	4.11
12/13/2018 7:59	36	750	2:55:07	169	6.08
12/19/2018 8:34	36	750	2:17:22	131	4.72
1/2/2019 6:04	36	750	9:06:10	384	13.82
1/16/2019 23:27	36	750	3:30:37	201	7.24
2/8/2019 5:50	36	750	3:52:18	223	8.03
2/13/2019 7:34	36	750	1:47:57	65	2.34
2/18/2019 11:14	36	750	0:30:44	47	1.69
2/20/2019 23:31	36	750	2:57:30	126	4.54

The extended data study period was due to the low frequency of use compared to the TSP-7000

The data recorded for the SP-4000 Stock Picker during the study period is shown in Figure 7. The capacity returned was recorded in Amp-Hours and a rolling average was plotted along the actual usage. The graph represent the average capacity returned per month during the study period.

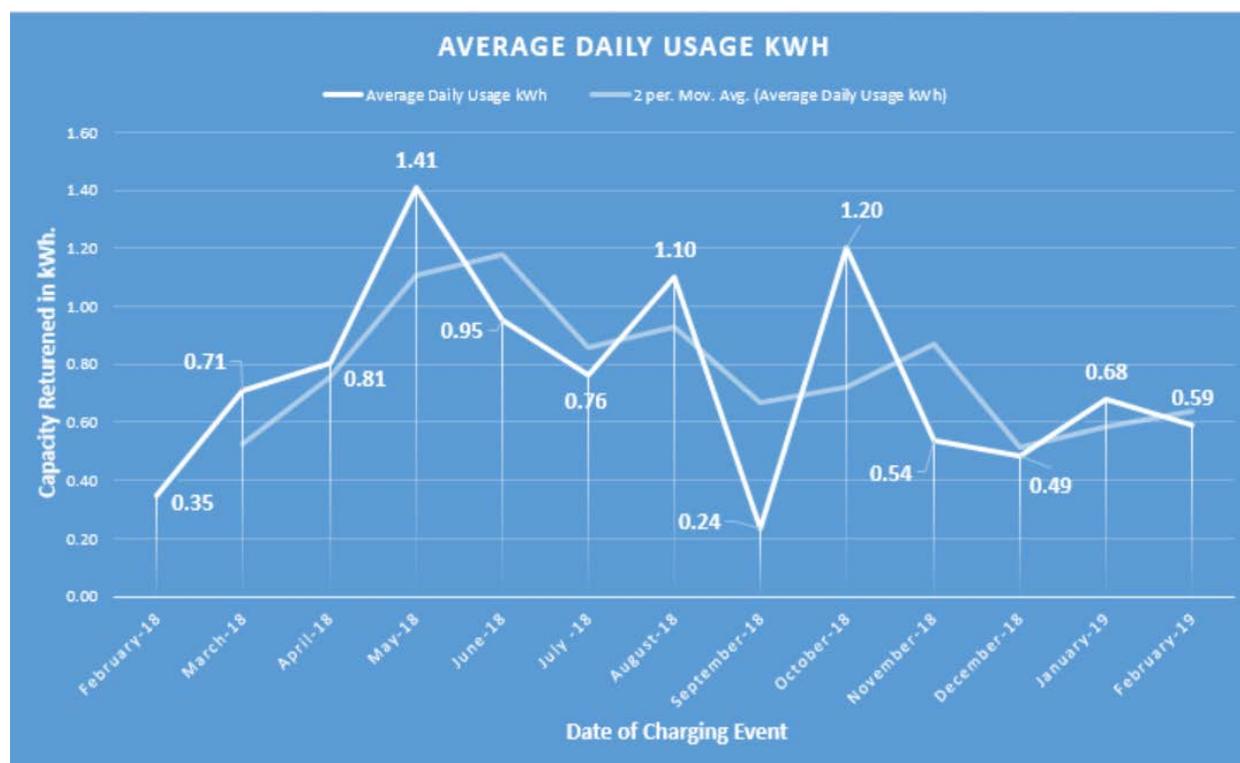
Figure 7 Capacity returned per charging event for SP-4000 Amp-Hours



The result of the study period showed the average monthly usage of 21.3 Amp-Hours, or .76 kWh. The study took the total Ah used during each month and divided it by the number of days per month. The graph illustrates the periods of low activity, compared to the TSP-7000. Although both vehicles operate within the same warehouse their capacity and Ah draw present drastically different charging profiles. Based on the charging data recorded during the study period, it was determined that a 1.3 kW system would meet 92% of the daily charging needs. The max draw used during the study period was 27 kWh used on August 23<sup>rd</sup> 2018, however the total monthly kWh usage for August 2018, was 34.1kWh. When averaged over the 31 days, daily usage was 1.10 kWh, easily met by and 1.3 kWh system.

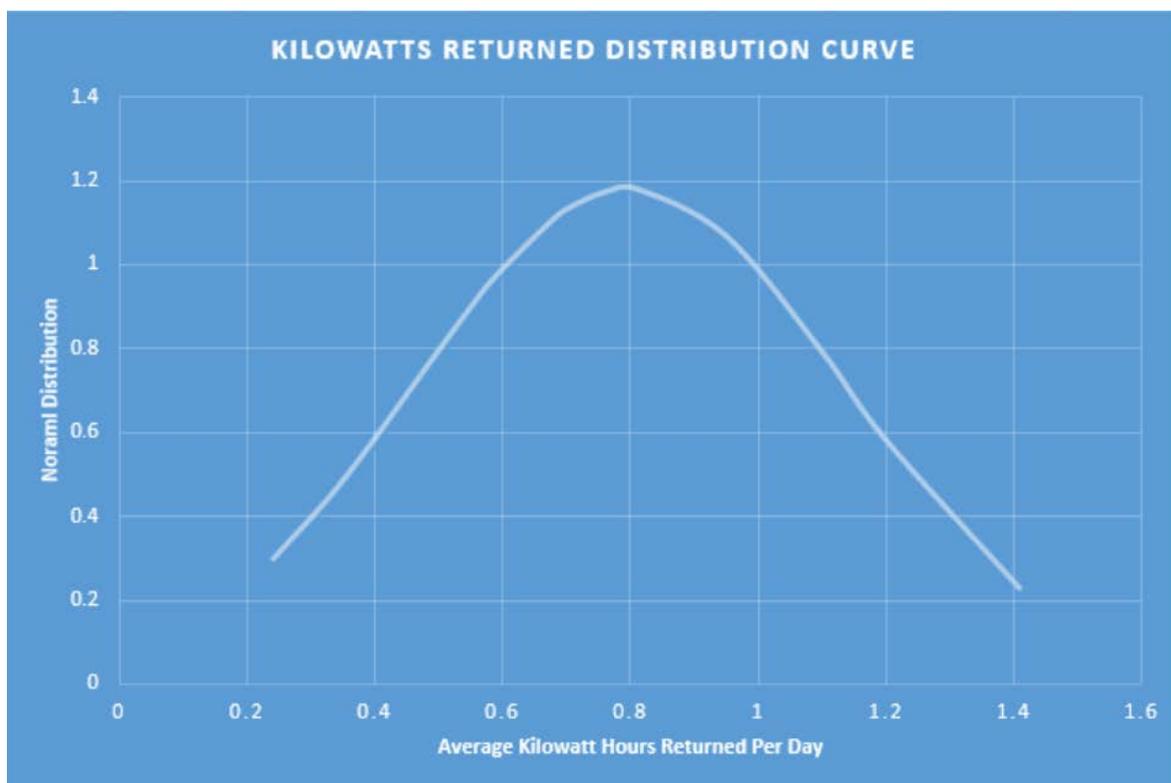
Shown in Figure 8, is the recoded data plotted using the average monthly kWh returned. The monthly kWh average was used to determine the size of the recommended photovoltaic array. The same formula used to determine the array for the TSP-7000 was used to size the installation for the SP-4000. Figure 8 illustrates the monthly charging profile of the SP-4000 using kWh during the study period.

Figure 8 Average KWh returned per Month SP-4000 Kilowatt-Hours



The distribution of the charging data is shown in Figure 9. The data is plotted along a curve to illustrate the distribution of the charging data. The result shows the data was evenly distributed about mean of .76 kWh used per day. The daily input of 1.3 kWh each day accumulates to replenish the maximum capacity of the battery used in the system. The maximum capacity for the 750 Ah battery was 27 kWh. The proposed system returns 1.3kWh per day or, 39 kWh per month. The maximum kWh used per month in the study period was May of 2018, where 43.6 kWh was used. Based on the study period a single 325 Watt solar module will meet 100% of the charging events for the SP-4000.

Figure 9 Kilowatt Distribution Curve SP-4000



The distribution curve shown in Figure 9 illustrates the magnitude and range of charging requirements for the SP-4000. The distribution curve also shows a 1.3 kWh installation will meet the charging demand during the one year study period.

#### 4.4 Summary

Based on the results derived from the data analysis, the TSP-7000 requires a 15 kW installation to meet its charging requirements. The recommended system includes 46 Panasonic 325 Watt Solar Modules. The SP-4000 Stock Picking truck, requires a 1.3 kW installation to meet its charging requirements. The recommended system to achieve the demand was a single Panasonic 325 Watt Solar module. Based on the combined demand from both systems, a (48) 325 Watt Solar Module system meets the charging requirements for both vehicles.

## **CHAPTER 5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS**

### **5.1 Summary**

Photovoltaic (PV) powered microgrids represent a feasible and cost effective method for generating electricity. Electrical storage systems (ESS) are the critical design feature that allows PV systems to operate 24 hours a day. The benefit of implementing an energy storage system is that “energy storage systems can adjust for power fluctuations, and reduce system disturbances brought by environmental factors and keep voltage stable and improve the power quality of PV system” (Wang & Jiancheng, 2016 p.1). Chapter four provides the evidence that a PV battery charging system was electrically and economically feasible in the defined environment. Based on the data provided in chapter four, a 15 Kilowatt photovoltaic system will meet the battery charging needs of the TSP-7000 Turret Stock Picker. The SP-4000 Stock Picker required a 1.3-Kilowatt photovoltaic installation to meet its battery charging requirements. The specified system size was based on the data captured during the study period listed in chapter four.

### **5.2 Charging Requirements**

Based on the data collected during the study period outlined in Chapter Four, the average daily consumption for the TSP-7000 was 807 Amp-Hours, or 38.7 Kilowatt-Hours. To meet this charging requirement, a 15 Kilowatt system was recommended. The 15 kW system was design to return 60 kWh, or 1250 Ah per day back to the battery system. The 60 kWh was distributed between two batteries in order to maximize charging opportunities. The average daily consumption for the SP-4000 was 21.3 Amp-Hours, or .76 Kilowatt-Hours. The recommended photovoltaic installation size to meet the electrical demand for the SP-4000 was 1.3 kW. The single module .325 kW photovoltaic installation was designed to return 1.3 kWh or 38.8 Ah per day to battery system. Due to extended periods of inactivity the 1.3 kW system accumulates surplus Ah when the system was not being used. The system returns 38.8 Ah per day and the when the systems is not in use, the surplus is stored in the 750 Ah battery. The Energy Storage System (ESS) allows the battery system to store more energy than is needed for daily operations.

### 5.3 Impact of Photovoltaic Installation

The goal of reducing toxic hydrocarbon emissions was achieved by leveraging renewable energy to charge the battery system. Using the *Greenhouse Gases Equivalencies Calculator* provided by the United State Environmental Protection Agency (EPA), “The national average carbon dioxide output rate for electricity generated in 2017 was 998.4 lbs. CO<sub>2</sub> per megawatt-hour, which translates to about 1,074.7 lbs. CO<sub>2</sub> per megawatt-hour for delivered electricity, assuming transmission and distribution losses of 7.1%”(US EPA, 2015). Annual kWh consumption was multiplied by the carbon dioxide emission rate (per unit of electricity delivered) to determine annual carbon dioxide emissions per vehicle system. Listed below are the calculations used to determine the amount of CO<sub>2</sub> removed from the atmosphere by installing each PV system.

TSP-7000 = 15kW Installation = 60 kWh per day x 365 days per year = 21,900 kWh per year removed from the electrical grid.

- 21,900 kWh x 998.4 lbs. CO<sub>2</sub> per megawatt-hour generated x 1/ (1-0.071) MWh delivered/MWh generated x 1 MWh/1,000 kWh x 1 metric ton/2,201.6lb =10.68 Metric Tons of CO<sub>2</sub>.

SP-4000 =.325 kW Installation = 1.4 kWh per day x 365 days per year =511 kWh per year removed from the electrical grid.

- 511 kWh x 998.4 lbs. CO<sub>2</sub> per megawatt-hour generated x 1/ (1-0.071) MWh delivered/MWh generated x 1 MWh/1,000 kWh x 1 metric ton/2,201.6lb =.25 Metric Tons of CO<sub>2</sub>.

Installing the 15 kW photovoltaic eliminates over 10 metric tons of CO<sub>2</sub> emission per year. While the .350 kW installation for the SP-4000 eliminates a ¼ Metric Ton of CO<sub>2</sub> per year. When combined, the photovoltaic microgrid project contributes to the reduction of greenhouse gases directly linked to global climate change. The microgrid project makes solar energy less expensive in the broad market by providing small practical applications of solar technology.

#### 5.4 Photovoltaic Installation Cost

The recommended solution to meet the charging requirements listed in chapter four was a fixed type rooftop mounted photovoltaic array. The SP-4000 required a single 325 Watt, south facing installation. The optimal pitch angle of the single 325 Watt panel, according to Professor William Hutzal, is roughly equal to the sites latitude (Hutzal, 2018). For General Stamping & Metalworks, the latitude was equal to 41.73 degrees. The photovoltaic solar modules (panels) used for the energy calculations were Panasonic Corporation VBHN325SJ47 325 Watt Solar Modules. Specifications include a maximum power rating 325 Watts with linear power output rated at 97% during first year. (Measurement Tolerance +/-3%).

The average national price for small scale industrial solar installations was \$3.05 per Watt (“EnergySage,” 2019). However working with Inovateus Solar, a Niles, Michigan based solar installation firm, the cost per kW for local installation was quoted at \$2.65 per Watt (Callender, 2019). General Stamping and Metalworks has a working relationship as a parts supplier for Inovateus Solar, so the \$2.65 discounted rate was used. The cost of installation was calculated using: price per Watt (\$2.65) x number of Watts (325) = \$861.25. Using the 30 % Federal Energy Tax Credit (ITC) brings the installation cost to \$602.88 (“(ITC) Department of Energy,” 2019). The utility electric cost per kilowatt-hour for General Stamping & Metalworks was 0.095 \$/kWh (*Billing Statement March*, 2019). The proposed system therefore returns an estimated 475 kWh per year for a cost savings of \$45.00 per year.

SP-4000 Installation: Single 325 Watt Panasonic solar module:

- Total cost of installation (\$2.65 per watt x 325 watts)=\$861.25 subtracting the 30% ITC tax credit =\$602.88 installation cost
- Electrical Production (.325 kW x 4 hours daylight x 365 days a year)=475 kWh (475 kWh x .095 cost per kWh)= \$45 per year
- Payback period: initial costs/annual return on investment. \$602.88 installation cost /\$45 per year = payback period of 13.38 years

TSP-7000 Installation: 15 kW 46 individual 325 Watt Panasonic solar modules:

- Total cost of installation: ( $\$2.65$  per watt x 15000 Watts)=\$39,750 subtracting the 30% ITC tax credit =\$27,852 installation cost
- Electrical Production: (15 kW x 4 hours daylight x 365 days a year) =21,900 kWh  
(21,900 kWh x .095 cost per kWh) = \$2,080.50 per year
- Payback period: initial costs/annual return on investment.  $\$27,825$  costs /\$2,080. per year return = payback period of 13.37 years

The payback period for both TSP-7000 and SP-4000 of 13.3 years was typical of the size and type of PV installation. When system reliability and environment impacts are taken into account, the solar micro grid installation was a cost effective application of solar technology. As PV technology develops, the ratio of cost to power output will increase, making solar installations more attractive to small scale users. The simple payback period calculation was used to clearly illustrate the installation costs and expected yearly return. Sophisticated and complex models are used in the solar industry to express best case scenarios and speculate on future costs. The inputs used to calculate the payback period gave a clear unambiguous picture of first costs and expected annual returns.

The changing economic forces that make hydrocarbon based fuels relatively inexpensive in the 2019 energy market can change rapidly. As climate and environmental changes continue to impact larger communities, legislation will likely make hydrocarbon fuels more expensive. Tariffs, restrictive emission standards and carbon taxes continue to make renewable energy sources like photovoltaics more attractive. “Rooftop solar installations can provide long-term economic and environmental benefits for building owners, and future tax breaks, technological advances in solar panels, and caps on carbon production may further increase the return on investment (ROI) for renewable energy sources” (Gellert, 2019). Based on the manufacturer’s warranty, the lifespan of the photovoltaic installation was estimated at 25 years. After the simple payback period of ~13.5 years, the net cost savings for the TSP-7000 was \$2,080.5 per year. At 11.5 years, the installation yields a total return on invest of \$23,925.75. The total return on investment for the SP-4000 after the 25 year warranty period was \$517.50. The price of electricity per kWh was expected to increase, reducing the simple payback period and increasing the total return on investment.

### 5.5 Project Goal

The goal of the photovoltaic installation project was to provide an alternative energy generation system free from environmentally toxic byproducts. Electrical generation in the United States and leading industrialized nations use hydrocarbon combustion for fuel. The environmental impacts of hydrocarbon combustion have long term detrimental effects on life across the planet. Photovoltaic microgrids represent an environmentally neutral alternative to hydrocarbon fuels. Microgrids reduce harmful emission by providing clean infinitely renewable source of electrical energy. Microgrids reduce toxic emissions by eliminating the reliance on utility scale electricity generation. The results from the data analysis period support the proposal that battery charging functions can be accomplished economically using PV installations. The rooftop PV installation represents a measureable step in achieving an energy neutral manufacturing facility.

### 5.6 Interpretations of Findings

Photovoltaic array systems are optimized by integrating effective energy storage systems. The ability to capture and store electrical energy produced during high solar activity was critical to successful photovoltaic installations. The ability to access stored electrical energy during low solar activity (nights) and heavy cloud cover was essential for production operations. Battery powered PV systems are designed to store unused electrical capacity in order to increase system reliability and protect emergency systems.

“Integrating Energy Storage Systems (ESS) with PV units can assure that the uncertainty of the generation is minimized or eliminated, and the addition of ESS allows the intermittent PV generation to provide supply and demand balance despite the varying nature of the sun irradiation and the load demand. The integration of ESS with rooftop PV units will also provide value added benefits by being able to reduce energy costs, improving power quality and increasing reliability” (Ariyaratna, Muttaqi, & Sutanto, 2017 p.1).

The battery storage system proposed in the PV integration project represents an ideal candidate for a renewable photovoltaic application. Solar applications are especially well suited to applications where energy generated during solar production can be stored and accessed when needed. By replacing the utility power with a solar photovoltaic array, the battery charging system eliminates over 10 metric tons of CO<sub>2</sub> per year. Electrical stability is increased within the organization and dependence on regional utilities is reduced. Installing a PV array to charge vehicle batteries represented a first step to achieving an energy neutral manufacturing facility. The end result of the photovoltaic analysis however, was that the proposed installation does not meet the organizations return on investment criteria. The return on investment and internal rate of return (IRR) exceeded the organizations threshold for authorization for expenditure. Chief Executive Officer John Ryal performed a comprehensive financial analysis using the results from section 5.4. Based on the financial analysis his decision was to not move forward with the project.

“Our standard ROI expectation, or Hurdle Rate, is 20%, pre-tax. With an assumed tax rate of 34%, this translates to an after-tax hurdle rate of 13.4%. The negative Net Present Value (“NPV”) indicates that the cash flows of the project do not meet the hurdle rate of 13.4%. Because the Internal Rate of Return was 5.5%, we would not go forward with such a project, but instead would try to allocate our capital to projects, or investments, expected to yield an acceptable return to our shareholder.”(Ryal, 2019).

The main issue preventing the adoption of the project was the low cost of utility produced electricity. PV installations are more financially viable in high priced energy markets when the price per kWh exceeds .15 \$/kWh. Example markets are California (.15\$/kWh), New England (.17\$/kWh) and Hawaii (.33\$/ kWh) (“EIA - Electricity Data,” 2019). Each the markets listed have drastically reduced payback periods when compared to Midwestern States.

## **5.7 Organizational Commitment to Renewable Energy**

The solar microgrid installation supports the organizations mission of protecting customer’s brands by providing a reliable supply chain partner. Energy storage systems that utilize battery systems, provide power for critical emergency systems. ESS provide low voltage power for data sensitive equipment and allows the organization to power vital climate control

and communication equipment. General Stamping & Metalworks is an environmentally conscience manufacturing organization that supports renewable energy applications within its manufacturing facility. The organization is a proud solar industry partner and supports the growing renewable energy generation sector. General Stamping & Metalworks is a primary supplier of fabricated steel component for solar tracking systems. The growth of the organization correlates directly with the growing solar market. Sales growth within the organization is expected to climb along with the solar industry.

“By 2023, roughly 30% of non-residential PV will come from community solar, and ~20% will come from solar-plus-storage projects. By 2020, 28 states in the U.S. are expected to have 100+ MWdc annual solar markets, with 25 of those states being home to more than 1 GWdc of operating solar PV. This compares to only two states with 100+ MWdc annual solar markets in 2010”... Wood Mackenzie forecasts 14% growth in 2019 compared to 2018, with over 12 GW of installations expected. Total installed U.S. PV capacity will more than double over the next five years, with annual installations reaching 15.8 GWdc in 2021 prior to the expiration of the residential federal Investment Tax Credit (ITC) and a drop in the commercial tax credit to 10% for projects not yet under construction” (Wood Mackenzie, 2019).Ail

Future applications of renewable energy technologies within the facility were discussed with the President and Chief Executive Officer John Axelberg. Specifically, Mr. Axelberg highlighted the merits of converting the entire fleet of material handling fork trucks from propane to battery power. Additional installations discussed were external charging applications for electric passenger vehicles and lighting applications (Axelberg, 2018). General Stamping & Metalworks supports and encourages the use of all economically viable sources of renewable energy. The organization is committed to reducing its environmental impact while increasing the reliability of its equipment and manufacturing systems. Photovoltaic power battery storage systems support both environmental and manufacturing goals. “In our region, we can do more for the adoption of renewable energy in the U.S. by producing components for tracking systems, with cheap nuclear based power and deploying them into regions of the county that have a lot of sun and expensive energy....We pursued the solar industry (as a customer) because we believe in

long term viability and understand the necessity of carbon free power generation”(Axelberg, 2019). Solar photovoltaic installations represent the carbon free fuel source capable of providing wide scale electrical production.

## 5.8 Recommendations

The ultimate goal of the solar installation project to bring an end to environmentally destructive energy generation processes. The health and well-being of future generations requires environmentally sound energy solutions. As global energy demand continues to grow infinitely renewable energy generation sources become the only viable solution. Without renewable alternative energy generating solutions, future generation will suffer the devastating effects of climate change. The detrimental impacts of hydrocarbon combustion impacts not only air quality, but can produce scarcity and starvation through weather pattern disruptions. The global effects of climate change also impacts mass migrations, economy collapse and war. Nations rely on weather sensitive agriculture to feed its people, and climate change has devastating effects on crop growth and yield.

## 5.9 Moving Forward

The solution to pressing environmental decay is investing in clean renewable energy sources that incorporate solar capture technology. Photovoltaic and solar capture technology represents the best singular source of fuel for the future. The sun is the one infinitely renewable resource capable of meeting mankind’s energy needs. The research in this report makes clear that photovoltaic technology has the potential to revolutionize how energy is generated, distributed and stored. The research conducted in the report clarifies the need and the ability to aggressively develop economically viable PV technology. The consequences of inaction will lead to global instability and war. Successful applications of renewable energy generation provides the environmental and economic justification needed to expand the cost effective solar installations. The answer to environmental degradation is to support renewable technology as a national energy policy and to seek new energy neutral systems.

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