DEVELOPING A PROTOTYPE OF A SMART-LIGHTING SYSTEM FOR ISOLATED RURAL INTERSECTIONS

FINAL PROJECT REPORT

by

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CSET
rural • isolated • tribal • indigenous

DISCLAIMER

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16. Abstract

Rural intersections are high-risk locations for road users. Particularly, during the nighttime, lower traffic volumes make it difficult for drivers to discern an intersection despite traffic signs. The lack of alertness may lead to severe crashes. An effective way to reduce the likelihood of crashes at isolated intersections is to warn road users of the intersection in advance. A smart-lighting system can detect approaching vehicles using sensors to illuminate the intersection. In the first phase of this project, we developed a prototype of a demand-responsive light. This report documents the second phase of development and deployment of a smart-lighting system at the University of Alaska Anchorage (UAA). In this phase, we developed an installation-ready smart-light system that is ready for site deployment and analyzed its ability to generate and store power during winter.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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EXECUTIVE SUMMARY

Rural intersections are high-risk locations for road users. Particularly, during the nighttime, lower traffic volumes make it difficult for drivers to discern an intersection despite traffic signs. The lack of alertness may lead to severe crashes. An effective way to reduce the likelihood of crashes at isolated intersections is to warn road users of the intersection in advance. A smart-lighting system can detect approaching vehicles using sensors to illuminate the intersection. In the first phase of this project, we developed a prototype of a demand-responsive light. This report documents the second phase of development and deployment of a smart-lighting system at the University of Alaska Anchorage (UAA). In this phase, we developed an installation-ready smart-light system that is ready for site deployment and analyzed its ability to generate and store power during winter.

CHAPTER 1. INTRODUCTION

Crashes at isolated intersections are dangerous, and most of the times they result in fatalities. Studies have found that poor lighting plays a significant role in crashes. Since the rural roads have low volume, especially at night, the drivers do not expect other vehicles. Intersection crashes during nighttime hours may occur because of poor driver visual cognition of conflicting traffic or intersection presence. In rural regions, the primary source of lighting is vehicle headlights. Roadway lighting improves driver acknowledgment of crossing point nearness and perceivability of signs and markings. Goal lighting provides some enlightenment to the crossing. States like Iowa and, Washington conducted a few studies, and they concluded that providing lighting intersection reduces the number of crashes by as much as 33 percent.

Most of Alaska is rural, and these are isolated. The challenges the people in these regions face are entirely different from those faced by people in urban areas. One of them is traffic safety. It is a serious concern among all rural areas. Since the rural regions have a lower population, they may not have sufficient technical know-how, workforce, or resources to develop and implement safety interventions. Due to various reasons, rural areas do not have an adequate mechanism to deploy safety interventions. Through this proposal, design and development of a smart-lighting system are proposed. Since Alaska is different from the lower 48 for various reasons, including weather, it is required to design and develop a smart-lighting system which is cost effective and functional in a harsh environment.

Since the rural intersections are isolated, most of the crashes result in serious injury and fatality due to various factors including lack of efficient incident management system and emergency response system. This proposal is a continuation of a project sponsored by CSET in 2019. In that project, the research team developed a prototype of a smart light system. In this phase 2, the focus is on fine-tuning the prototype and making it ready for commercialization, specifically focusing on the energy generation and consumption of the system to test its ability to be deployed in remote rural intersections not connected to a power grid.

CHAPTER 2. AN OVERVIEW OF THE PROTOTYPE DEVELOPED

In the first phase of this project, a working prototype of a smart-lighting system was developed. The system detect moving vehicles, communicates the information wirelessly to a receiver, which powers the light on based on the detection. The following are the parts of the system. Figure 2.1 shows a schematic diagram of the proposed set-up. (1) sensor & transmitter units, (2) a receiver unit, and (3) a light unit. Depending on the number of approaching roads, the number of sensor & transmitter units will vary.

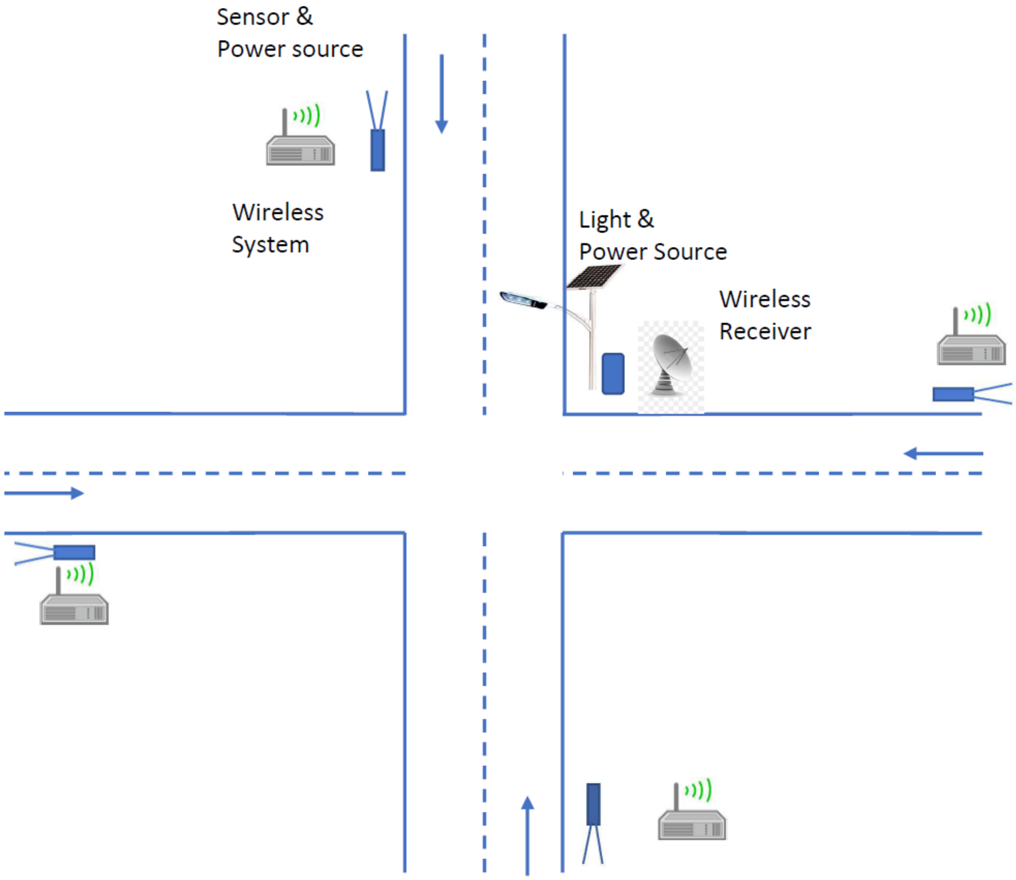

Figure 2-1 Schematic diagram of the proposed smart-lighting system

2.1. Components

Sensor & Transmitter Units: Since an accurate vehicle detection is an essential requirement of the system, the research team explored various sensor options. Among the available options, the team found both laser detector and Doppler radar as promising choices for the proposed system. The advantages and disadvantages of the two sensing technologies were meticulously studied. Doppler radars are inexpensive and can detect objects within a more significant portion of the road. Laser detectors are typically more expensive and precise calibration must be maintained in order for them to work properly. In order to meet the objectives of the project in developing a low maintenance and easy-to-deploy smart-lighting system, we chose Doppler radar. Among multiple Doppler sensors available, we chose OmniPresense OPS243A. With a range of up to 100 m (~328 ft), this sensor has the most extended range among all the low-cost options available. The radar is capable of sampling between 1,000 and 100,000 samples per second. Lower sampling frequency means higher accuracy in locating the object; however, it limits the detection sensitivity only to slow-moving objects. Increasing the sampling frequency could enable detecting objects with higher speed, but will compromise the accuracy of reporting the exact location of the object (for example, if frequency is set to 1,000 the max reported speed is 7.0 mph ±0.014. While with a frequency of 100,000 the max reported speed is 696.4 mph ±1.358).

The second major component of the sensor & transmitter unit is the transmitter. We purchased RF Link 434 MHz transmitter (from www.sparkfun.com). The sensor continuously monitors the detection zone for moving objects. Once an object is detected, the information is processed to capture the required parameters such as speed and location of the detected objects. In our project the processing was performed in an Arduino interface. The Arduino and its underlying software will trigger the transmitter when the sensed values exceed the defined thresholds. The thresholds include approaching speed and size of the moving objects and they can be adjusted based on the ground conditions. This will provide the end users to customize the prototype based on the specifics of their deployment site. We performed several sensitivity experiments to determine initial thresholds that could best fit the rural traffic in Alaska
Receiver Unit: The purpose of this unit is to receive the signal from the transmitter, process it, and turn the light unit on. We used RF Link 434Mhz receiver in this project. This unit uses an Arduino to process the received data. Once this unit receives the detection information from the sensor & transmitting unit, it will send a signal to the light unit.
Light Unit: Light unit is another integral part of the smart-lighting system. In our design, we used an LED light as the light unit. The LED light was used to test the functionality of the prototype; however, this will be replaced with a high-intensity light in the next phase of the project.

Figure 2-2 shows the experimental set up of our prototype. As it can be seen, the LED bulb lights up after the sensor detects an approaching vehicle.

Figure 2-2 The prototype developed in Phase 1

CHAPTER 3. MAKING OF COMMERCIALIZABLE PRODUCT

The sensor technology worked flawlessly in the prototype. The main challenge was the design of light unit. Since many rural intersections in Alaska are away from reliable power grids, we had to look for alternate energy sources. We finalized the system to be a battery powered unit powered with solar and wind energies.

3.1. Power Requirement

To start the design of the light unit, the first step is the selection of the light. Since the purpose of this smart light system is to warn the road users, including the driver of the vehicle, of approaching an intersection and be alert, basic street illumination requirements may be sufficient. LED street light wattage requirements vary based on factors like road type, pole height, and desired brightness, but generally range from 30 to 300 watts are used. Since the intersections where the smart lighting system will be deployed are low-volume rural areas, we chose the 80 watts LED light.

The next step is the determination of battery and power generation requirements, which depend on the expected use of the system. Nationally, the average AADT for low-volume rural roads typically falls within the range of 400 to 500 vehicles daily. In rural Alaska, this number is expected to be much lower. For this task, we assumed the AADT to be 250 vehicles daily. Since this smart-lighting unit will be installed at an intersection, the total approaching traffic (for two roads) can be assumed to be 500. The general range of the proportion of daily traffic occurring during the peak hour in rural areas is 0.15 to 0.25. Taking the average value of 0.20, we will have 100 vehicles approaching the intersection during the peak hour, and the remaining 400 vehicles during the remaining 23 hours of the day. As the worst-case scenario of power consumption, we can consider the case of uniform arrival rate. This would mean a vehicle will arrive every 36 seconds (3,600/100). If we keep the light on for 10 seconds, the light will be turned on for 16.6 minutes during the peak hour.

For the off-peak period, the 400 vehicles would be distributed over the remaining 23 hours, resulting in approximately 17.4 vehicles per hour (400 / 23). Assuming a uniform arrival rate during off-peak hours, a vehicle would arrive roughly every 207 seconds (3600 / 17.4). Keeping the same 10-second lighting duration per vehicle, the light would be on for about 174 seconds, or 2.9 minutes, per hour. Over the 23 off-peak hours, this results in a total of approximately 66.7 minutes of lighting.

Combining both peak and off-peak periods, the total daily lighting duration is approximately 83.3 minutes (16.6 + 66.7 minutes). This estimate will serve as the basis for sizing the energy storage and power generation components of the system.

To model the variability in vehicle arrivals and improve the accuracy of power consumption estimates, we fit a Poisson distribution to the vehicle arrival process. The Poisson distribution is commonly used for modeling the number of events (in this case, vehicle arrivals) in a fixed interval of time, assuming events occur independently and at a constant average rate. During the peak hour, with an average of 100 vehicles per hour, the arrival rate (λ) is approximately 1.67 vehicles per minute. During off-peak hours, the arrival rate drops to around 0.29 vehicles per minute (400 vehicles spread across 23 hours). Assuming each vehicle triggers a 10-second activation of the light, we simulate lighting durations by sampling from the Poisson distribution. Based on this model, the expected lighting duration is approximately 17 minutes during the peak hour and 65–70 minutes across off-peak hours, resulting in a total expected daily lighting duration of about 82–87 minutes**.** This probabilistic modeling allows for more robust design of the battery and power generation system by accounting for natural fluctuations in traffic patterns.

CHAPTER 4. COMPONENTS

Based on the requirements identified in the previous chapter, the various components required for the light unit are identified. The details of each of the components are discussed as follows:

4.1. Battery

Although the power requirements were not very high, adding some factors of safety, we decided to go with a 12v 150Ah battery for power storage. This battery can run a load of 350watts for slightly more than 4 hours, which is a lot more than our design requirement. An additional battery could be added in a parallel connection to add assurances and oversizing.

4.2. Power Sources

There are two power sources that we explored: solar and wind. For solar, we chose a 370w solar panel due to factors including the power production rate and size. For the wind turbine, we chose Primus Air 30 12V Wind Turbine that has 400w peak output.

4.3. Power Integration and Control

All power sources and the battery are integrated using a Victron SmartSolar MPPT charge controller (Component 2), which efficiently manages solar energy harvesting and battery charging. To monitor wind energy production and system parameters, a Wind Meter (Component 3) and Wind Meter Shunt (Component 8) are included. A communication hub (Component 4) enables remote monitoring and data transmission. The system also includes a set of breakers for safety and isolation: a solar breaker (Component 5), DC bus breaker (Component 6), and a charge controller-to-battery breaker (Component 7). Power is distributed through DC bus bars—positive (Component 9) and negative (Component 10)—which streamline and organize the system wiring. This modular and protected layout ensures robust performance, safety, and ease of maintenance in harsh rural environments.

CHAPTER 5. THE FINAL SETUP

After identifying the components, the team worked with Susitna Solutions, a private contractor to create a deployable unit. This contractor connected different parts through the smart controller and placed them inside a weatherproof cabinet. The unit was installed at UAA campus. Figure 5.1 shows the photo of the unit on UAA campus, and Figure 5.2 shows the components inside the cabinet.

Figure 5-1 The smart light unit at UAA campus

1) Battery
2) Smart Solar Charge Controller
3) Wind Meter
4) Communication Hub
5) Solar Breaker
6) DC Bus Breaker
7) Charge Controller-to-Battery Breaker
8) Wind Meter Shunt
9) + DC Bus Bar
10) – DC Bus Bar

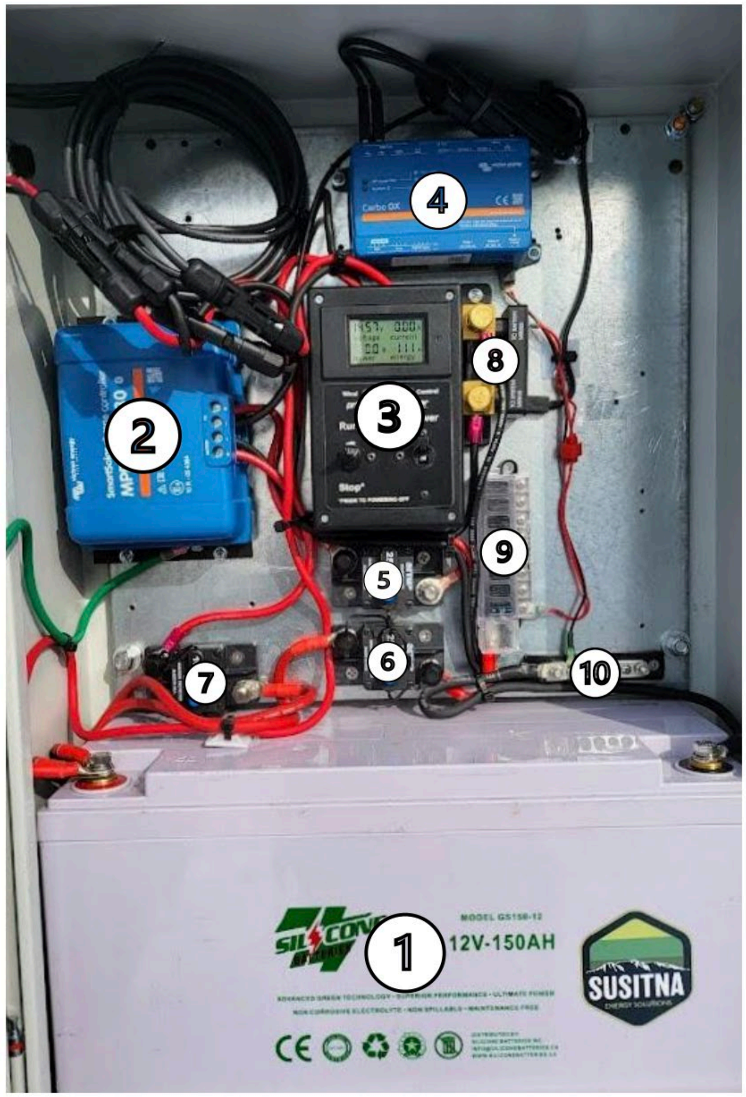

Figure 5-2 Components inside the cabinet

This set up makes it easy to deploy with limited supervision remotely. The connections and settings after deploying the smart light unit are simple and can be completed with minimal instructions. The unit is powered with both solar panel and wind turbine; therefore, it can generate power itself during long dark winter days. In summer months, the energy generation would not be an issue due to longer sun exposure. Since the energy requirement during peak activity hours are low, probability of battery drain is negligibly low even in winter months. Overall, the system satisfies the requirement, satisfying the requirements for its deployment in rural Alaska.

Figure 5-3 presents examples of the system's recorded data. The time resolution of the time series can be adjusted as needed. The monitoring system and dashboard allow users to check the battery's remaining charge, track voltage levels, and leverage the data to predict future patterns of solar and wind generation, as well as potential energy shortfalls required to keep the lighting system operating.

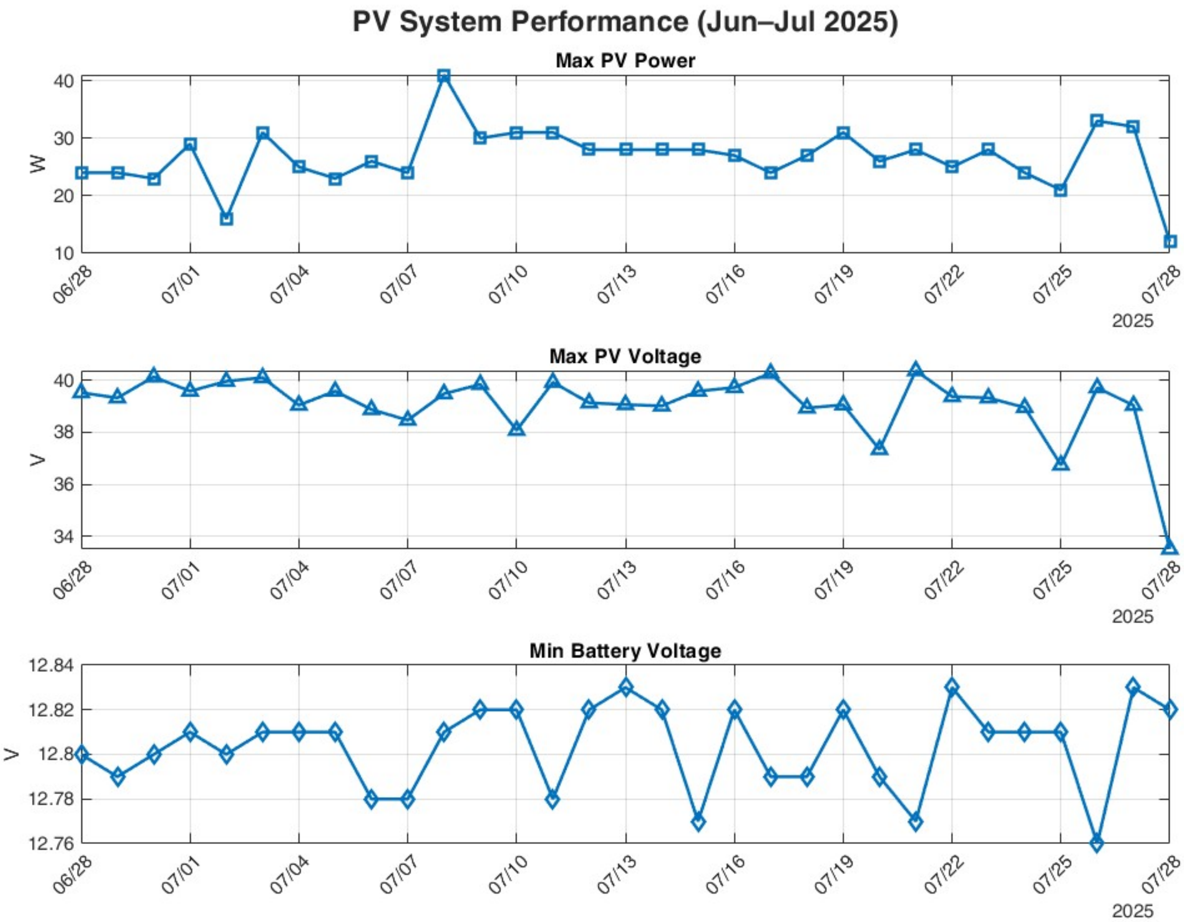

Figure 5-3 Online monitoring of recorded data