VITRONIC MEA LLC
Dubai Hills Business Park

Traffic Technology

Technical Documentation

High Level System Design (HLD) technical System Description for Power Solar Solution

Solar Enforcement Trailer

Document:	High Level Design System Description Power Solar Solution	
Reference	RFQ for Power Solar Solution	
Company:	VITRONIC Machine Vision Middle East LLC	
Location:	Headquarter and production facility Germany	1.0

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1 Legal Notes

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2 Introduction

2.1 Objectives of the Document

This document provides a preliminary description for the high-level system design (HLD) of VITRONIC’s Solar Power Solution. The HLD document presents an overview of the structure of the system comprising description of the required system components and the required infrastructure at the front and back end. Further details of the system specification and requirements are subject to the specification stage of the project after contract awarding.

2.2 Audience

This document is intended for the use of VITRONIC’s project team, which is involved in the creation of the solution proposal and commercial quotation. The audience for this HLD also includes the customer`s project team.

3 Problem Statement

3.1 Background

VITRONIC has a strong presence and more than 10 years of experience with thousands of stationary and semi-stationary traffic enforcement systems in the Middle East for example Saudi-Arabia and UAE to name a few and Western Europe (e.g., Germany, France).

VITRONIC started developing the Solar System Solution back in 2017, when appliances such as VLidars, PCs, emergency lights, etc., which are supplied by the public grid and cannot afford any power cut, need to be electrically secured.

Some sites are in the desert where electric poles have not yet been installed and are far from any electrical grid.

An inverter/charger with transfer relay or a combination of an inverter and a charger guarantees that the battery is well maintained and that an uninterrupted power supply to strategic appliance is sustained.

3.2 Enforcement Trailer

VITRONIC’s enforcement Trailer is the ultimate solution for effective traffic monitoring in areas that are too hazardous for operators or lacking appropriate infrastructure. In the same way conventional trailers are transported, the enforcement trailer can be easily repositioned to any location to monitor traffic autonomously over several days. It can be rapidly set up and includes a remote-controlled drive-in order to minimize any physical risks to operators while it is being positioned on the roadside. Furthermore, the enforcement trailer has optimum protections against potential vandalism.

- Autonomous, unmanned enforcement operation (up to ten days)
- Suitable for transport by virtually any vehicle with a tow bar » High protection against vandalism
- Remote-controlled drive for convenient positioning and on-the-spot manoeuvrings
- Optionally integrated modem for wirelessly transmitting case data and remotely accessing the POLISCAN system

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3.3 Problem Statement

The enforcement trailer can run autonomously and continuously for a total period of 10 days based on the current battery solution of the system. The operation/running time must be extended and pushed to a minimum requirement of a month with uninterrupted operation. Exploring different viable options that will be discussed later into the document will provide insight how a solar solution provides a better adaptability of the system both sustainably and economically.

4 System Description and Overview

4.1 Main Features

The Solar Power Grid Solutions by VITRONIC can be divided into 4 Sub-Categories depending on the respective VITRONIC Solution System chosen by the customer. Each solution can further be adapted to consider specific customer needs. The generic features for all solutions are:

- Solar Power System Solution for the respective VITRONIC Solution
- Easy and Safe Commissioning with full protection against incorrect wiring
- High Quality & Low Energy Consumption Components for High Energy Conversion Rates
- Components chosen to perform in harsh environmental conditions (Temperature, Humidity)
- Adaptable to specific customer needs (e.g., “Offline Operation Duration, etc.)

4.1.1 Component Overview

The architecture of the VITRONIC Solar Solution consists of the following components:

- High Performance Solar Cells (Half Cell Technology, Monocrystalline, Long Warranty)
- High Quality and High Efficiency Solar Charge Controller MPPT
- High Quality and High Efficiency Solar Inverter
- High Quality Batteries (Lead/Acid or Gel or Lithium Batteries) for Energy Storage
- High Quality Battery Status Processor & Battery Management System (BMS)
- Communication System consisting of a Remote Control & Programming Centre and Data Logger

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- VITRONIC “Solar” Cabinet to store Batteries & Equipment
- High Performance Cooling Fan for Air Circulation
- Solar Structure & Solar Post for Mounting of Solar Cells

The number of Solar Cells & Batteries, as well as the Solar Structure Design are depending on the respective power and storage requirements for the VITRONIC Solutions. A static calculation for the Solar Structure must be done to ensure the safety against environmental forces (e.g., wind).

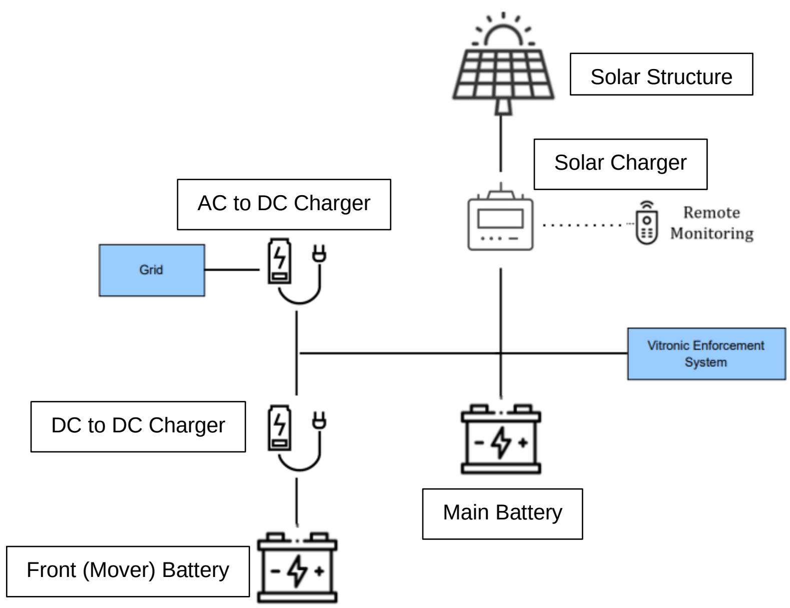

Figure 1: Architecture Overview

The same architecture will be applied for every Solar System Enforcement Trailer Solution. Independently, each VITRONIC System Solution in combination with the Solar System will be explained further in the respective chapters.

4.1.2 Overview of different Battery Systems

The VITRONIC Solar Solution is capable to use different Battery Systems for example Lead/Acid Batteries, Gel Batteries or Lithium Batteries or any deviation/mixture of these batteries. Using the different Batteries have different advantages regarding price, availability, capacity, lifetime and more. To allow customers, the flexibility to choose the Battery System, the chapter aims to provide a short overview of the advantages and drawbacks of each system.

Battery Type	Lead/Acid Battery	AGM Deep Cycle Battery	Gel Battery	Gel Deep Cycle Battery	Lithium Battery (e.g., LFP)
Weight	Heigh Weight	Heigh Weight	Heigh Weight	Heigh Weight	Lower Weight
Cycles	Medium Cycles (400 Cycles)	Medium Cycles (600 Cycles)	Medium Cycles (500 Cycles)	Medium Cycles (750 Cycles)	High Cycles (6000 cycles)
Depth of Discharge	High DoD (e.g., 80%)	Low DoD (e.g., 50%)	High DoD (e.g., 80%)	Low DoD (e.g., 50%)	High DoD (e.g., 90%)
Energy Density	30- 40 Wh/kg	30- 50 Wh/kg	30- 50 Wh/kg	30- 50 Wh/kg	90- 130 Wh/kg
Maintenance & Service Life	Frequent Replacement Medium Life	Service Free Long Life	Service Free Long Life	Service Free Long Life	Service Free Very Long Life
Costs	Medium Costs	High Costs	Medium Costs	High Costs	Very High Costs

Table 1: Overview Battery System Technologies

4.1.3 Overview Solar Cells

The VITRONIC Solar Solution is capable to use different Solar Cell Types. The status of Solar Technology development proposes to use the so called “Half-Cell” Technology using Monocrystalline Type Cells. In comparison to “Polycrystalline Panels”, the Monocrystalline panels have a higher conversion efficiency, which means the Cells produce more kilowatt-hours of electricity. The so called “Half-Cell” is a “standard” in the Solar Industry, which allows to swap Solar Cells from different suppliers for an existing infrastructure. The VITRONIC Solar System solution uses high performance and high-quality Solar Cells that can produce electricity even when they are partially covered for example by dust. VITRONIC uses the newest Half-Cell Standard Solar Cell. This status is from June 2022 and can be adapted to higher Power Yields as soon as the suppliers progress in the Half-Cell Technology accordingly.

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4.1.4 Structural and Design Overview

The Enforcement Trailer has a non-standard design with different unproportionally surfaces to impose a visually pleasing appearance as show in the image below. The structure also allows the ability to lower on the ground hiding the wheels to avoid any possible vandalism to the system especially mobile components.

Figure 2: Enforcement Trailer

5 Alternative Solutions

The power system of the enforcement trailer must be increased to allow the extension for run-time or period of operation and enforcement. The system is currently running by a battery-operated system. The batteries are lithium type (LiFePO4) battery that have a capacity of 700Ah consisting of a total quantity of 4 units that are connected in series offering a total capacity of 2800Ah. The entire unit runs and consist of the following systems: a core element, the enforcement measuring device known as the FM-1 that consists of cameras and Li-DAR; their combination with a COM-PC allows this core unit to place into different housings as the enforcement trailer for instance, a flash for better image quality, the main board of the system that allows for the powering of the FM-1 and flash with the control of the housing in this instance the trailer, and finally the mobile unit of the trailer, consisting of drive system that allows the transport of the trailer either by towing for long distances or remotely controlled for small distance and deployment.

The power extension should allow a minimum run-time of at least a month; this can be explored as this system is an off-grid solution that is required to deploy at different sites constantly by the client; therefore a constant power supply cannot be provided, however, the possible solutions to tackle this approach are the following: Increasing the capacity of the batteries allowing the system to run for a longer period, exploring different off-grid power solutions as Solar Energy.

Extending the capacity of the batteries will allow the increase of run-time; however, will increase in cost, maintenance, and the risk of HSE concerns (Health, Safety, and Environmental). Furthermore, this option allows for cheaper implementation than a Solar Solution.

Alternative off-grid solutions for this system; most used approach is a solar tactic as it is the most versatile and best effective as compared to other renewable sources especially for a small system as this. The solar option will not only provide a constant energy source and require less maintenance, it will allow the system to run continuously pushing the minimum requirement of a month of operation time and is more sustainable; however, the cost might be high but Solar solution eventually show a ROI (Return on investment) in the long run.

6 Method of Implementation

6.1.1 Overview of the System

As Discussed above, The Enforcement trailer is one of the many housing that VITRONIC offers and the core units consist of the FM1 and the Flash running simultaneously; Therefore, to modify the power necessitates of the system; The housing of the enforcement trailer will be modified which includes the main board, drive system, and the battery management system. The main board of the system monitors the housing environment as adjusting the temperature and powering the core elements; the flash and the FM-1. The following electrical diagram demonstrates the overview of the system; The left side displays the drive system, and the right side represents the functionality of the entire system.

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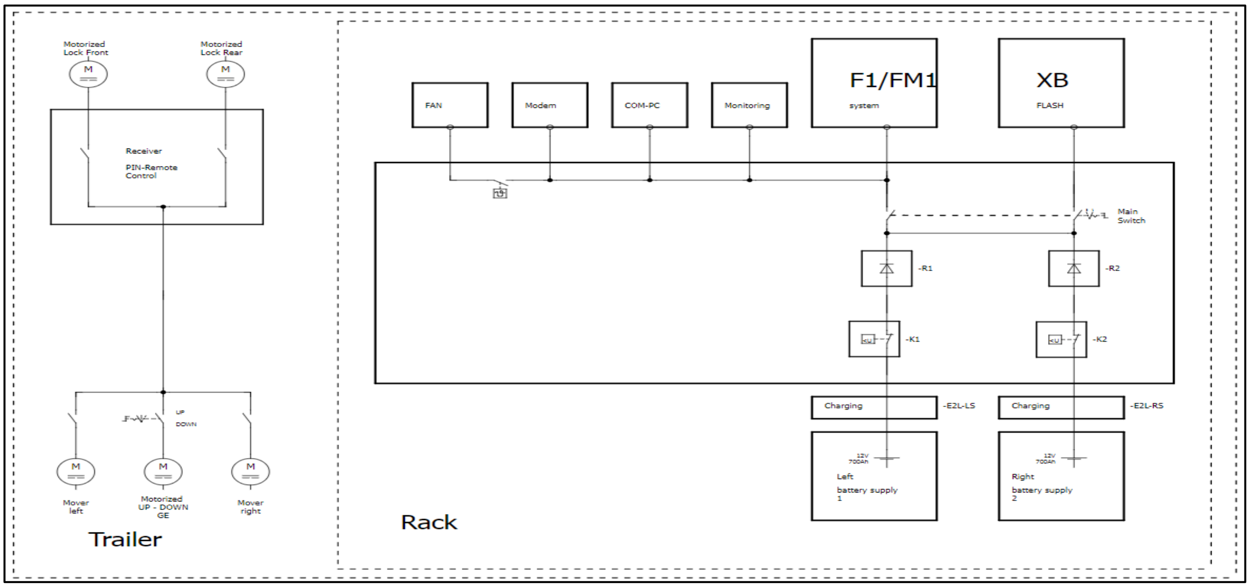
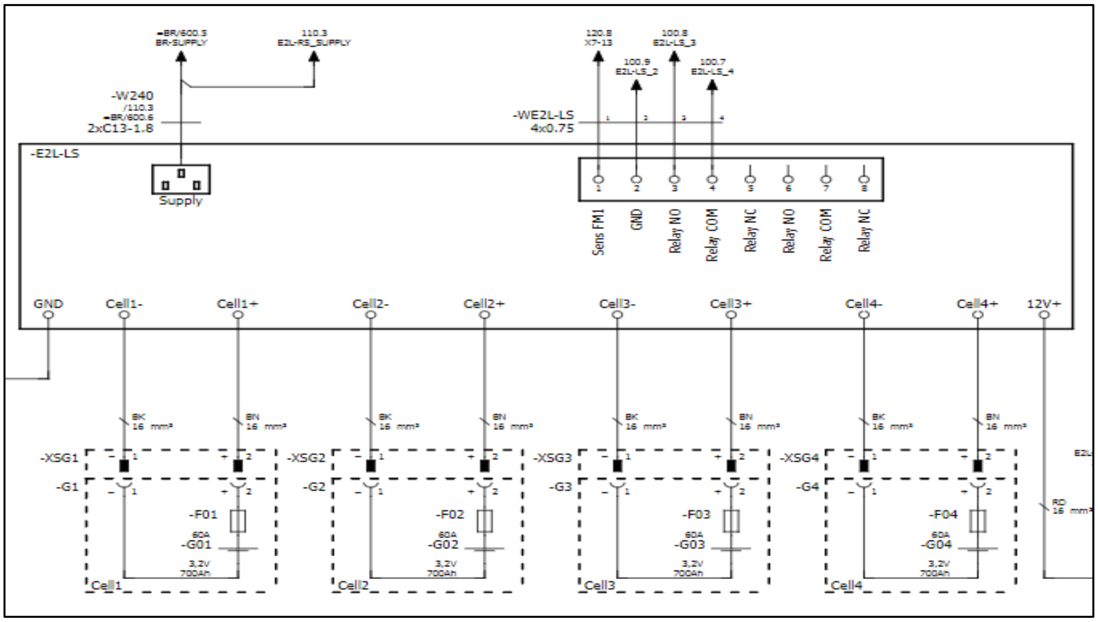


The drive system of the trailer includes the method of transport of the trailer, which includes the towing elements for large distance transport and remotely controlled motor for small adjustment and distances during deployment. This is achieved by disengaging the gears allowing during towing and re-engagement during remote transport that is power by motors along each side of the two wheels.

The Battery and the BMS of the enforcement trailer which powers up the entire system. The current setup of the batteries are lithium (LiPO4) batteries that are connected in series with a capacity of 700Ah each allowing a total of 2800Ah. The following batteries are connected to the BMS of the system that will monitor the supply of each battery and ensure equal distribution of voltages and regulate the amount of current being drawn. The electrical diagram below displays the cells of the batteries and the connections to the BMS. As for the drive system, it consists of a single AGM 110Ah battery that will supply the power to the drive system of the trailer.

The Main Board is powered through the BMS and allows power to flow through relay and diodes to avoid damaging the core and supporting elements of the system which later passes through into distribution channel that flows into the controllino, Modem, COM-PC, FM1, and XB-2 Flash, and fan.



6.1.2 PV Technologies and System Design

Photovoltaic cells or PV cells can be manufactured in many ways and from a variety of different materials. The most common material for solar panel construction is silicon which has semiconducting properties. Several of these solar cells are required to construct a solar panel and many panels make up a photovoltaic array.

There are three types of PV cell technologies that dominate the world market: monocrystalline silicon, polycrystalline silicon, and thin film. Higher efficiency PV technologies, including gallium arsenide and multi-junction cells, are less common due to their high cost, but are ideal for use in concentrated photovoltaic systems and space applications. There is also an assortment of emerging PV cell technologies which include Perovskite cells, organic solar cells, dye-sensitized solar cells, and quantum dots. The main three categories used in the market include the following: Monocrystalline Silicon Cell, which was used in this project, Polycrystalline Silicon Cell, and Thin Film Cells. Monocrystalline cells are the most common in the market is extreme pure form of silicon that are mechanically sawn into thin wafers, polished and doped to create the required p-n junction. They are highly efficient making them more efficient than their counterparts Polycrystalline and Thin Films; Polycrystalline cells are instead of a single uniform crystal; they consist of several small grans of crystal making them less efficient. As for thin films, they are flexible, and durable produced by depositing thin layers of silicon on to a glass substrate. Their efficiency, however, is greatly reduced because the silicon atoms are much less ordered than in their crystalline forms leaving 'dangling bonds' that combine with other elements making them electrically inactive.

PV Systems are heavily dependent on weather conditions and the availability of the sun; thus, a compromise must be considered that the system will be allowed to increase the run time of the system at the compromise of inefficiencies during bad weather conditions as rainy, gloomy, sandstorms, etc. This point will require the system to operate independently during this period. The batteries must be able to cover that period in that scenario. The load is the amount of energy needed at a specific site that considers the maximum, minimum, daily, seasonal requirements. The designed system will consist of components that need choosing for a 12-volt system: Solar panels, charger controller, solar oriented batteries, AC-DC & DC-DC Chargers.

https://energyeducation.ca/encyclopedia/Types_of_photovoltaic_cells

http://samples.jbpub.com/9781449624675/24675_Design1_CH02.pdf

6.1.3 Electrical Adaptations

6.1.3.1 Load Analysis Overview

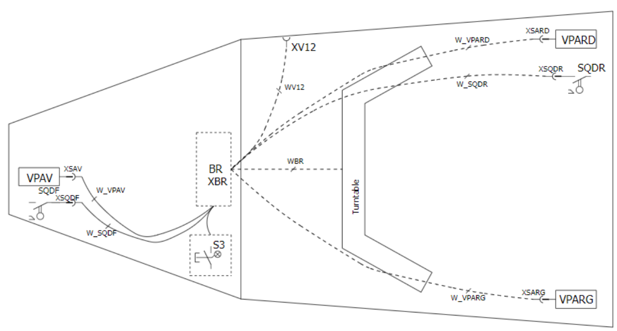
The Power setup of the system is power through the batteries and regulated through the BMS and the main board for protection, conversion, and implementation. The entire setup is estimated ideally to consume a total of 75~80 Watts of power per hour throughout operation. The main power consumption is drawn by the core elements during enforcement (FM-1 and XB-2 Flash), which will be later shown that it was tested with the solar panels during a burn-out procedure, the COM-PC, and the Fan unit. The table below shows the power consumption that will be needed to operate the setup on different time scales. Therefore, the solar solution must cover these requirements.

Time	Power Consumption (Safety Factor Added of 20%)
Hourly	100 W
Daily	2.4 kW
Weekly	16.8 kW
Monthly	67.2kW

The solar will requires to cover the power requirements on an operational time 8-9 hours of sunlight and based on seasonal changes as well. A point to be considered that the solar solution will greatly be affected by the weather conditions of the surrounding environment.

6.1.3.2 Solar Implementation

The trailer consists of irregular shapes due to its aesthetic look which makes it difficult for traditional solar panels to be utilized as simple as a square or rectangular shape with the following power requirements. The trailer is made up of two main spaces; the front space which houses access to the drive system and the back spaces which houses the enforcement system. The figure on the right shows the top view of the trailer. The trailer area as well consists of 3 main sections: The top section (The flat top with a downward sloping top connected to it), and a left and right sloping section. Therefore, the solar panel required a custom shape requirement to cover the surface of the trailer and the cells utilized were mono crystalline cells as there the most common and efficient in the current market.



The total area 1000 cm^2 utilized for the solar mounts is as follows and the table below will provide their specifications. The panels provided from a Chinese supplier Shenzhen Shine Solar Co.

Table 2

Panel Type	*Quantity*	*Area (Cm^2)*	*Peak Power (W)*	*Max Voltage (V)*	*Max Current (A)*	*Open Cir. Voltage (V)*	*Short Cir. Current (A)*	*Cell Efficiency*
Top: Front Flat	1	7300	100	18	5.56	21.2	4.62	24
Top: Sloped	1	7961	100	18	5.56	21.2	4.62	24
Side: Sloped front	2	10207	100	18	5.56	21.2	4.62	24
Side: Sloped Back	2		75	18	4.20	21.2	4.62	24

Therefore, the total output of the solar peak power output is 550 W however due to the cell efficiency a constant supply of the total output will never be achieved but it is the maximum possible output; this will cover the power necessity by the trailer, but this is heavily based on weather conditions as well.

The diagrams below provide the layout of the solar panels and the cells size utilized as well.

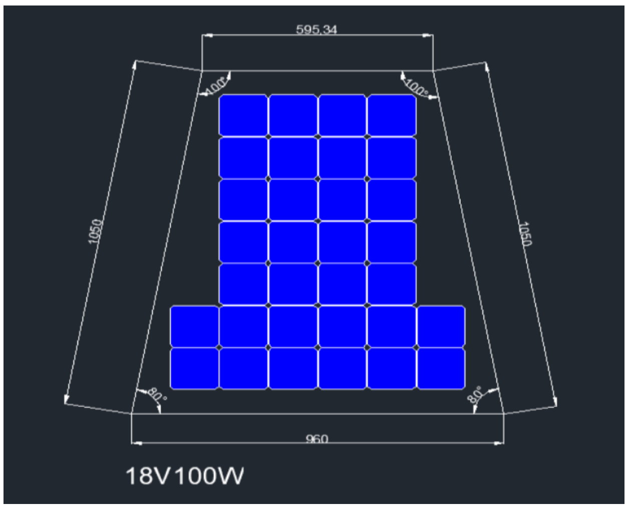


Figure 3: Top- Sloped Panel

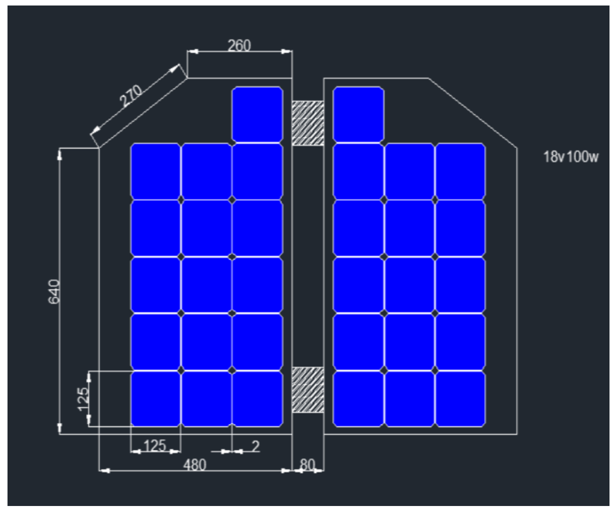


Figure 4: Top- Front Panel

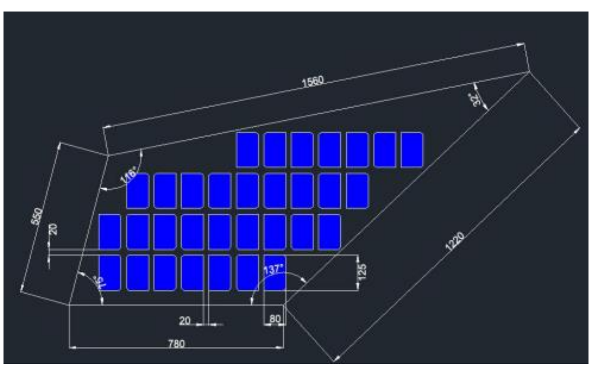


Figure 5: Side: Sloped Back Panel

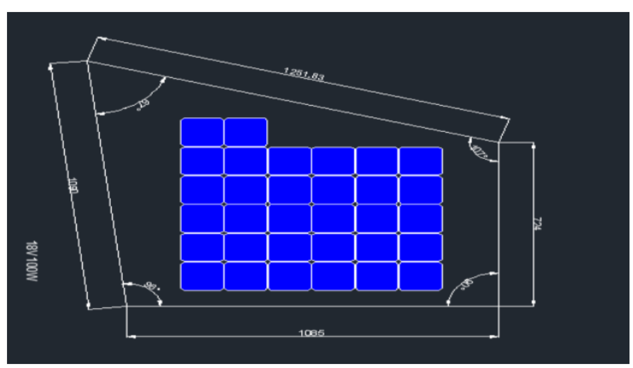


Figure 6: Side: Sloped Front Panel

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The following images will visualize the setup of the panels onto the trailer.

Figure 7: Back View of the Enforcement Trailer

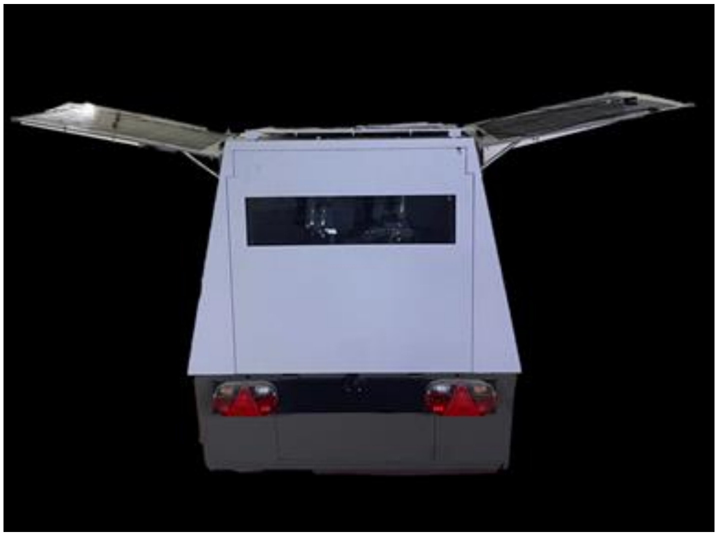

Figure 8: Front View of the Enforcement Trailer

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6.1.3.3 Board Adaptation

The panels will provide a constant supply of power based on ideal sun conditions and connected through three different strings into the charge controllers. This is to maximize the power output for the panels as the panel will affect one another if connected either in series or parallel since the trailer has opposing surfaces that will drop power outage of the panels if connected since one exposed to sunlight and following might not. Each two solar panels were connected in series increasing the voltage to avoid any voltage drops and protect the components from any current surge. The solar panels are then controlled and regulated by the solar charge controller (MPPT); the solar charges work in synchronization to ensure that the voltage delivered to the system at 12 Volts and current from all three strings are in sync to not affect the system.

The table below provides the specifications of the Victron devices used throughout the solar adaption.

Device	Load Output (A)	Battery Voltage (V)
SmartSolar Charge Controller (100/20)	20/20/1	12/24/36/48
Orion-Tr Smart DC-DC charger (12/12-30)	Cont. Output: 30A Max Output: 40A SC Output: 60A	Input: 10~17V Output: 10~15V
Phoenix Smart IP43 Charger	Charge Current: 30/50 A Low Current Mode:15/25A	Input: 230 VAC (range: 210 – 250 V) Absorption: 14.4~14.7 V Float:13.8V Storage:13.2V
BMV-712 Smart Battery Monitor	Supply Voltage: 6.5 - 70 VDC Current Draw: < 1mA Battery Capacity Handled: 1-9999Ah	
All devices have VE.Direct communication		

The solar connectivity to the main system is regulated through a shunt for protection from large current draws while the battery monitor device allows the analysis of the battery with state of charge, voltages and current entering and being drawn from them. As for the DC-to-DC charger, it will allow the charging of the drive system battery from the main system batteries, which the drive system battery is currently independent of the system and needs to either being charged or replaced separately. The AC to DC charger allows another option to charge the entire enforcement trailer setup externally to the grid without the need of removing the batteries and charging them independently which is the current

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situation. The raspberry Pi control the monitoring of all the solar equipment provided by Victron and enables it to be uploaded to the Victron dashboard where we can monitor the devices that will be shown later in the results and testing section. Raspberry Pi allows as well a remote access for the setup of all connected VE.Direct communication devices.

The following drawing below demonstrates the overview of the solar adaptation completed.

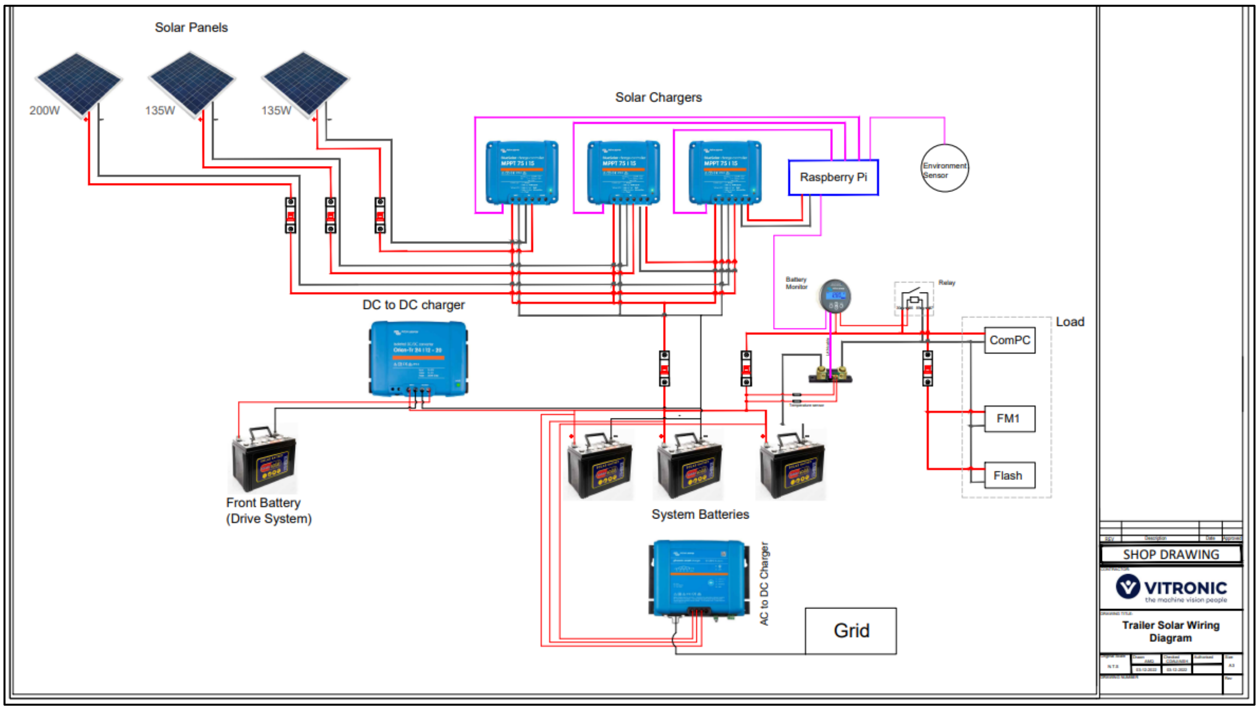

Figure 9: Solar Circuit Diagram

6.1.3.4 Battery/BMS Modification

The enforcement trailer current model is charged by an external BMS as shown in the figure below. The BMS requires a 230 Volt requirement to operation; therefore, there exist a power convertor on the main board that will convert the 12 Volts to the needed 230 Volts to operate the BMS for charging and regulating the batteries. However, it is the only device in the setup that requires to operate on 230 Volts.

As for the solar solution, bringing the BMS used in the trailer will require a solar specification inverter, since it is the only device that operates on such power requirements, it can be bypassed allowing the entire system to run purely on 12 Volts. This approach is done since the inverter itself will contribute energy losses based on its efficiency especially if the inverter is a pure sine output type.

The choice of battery is a very important factor for the total operation of the system as all produced and withdrawn energy must come via the batteries. Small off-grid PV systems today consist in general of open lead acid batteries as they are the most commonly available and the cheapest. Major factors that influence the battery lifetime are deep discharge, overcharge, low electrolyte level and high battery temperature.

The lithium batteries pre-existing and utilized in the trailer, they have a sliding mechanism and according to the table above; lithium batteries are highest on the price range and the solar solution will require specific batteries; lithium batteries could be damaged by regular charging because of their charge response, among other things. Most kinds of solar batteries are charged in three stages, which are bulk, acceptance, and float. Lithium batteries, on the other hand, are charged in two stages. Different Types of Solar Batteries include Lead Acid, Lithium-ion, Nickel Cadmium, and Sodium Nickel Chloride. Due to the characteristics as the capacity needed, Depth of Discharge (DOD), the best option is Lead Acid Battery specifically valve-regulated lead-acid (VRLA) batteries which is the absorbed glass mat (AGM) type because they are reliable energy supply for off-grid areas. They are typically deep-cycle and inexpensive. Lead-acid batteries are attributed to high power and discharge current but low energy.

The batteries utilized in the solar setup are AGM batteries from Victron with a capacity of 110Ah that are connected in parallel giving an entire capacity of 330Ah. This is lower than the current setup however, the setup will be powered by solar and continuously operate through discharge cycles with the room to add more AGM batteries due to the size allocation and price difference.

Recommended charge voltage:

	Float Service	Cycle service Normal	Cycle service Fast recharge
Absorption		14,2 - 14,6 V	14,6 - 14,9 V
Float	13,5 - 13,8 V	13,5 - 13,8 V	13,5 - 13,8 V
Storage	13,2 - 13,5 V	13,2 - 13,5 V	13,2 - 13,5 V

6.1.4 Mechanical Design

6.1.4.1 Solar Panel Framing/Arrangements

The usable amount of solar radiation available at a site is dependent on the local conditions, climate, latitude at which the angle of sunlight will hit the panels; these major factors will affect any PV system with the additional influence that the enforcement trailer will be deployed on different sites poses a large challenge unto the solar panels; furthermore due to the limitations of usable surface area on the trailer and the awkward sloped surface, a mechanically framing for the panels were required to maximize the output of the solar irradiance achievable at different location.

The enforcement trailer consists of two sides that poses a challenge for exposable solar irradiance as they are shaped as the sides of a cube with a small slope. To achieve the maximum desirable solar exposure; a mechanical hinge framing setup was introduced to support the load of the panel and the frame. The following images demonstrates the panels at a closed and open position of the panel. This ensure a maximum exposure to the sun if the trailer is placed at any site location with different positioning and latitudes to the sun path during the day. Each panel had its own framing made from stainless steel and powder-coated to avoid corrosion and rust.

Figure 10: Demonstrates different positions of the panel, during deployment and idle modes

7 Results

The proof of concept that the enforcement trailer can function through a sustainable solution specifically a PV solar system had to undergo a series of testing, through power monitoring, functionality of the system to ensure survivability for term use.

7.1.1 Testing

The requirements of enforcement trailer were to push the run time of the system to at least a month of operation; however, with the PV solar solution, it will be able to run constantly. The enforcement trailer was tested initially with a naked setup, which involved testing the equipment without the housing, then tested with a short road drive test, and finally a deployment test, which include the enforcement was deployed to remote site location to operate independently while remote monitoring.

A burn out test was also conducted; A burn out test consist of the core elements where the FM-1 and the flash constantly run enforcement at a capturing rate of a single enforcement every five minutes; in comparison with the estimated value by Vitronic's systems to have an average violation every 10 minutes. This is conducted to test the full capabilities to the solar setup by constantly drawing power throughout the day and night and ensuring the PV solution will fully charge the batteries and supply constant power to the setup during the day and the batteries will take over during the night without depletion.

7.1.2 Environmental conditions

The tests were conducted during the following periods: May, the 12th till the 24th. The environmental data is a large factor that affects all PV system and is the main concern when relying on a fully independent system as the trailer thus precautions must be taken. The following environmental data located in Dubai, United Arab Emirates are as follows: the average high and low temperatures, Hours of daylight, average daily incident shortwave solar energy, and cloud coverage.

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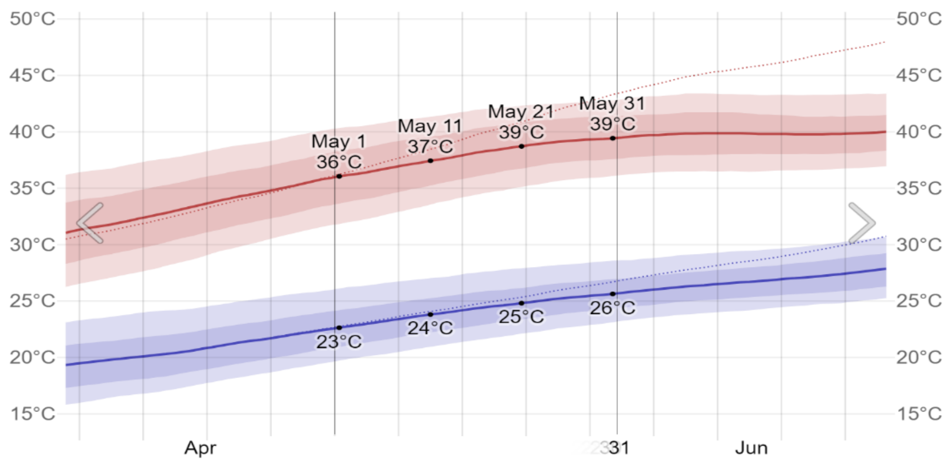
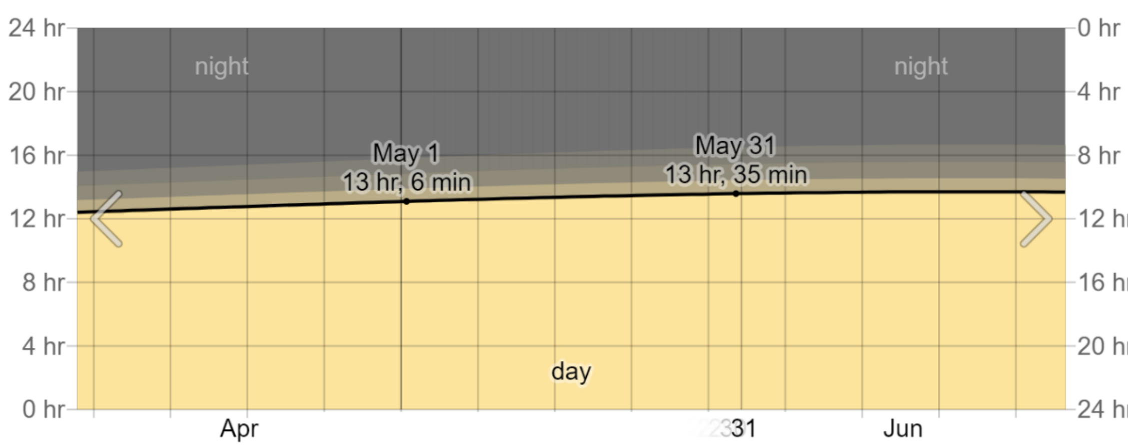
The following temperature data indicates the temperatures during testing beginning with 37 degrees and inclining to 39 degrees by the end of testing.



The hours of sunlight during testing were around 13 hours with sunrise at 6 AM and sunset at 7 PM with peak solar performance around noon and early afternoon.



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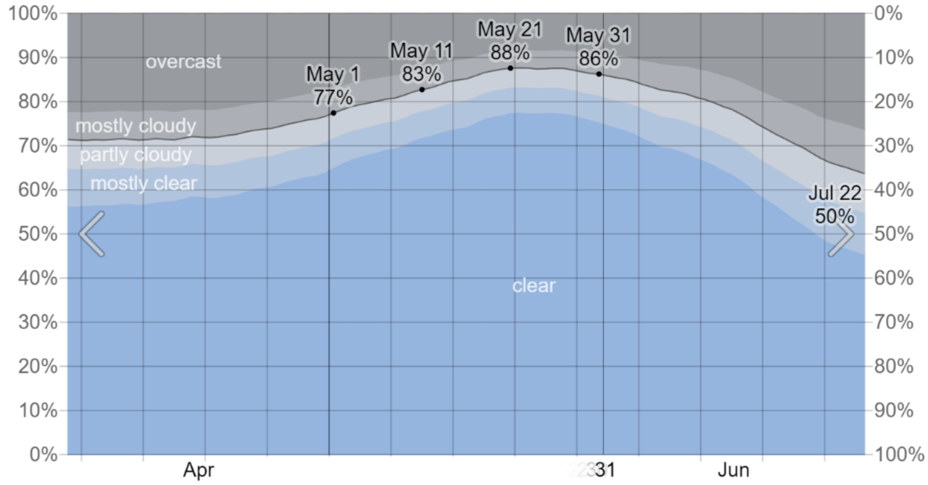
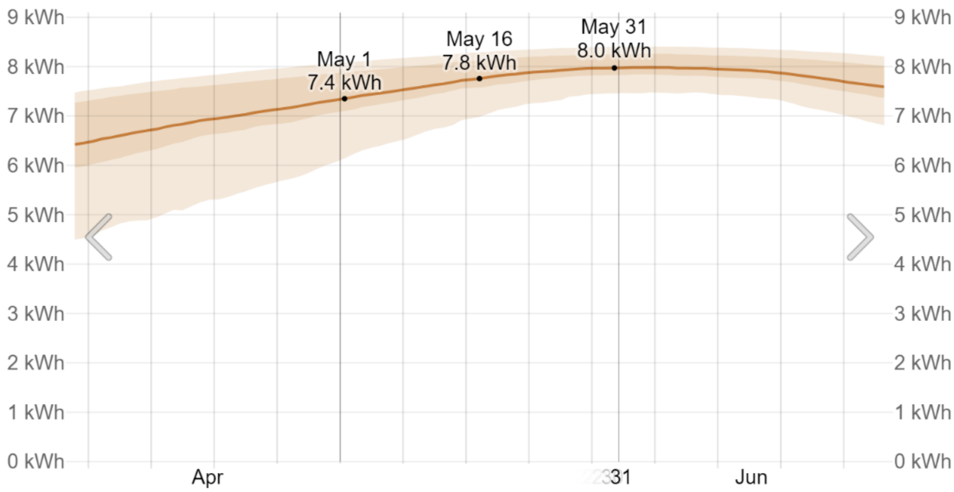
The cloud coverage throughout the testing period as shown in the graph below indicates that the weather was mostly clear ranging from 83 to 88 percent.



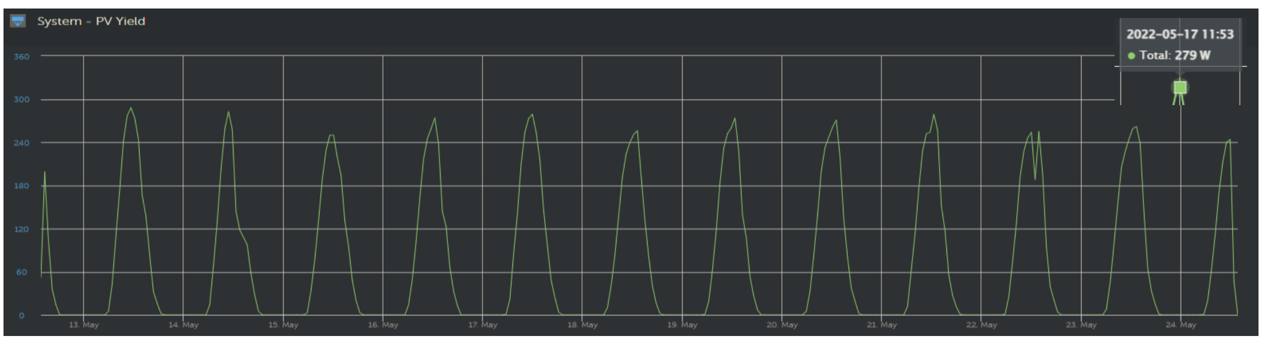
As for the Solar incidence, it is on a daily range scale of 7.5 kWh to 7.9kWh throughout the testing period.

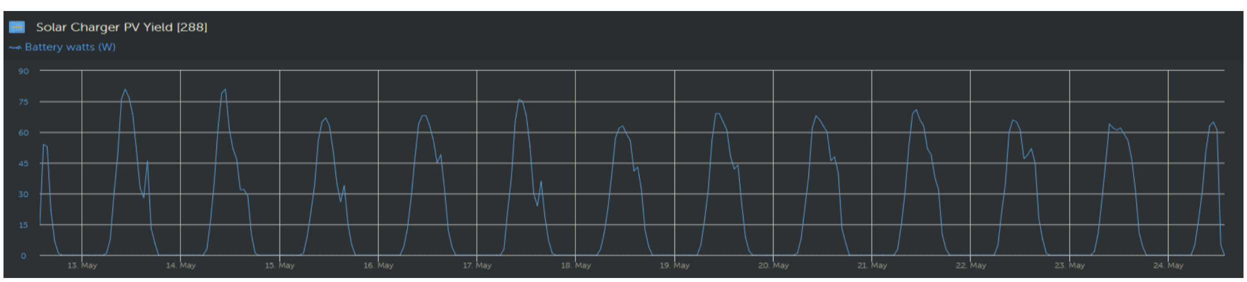


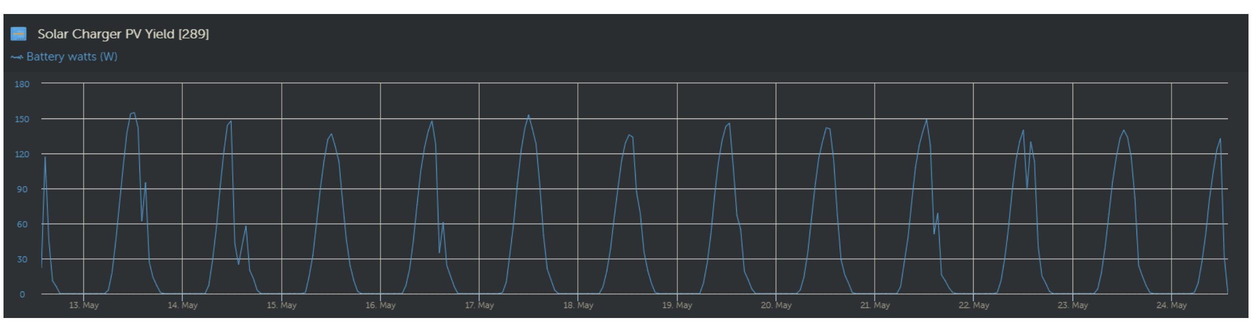
Document:	High Level Design System Description Power Solar Solution	
Reference	RFQ for Power Solar Solution	
Company:	VITRONIC Machine Vision Middle East LLC	
Location:	Headquarter and production facility Germany	1.0

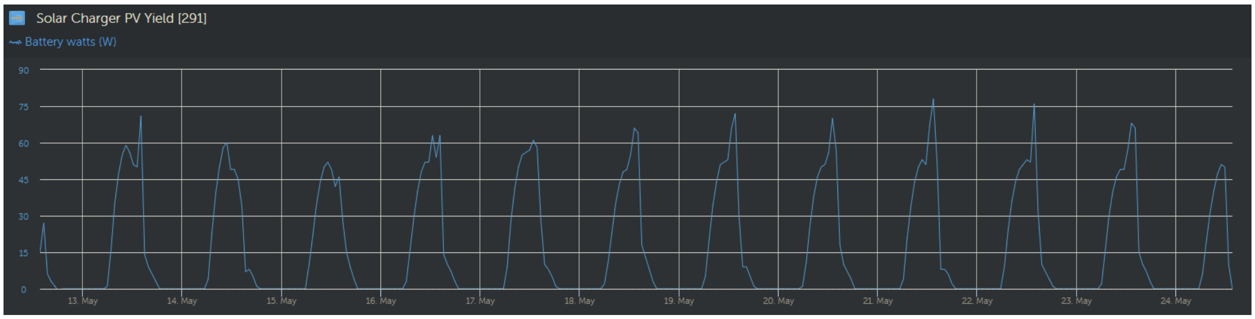
7.1.3 Results

The Victron dashboard allows the monitoring, logging, and remote access to control the MPPT charge controller; BMV-712 Smart battery monitor, and AC-to-DC Charger. This ensures data collection to better analyse the PV system. The system was tested through the month of May dating from the 12th till the 25th. The data below shows the yield graph for the panels and each individual charge controller; left, middle, and right sections. The total average for a peak yield was a daily of 255 Watts where charge controller 288 (left section) had an average of 66 Watts, charge controller 289 (middle section) had an average of 130 Watts, and charge controller 289 (right section) had an average of 60 Watts.

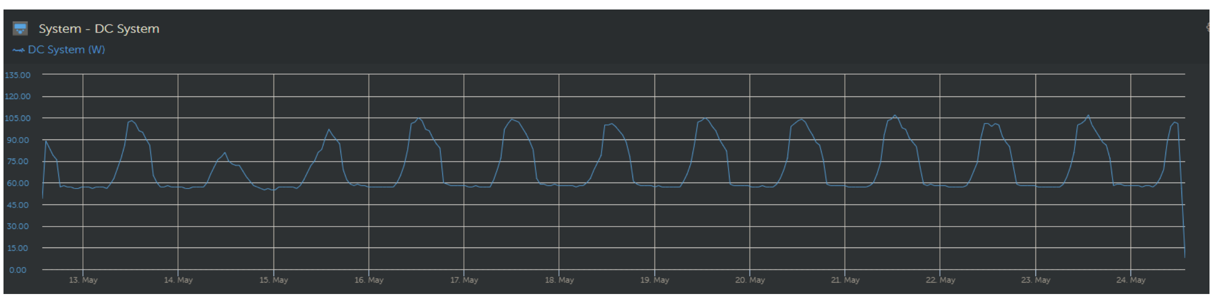


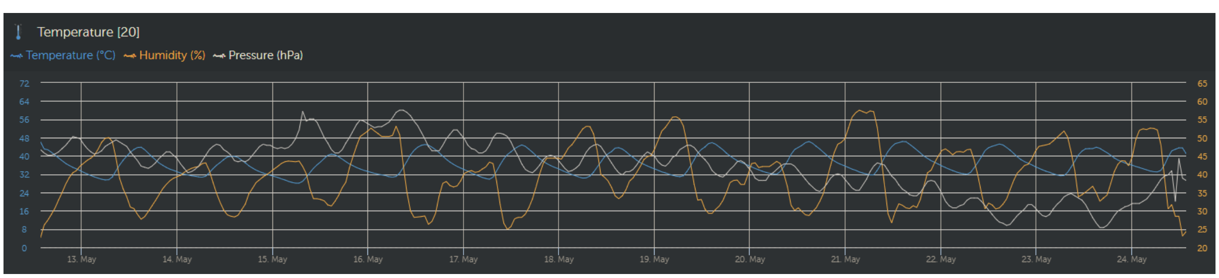




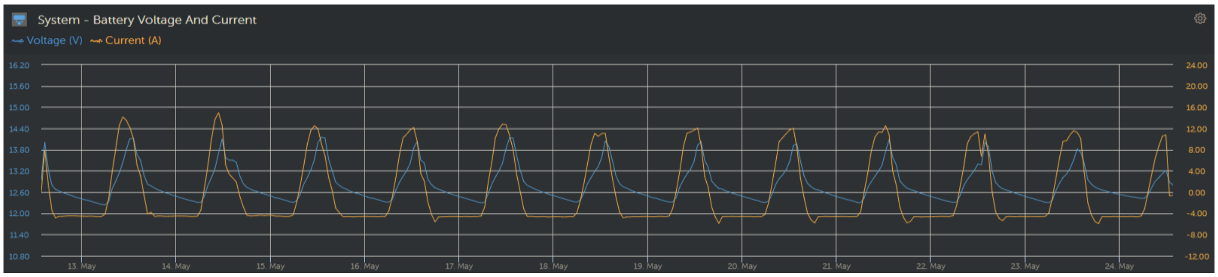


The following graphs will demonstrate the power being pulled by the system throughout the entire day where it hit peaks throughout the day around noon to 1 PM as the temperatures during that time would hit peaks of 40 to 45 degrees represented by the blue line in the temperature graph below. The DC power shown in the graph would pull an average of 58 Watts during the night and a peak average of 100 Watts during the day. This is since the fan is running to the set temperature of 40 degrees. The graph below as shows the measured peak and dip values of the voltages and currents during the day when it is charging and the night when it is discharging (Current is Negative).

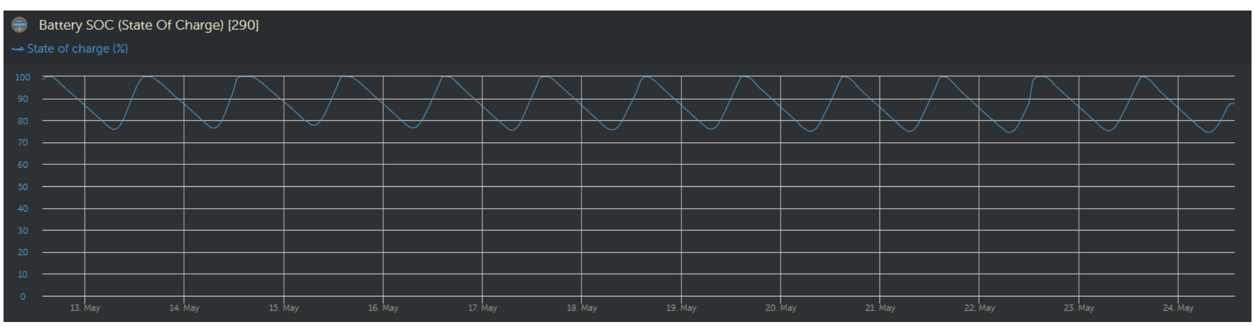


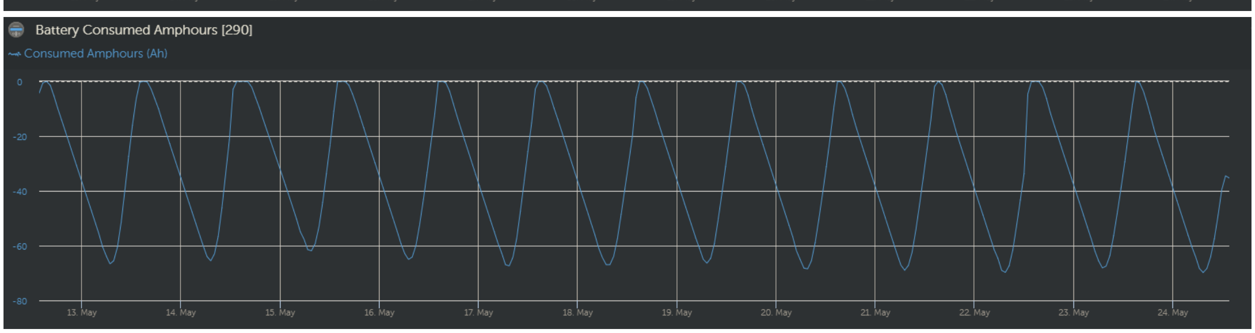


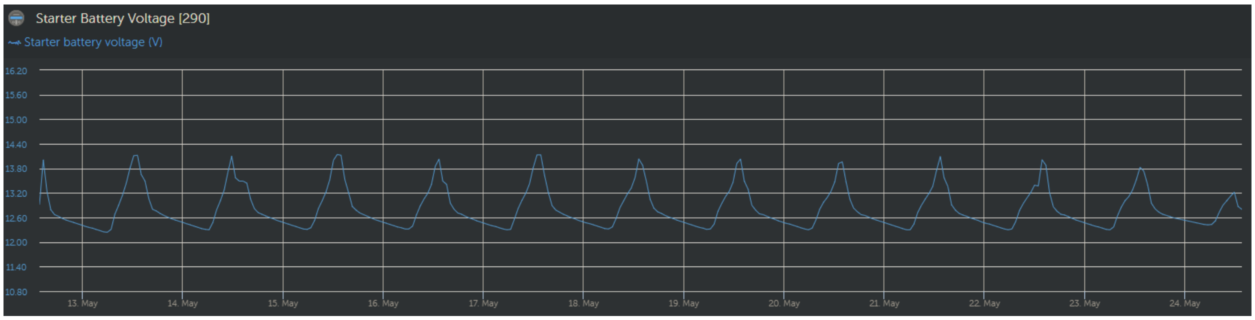
The peaks for the voltage of the system during the day reach an average of 13.5 Volts which indicate that the system is charging and drops to the lowest of 12.34 Volts that indicates the system is still charged and operational. As for the current, the system reaches peaks of 11.5 Amps during the day and -4.60 Amps during the night.

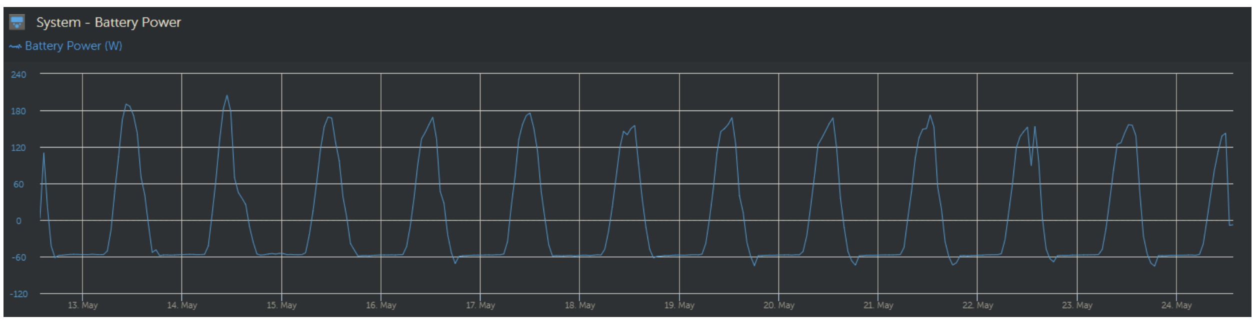


The following graphs will display the results for the batteries viewpoint as Battery State of Charge (SOC), the consumed Amp Hours, and the starter battery voltage, and Battery power. The battery SOC graph demonstrates the battery level dropping from a full charge during the day to an average for the lowest peaks of 76% pulling a total average of 66 Ah every day. The Battery voltage graph confirms this by sharing the voltage during the day to hit peaks 14.0 Volts and as low as 12.33 Volts during the night that indicates the battery are still charged while the battery power graph shows that during the day there exists peaks where the batteries receive 150 Watts of power and the rest from the PV yield graph is to run the system during daytime while during night-time; the indications shows lowest values of -60 Watts being pulled from the battery to operate.









8 Conclusion

The PV system allows the extension of operation for the enforcement trailer from original ten days and pushing the requirement of a month to continuously run off-grid based on the weather conditions. As this system was tested in the middle east region where solar is heavy resource, the trailer will be capable to run continuously with the rare occasions of bad weather throughout the year; which is a better alternative than constant requirement of transporting the trailer for recharging; as the additional features will allow easy access for charging from the grid with a simple plug as opposed to removing the batteries to charge them and requirement to independently charge the front battery of the drive system. The additional features will allow the charging of all the batteries from the grid if necessary.

8.1.1 Future Recommendations

As this is the initial design for the PV system, the room for improvement is large and could be implemented in several different directions. Beginning with the solar panel design and performance, the design and sizing of the panels; allowing the increase in size will lead to more power generated for the system.

The solar panel's cell efficiency is another factor that can be improved upon to ensure the same constant power supply in the scenario that a part of the panel might face some shadows, the panel will continue to operate in pulling the same power thus not plummeting the voltage generated from the panel.

The battery chemistry and capacity, moving for the bulky lithium cells used previously to AGM cells allows for storage space which allows for the increase in capacity for the future requirements and increase in run time independent of the PCV system. Looking into different battery chemistry to allow for better efficiency in cycle life and depth of discharge.

As for the MPPT charge controllers, each solar panel can be introduced to their own to avoid power drops when one of the two connected panels face less sun exposure or exposed to a shadow as the trailer surfaces have different orientations. The introduction of diodes for the solar for their extra protection to avoid any current backflow into the solar equipment when high loads are applied by the system.

General Conditions

8.1.2 Handling & Transport

The enforcement has two modes of transport; for large distance the trailer must be towed or transported and for short distance usually tuning the trailer for deployment, this can be using remotely controlled motors. For towing, the clutch is disengaged and allows for free flow on the wheel while when remotely controlled the clutch is engaged to allow the movement of the motors.

The solar modification and add-on of the solar panels unto the trailer increases the necessity for their safety to avoid any damages. The panels were tested through a simple drive test to ensure their fixatures allowing a max speed of 60km per hour during transport however it is recommended for the removal of the frames that contains the solar panels and reattachment during deployment.

8.1.3 Storage and Deployment

Deployment of the trailer with the solar implementation must consider the sun path, surrounding environments, and orientation of the trailer for maximum achievable results. This is done to avoid any shadows that could decrease the performance of the PV system.

-END OF DOCUMENT-