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AGRIVOLTAICS PV SYSTEM WITH BATTERY ENERGY STORAGE AND BACK-UP POWER (AGRIVOLTAICS MICROGRID) FOR INTEGRATION TO THE GRID AT FARMING FACILITY IN MOCA, PUERTO RICO

Revision History

Revision	Originator	Reason for Change	Date
0	José E. Garcia, PE	New Document for Revision of CDBG-ER2 program	OCT 26, 2024
1	José E. Garcia, PE	Removed ICE generator specification	DEC 28, 2024
2	José E. Garcia, PE	Revised according to program requirements and new information generated for project.	MAY 25, 2026

1. PURPOSE

Agroenergética LLC submitted a proposal under CDBG-DR ER2 program funding in support of the project “Agrivoltaics for Energy and Food Security in Rural Northwestern Puerto Rico”. The proposal was among the 20 proposals selected to proceed to the next phase of project awarding. This document provides the specifications for both main project activities within the AgriVoltaics project, which are the production of continuous, resilient energy for the benefit of a Low- to Moderate-Income (LMI) people while maintaining the main purpose of agricultural land which is the production of food.

The goal of the project is to design and perform strategic project delivery of a 2.2 MW DC photovoltaic (PV) facility co-located with local specialty agricultural crops at Hacienda Gosén, a farm and food processing facility in the Barrio Cerro Gordo of the municipality of Moca.

2. SCOPE

This document intends to present the functional design of the different energy generation and/or management equipment components that will make up the Agrivoltaics Microgrid. Functional Specifications are limited to the integration of the system components that are required to fulfill the energy generation, storage, distribution and interconnection to the utility grid.

This document includes information about:

- Proposed MicroGrid system architecture
- PV Solar system energy generation projection
- Proposed energy export to utility grid
- Proposed point of interconnection, location and coordinates
- Total land area requirements
- Available land for agricultural production
- Energy Impact coverage for neighboring communities
- Benefits for the Utility company
- Operation and Maintenance plan, procedures and template contracts

3. ACRONYMS AND DEFINED TERMS

The following list intends to facilitate the understanding of the terms or acronyms used within the pharmaceutical industry in general, as well as those specific to the client facilities.

Acronym/ Term	Definition
User	A person (or persons) whose job involves the use of a computer system or application but does not need any detailed knowledge of computer programming.
PV	Photovoltaic
EMS	Energy Management System
BESS	Battery Energy Storage system
PPC	Power Plant Controller
MC	Microgrid Controller
SOC	State of Charge
CT	Current Transformer
PT	Power Transformer
POC	Point of Interconnection
KW	Kilowatt
KWh	KW-hour
KWh/day	KW-hour per day
EMS	Energy Management System
DER	Distributed Energy Resources
MPP	Microgrid Power Plant
Grid Forming	The electrical power producer that provides the voltage and frequency reference
Grid Following	Electrical power generation units that will follow the reference provided.
Ed	Energy per day
Pt	Total size of DC solar energy system
Peak hours	Sun irradiation peak hours based on meteorological data
η	Efficiency
PCS	Power Conversion system (i.e. Inverter)
PQ mode	Refers to equipment in grid following mode
UF mode	Refers to equipment in grid forming mode, regulating voltage and frequency

4. SYSTEM OVERVIEW

4.1 Purpose of the System

The Agrivoltaics Microgrid consists of the combination of a photovoltaic solar energy generation system, a battery energy storage system (BESS) as a centralized energy storage and management system, and the microgrid controller who manages the energy assets and the electrical ancillary equipment which provides the electrical combination and interconnection. The combination of these technologies provides the electrical power capacity sufficient to support approximately 400-450 household units in the nearby community. Also, it will serve as an electrical power enhancement to the utility electrical feeder in the vicinity.

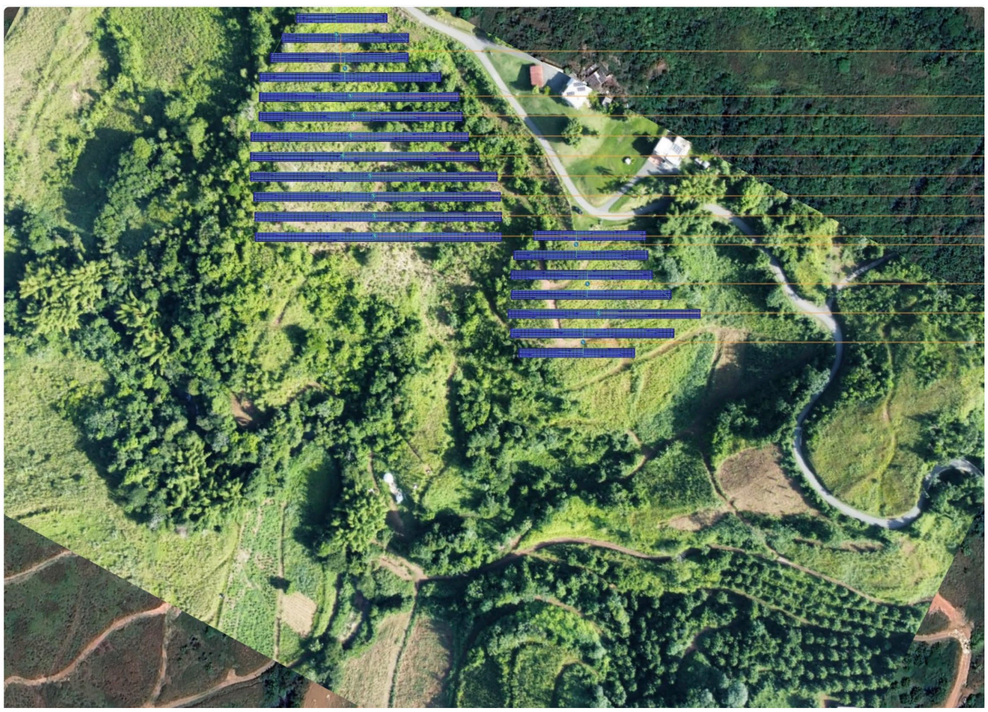


Figure 1: Conceptual Layout of PV new solar energy system.

From a power generation/electrical systems perspective, this utility-scale PV system will be tied to two (2) units of 750 KVA, 2.5 MWh BESS interconnected to the grid through nearby substation and bus tie-ins. The system's operations and energy delivery to the grid will be regulated, or capped, at a maximum power capacity to ensure consistent power supply during daytime hours when solar power generation is in progress, as well as peak demand hours (between 4 - 9 pm) with BESS discharge. The system will be a local microgrid providing power-as-a-service to the local community and grid operator via a power purchase and operating agreement (PPOA). The most value-added functionality for the grid operator is the available power during peak demand periods which are usually from 4 PM to 9 PM.

From an agricultural perspective, this project will provide approximately 10 acres of conditioned and enriched soil for the cultivation of horticulture and high value crops. Land between structure rows could become vegetable and greens crops cultivation areas, while shaded soil below structures could become ginger, turmeric and cocoa crop areas. It will also add opportunities for research and agricultural land use, leading to new crop development, product availability, and job creation in the area.

Objectives for this project:

1. Provide an isolated and autonomous power plant with resilience that could provide power in the absence of the utility. Significantly enhanced the power quality and availability within the area.
2. Contribute to support the efforts of enhancing two main critical needs of the community, available energy and food production.
3. Become a model for sustainability by inserting the community and the academics into the development, support and education efforts.
4. Create local jobs for the maintenance and operation of the system. Create jobs for food production.

4.2 Community demographics

The community near the Agrivoltaics Microgrid is the Cerro Gordo Ward accessed via PR-495. The cerro Gordo Ward is the most extensive territorial ward of Moca. Based on US 2020 census data, the population of Cerro Gordo Ward by 2020 was 2,421. There are 1,051 households, where 78% are 2-3 bedrooms units. Population of the household is around 2 people per unit. The average size ranges from 1,100 to 1700 sq ft. 75% of dwelling units are owned. Based on size of houses and population, the average energy consumption ranges from 15 to 25 kWh per day.

4.3 Operating Scenario

The Agrivoltaics Microgrid main energy power generation subsystem will be the PV solar energy system. The 2.25 MW solar system will generate approximately 9,000 kWh during a day, 3,250,000 kWh per year. Based on an average energy demand of 20 kWh per dwelling unit, the MicroGrid would be able to provide energy to 400-450 households.

The BESS in combination with the MicroGrid power plant controller will manage the energy to the utility in a continuous, stable and regulated supply within a time frame of 8-10 hours. As part of the integration, the overall system will also be comprised of other subcomponents that are essential to the main components integration.

a) An energy network infrastructure that includes equipment for energy generation (usually multiple distributed energy resources, or DERs), energy distribution network(s), and energy data networks.
b) Sensors and meters
c) Controls at the DER level (PV System and BESS)
d) Controls at the microgrid level, aimed at best managing the entire system
e) SCADA system interface with microgrid op-based services such as demand charge optimization, demand response, self-consumption management, blackout management, CO_2 reduction, etc.

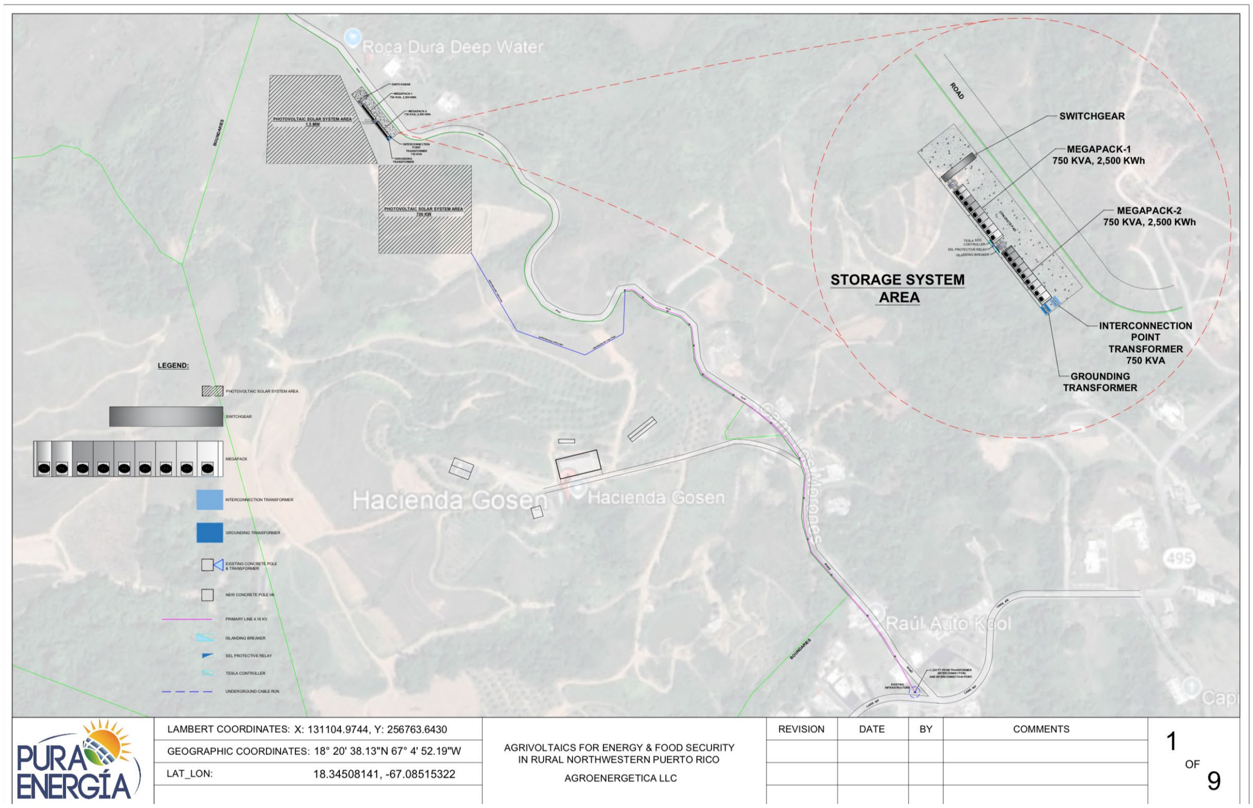


Figure 2: Agrivoltaics Microgrid conceptual site plan.

The Agrivoltaics power plant operates in a grid following mode scenario. The solar energy generated during the day will be distributed between the BESS system for the recharge of batteries and the regulated output to feed the grid. Once the power exported from grid is not sufficient to reach 750 KVA by the solar system itself, BESS will contribute with the difference required by to achieve the 750-kWh output. The BESS system will discharge to an SOC of 15-20% daily.

The following day's energy generation will mainly be dedicated to BESS charging during morning hours. The Microgrid controller will manage the balance of energy distribution and power output between the BESS and the grid. AC output power will be modulated during AM hours. It will gradually reach 750 KVA, once BESS SOC is restored to 100%.

The regulation of the exported AC output to the grid allows the interconnection to the nearby primary feeder at a voltage of 4,160 Vac. The capped, regulated output will transmit a current of 105 amps to the primary feeder. Therefore, we understand that upgrade to primary feeder cables would not be required. The interconnection point is expected to be 1,900 ft from the interconnection substation. Power lines are required to extend the primary line feeders up to the substation transformer.

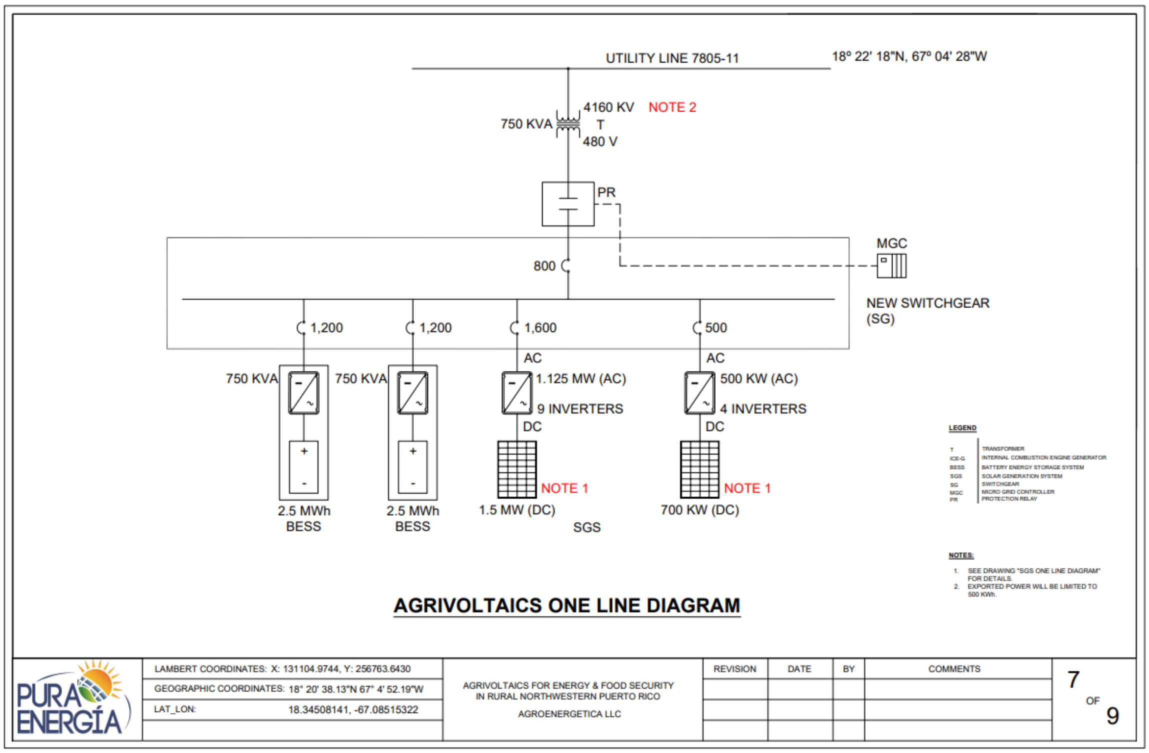


Figure 3: Agrivoltaics Microgrid system single line diagram.

4.4 System Configuration

4.4.1 PV Solar Energy System

The Agrivoltaics microgrid will mainly rely upon the PV solar energy generation. The proposed solar energy system 2,250 KW DC solar system with a 1.6 MW AC power output distributed and interconnected to the battery energy storage system. It generates about 9,000 KWh per day.

The estimated energy production by month for the total 2,250 KW solar system is shown in the graph.

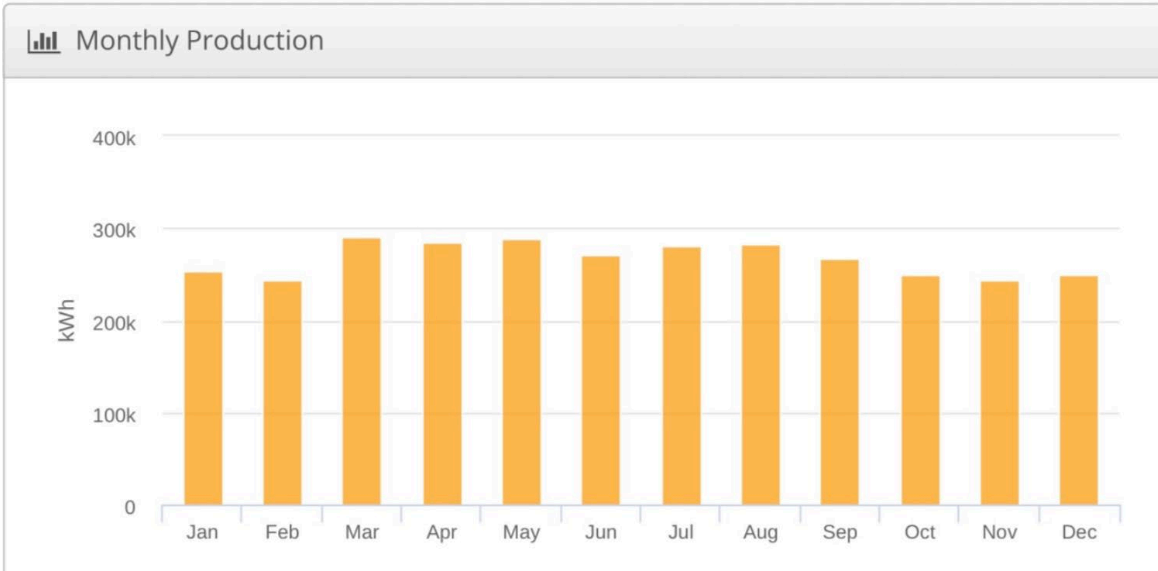


Figure 4: PV System system expected monthly production.

The solar energy produced by month by the system will oscillate between 7,700 to 9,700 KWh/day. The solar energy produced by day is calculated based on the equation below:

$E_d = P_t$ X (peak hours) X η
E_d = 2,250 KW x 5.3 X 0.78
E_d = 9,300 KWh

The solar energy production will mainly occur during a timeframe of 5.3 hours. If the energy produced by the new system is divided into the five hours of solar energy production the energy per hour is:

E_d per hour = 9,300 KWh ÷ 5 = 1,860 KWh per hour.

During sun peak hours, the Agrivoltaics microgrid system will store about 1,000 kWh to replenish the BESS capacity to 100%. The remaining energy will be exported to the grid, regulated to 750 kWh per hour, not to exceed the interconnection transformer capacity of 750 KVA.

4.4.2 Battery Energy Storage System (BESS)

The BESS provides the following functionality:

1. The storage for the excess of solar energy produces during the solar irradiation peak hours (5 hours).
2. The energy supply during off sun peak hours.
3. The central power provision system that will become the Grid Forming distributed energy resource, in the event of utility power shutdown.
4. A high quality electrical regulated power to be provided to the operations overall electrical loads.

Figure 5: Tesla Megapack 2 XL.

The BESS shall be capable of storing energy from the solar system, but also, from other DER present as a source of power generation.

4.5 Critical Design Considerations

- Design shall fulfill the mission of having reliable and resilience energy available for the Cerro Gordo Ward community at Moca, Puerto Rico.
- Design agrivoltaics system that considers agriculture as primary use of land. Of the leased land, a minimum of 30% should still be usable farmland.
- The Microgrid power plant will have the capability to provide energy to the utility feeder even in the absence of power from the utility.
- The main source of energy shall be the solar energy/energy storage DER component.
- The BESS DER component will act as the GRID forming component in the absence of the utility. It will be the master unit establishing and

regulating the voltage and frequency of the distributed power interconnected to the grid.

- THE BESS response time shall comply with standard UPS systems response time (100 ms or less).
- The Microgrid operations shall require personnel from the provider either at the site or remotely monitoring the system operation.
- A SCADA application shall provide real time monitoring and control.
- Major components must be rated for jurisdictional seismic events and hurricane force winds of 175 mph.

PV	2.5 MW - 14 * SMA PEAK3 125 kW
BESS	1.5 MW - 2 * 2,500 kWh Storage
Interconnection Transformer	750 KVA pad-mounted, step-up, 480 VAC to 4,160 V
Application	Main Mode: BESS Grid Following BESS Island Mode: No utility presence

Table 1: Agrivoltaics Microgrid proposed power plant equipment

5. SYSTEM OPERATION

5.1 System Modes of Operation

The system modes of operation are based on the single-line diagram presented in Figure 3.

5.2 Microgrid Controller Hypothesis

Table 1 lists the conditions, or hypothesis made by the Microgrid controller in the execution of the design of the Delivery. It is the responsibility of the Customer to make sure that all these conditions are verified. The provider could not be held responsible if observed controller behavior was not in conformity with one or several items of the List of Requirements if any of the mentioned conditions were not met. These requirements should be met before the beginning of the Commissioning of the Delivery.

Hypothesis	Description
1	The plant configuration should be in conformity with the one represented in Figure 1, including the number of power units, their types, the topology of

	the power plant and the position of power meters. In the following the nomenclature reported there is followed.
2	It is the responsibility of energy system integrator to ensure that all devices to be controlled support Modbus TCP and Modbus RTU, and to provide Elum Energy with the Modbus register maps, and to ensure that the devices are in conformity with the requirement listed in Appendix A - Required IO Access.
3	The system is initially configured to work in UF mode.
4	The system can transition from UF mode (mode in which the utility regulates the voltage and the frequency of the system)) to PQ mode (mode in which the BESS allows the reception and application of active power commands) via a Modbus command to the Tesla site controller.
5	All electrical protections such as reverse power protection, over voltage protection, sync check and any other fast acting protection functions are achieved by third party devices and not included in the Elum PPC controller scope.

Table 2: List of hypotheses

5.3 MicroGrid Control Requirements

The plant will operate under the following two modes:

- BESS in command
- BESS in following mode

This section describes in detail each control mode including the control functions enabled and the conditions for the definition of the mode.

5.3.1 BESS in command mode (no utility power presence)

During command, the BESS is regulating the voltage and the frequency of the system while the PV inverters are in PQ mode and will receive active power commands from the Microgrid PPC Controller.

5.3.1.1 Control functions

Below are the control functions proposed for the BESS in command mode:

Unit	Function	Description
PV	Ramp Rate Control	Constrain PV curtailment setpoints so as to keep setpoint induced ramps of the total PV active power in a configurable range (NB: does not compensate for natural variability of the PV production).
PV	SOC limit management	Curtail PV active power when SOC reaches a configurable limit.
PV	PV fraction control	This function controls the active power setpoints by sending to the inverters to keep the part of active power mix generated by PV under a configurable threshold.
PV	Battery Power Limits	Curtail PV active power to limit the charging of the battery to a configurable maximum.

5.3.2 BESS in following mode

When User Command is received to declare the BESS in following mode, the MicroGrid controller will send a shutdown command to the BESS, switch the operating mode from PQ to UF, and perform a black start with the utility. If utility becomes unavailable, the system will send a stop command, set its operating mode from UF back to PQ, and perform a black start with the BESS.

5.3.2.1 Control functions

Below are the control functions proposed for BESS in the following mode.

Unit	Function	Description
BESS	Mode Orchestration (PQ to UF)	Change the operating mode of the BESS from PQ (mode in which the BESS allows the reception and application of active power commands) to UF (mode in which the BESS follows the utility regulates voltage and frequency).
PV	Ramp Rate Control	Constrain PV curtailment setpoints to keep setpoint induced ramps of the total PV active power in a configurable range (NB: does not compensate for natural variability of the PV production).

6. DER COMPONENTS DESCRIPTIONS

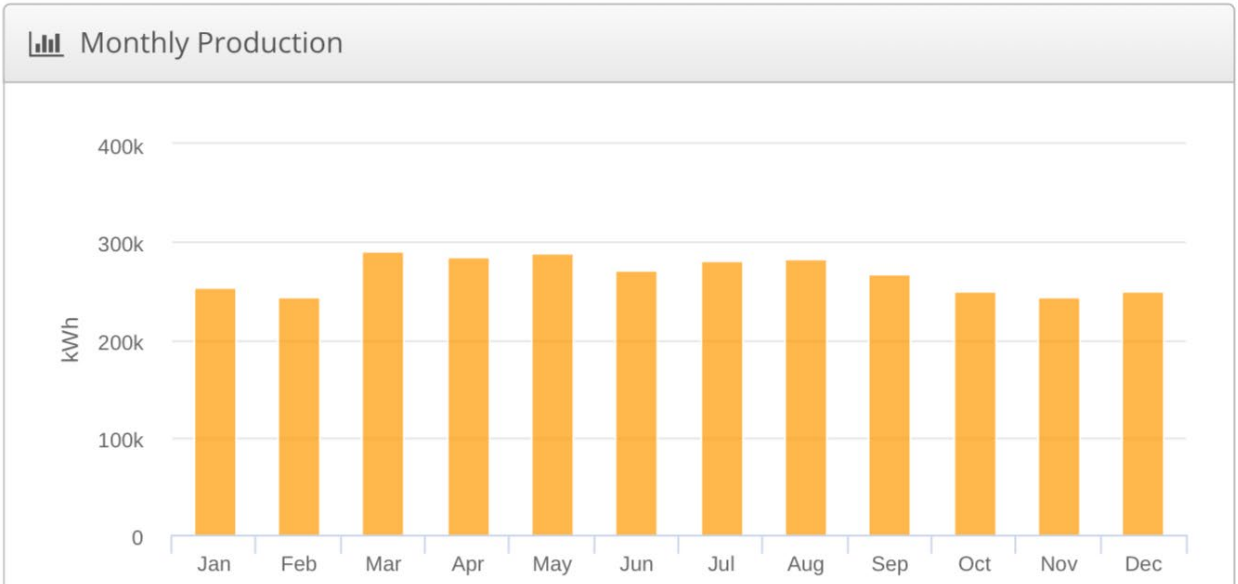
6.1 Photovoltaic Solar Energy System

The PV solar energy system will have a total capacity of 2,250 KW.

The system is composed of two main areas, the top one of 1.5 MW and the bottom one of 750 KW. Product selection shall consider wind loading capacity of the PV panels, and any PV panels selected shall withstand at least 3500 Pascals of wind uplift pressure. As per the graph and table shown in Figure 6, the months of least production are November and February. March is the month of the highest production. There are six months with production estimates over 270,000 Kwh per month, that represents 9,000 kWh per day. The total annual production is approximately 3,243,000 kWh.

The design of the PV system shall contemplate the addition of instruments to continuously monitor every single solar PV string. This will ensure that the operation and maintenance department has all tools necessary to monitor, diagnose and repair any solar panel malfunction. The above schematic shows the DC side of the 2.25 MW system. A group of 5 to 7 strings will be wired up to a combiner box with fuse protection and string monitoring instruments. Network communication from each combiner box will be transmitted to the energy control center room located in the vicinity of the BESS area. In case of the need to diagnose any string, the combiner box could be switched off from the rest of the system.

The design has taken into consideration the required instruments, tools and safety precaution means for the continuous operation and maintenance of the system, locally or remotely.



Month	GHI (kWh/m^2)	POA (kWh/m^2)	Shaded (kWh/m^2)	Nameplate (kWh)	Grid (kWh)
January	139.6	149.3	149.2	315,723.2	253,597.1
February	138.2	144.8	144.7	307,017.0	243,372.0
March	170.0	174.5	174.5	371,931.9	289,860.3
April	171.2	171.8	171.7	366,140.8	284,607.0
May	172.6	171.0	170.9	362,545.6	287,821.6
June	163.2	160.9	160.8	341,413.1	270,837.1
July	167.8	166.1	166.0	353,245.5	281,130.3
August	169.1	168.9	168.8	359,085.2	282,629.3
September	157.3	159.9	159.8	341,012.2	267,178.8
October	144.1	149.6	149.5	318,715.4	249,089.6
November	135.0	143.4	143.3	303,997.6	243,417.3

Figure 6: PV Solar system generation by month.

6.2 PV system mounting structures

Prefabricated carport type mounting structures are planned to be used. Installation time could be reduced significantly, and also structural components management is more feasible in a farm environment.

Structural design of the canopies shall comply with the Puerto Rico IBC 2018 Code and the most recent version of ASCE 7 at the time of design. Design of structures shall tolerate wind gusts of 175 mph and consider

Figure 7: Typical ground-mounted canopy style PV system in open fields.

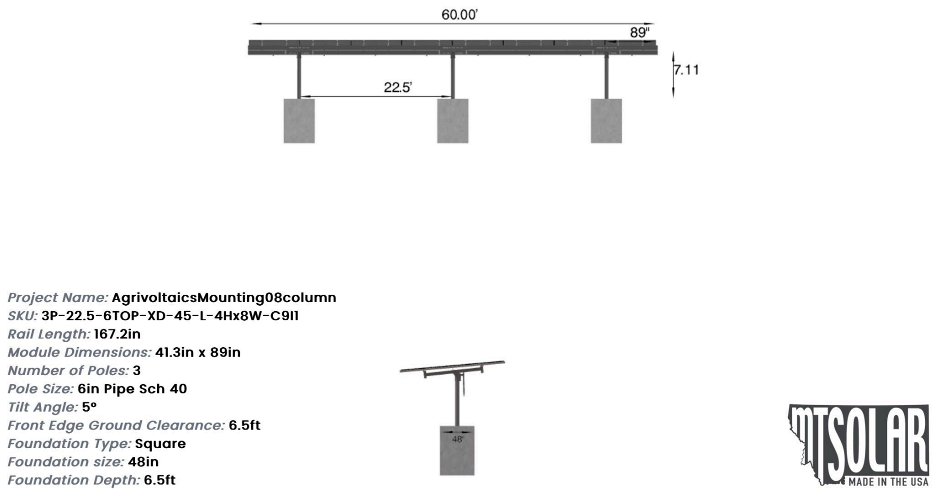


Figure 8: Typical structure for Agrivoltaics project based on MT Solar.

6.3 Battery Energy Storage System (BESS)

The BESS DER consists of five (5) 30-ft. containers. Each container encloses 2,500 kWh of batteries and a 750 KW PCS. The containers are electrically connected in parallel to the main power bus. The main power bus voltage is 480 VAC. The total energy storage is 5,000 KWh.

The ancillary equipment associated with the BESS are site controllers, instrumentation meters, controls and distribution electrical equipment.

Special considerations need to be made for concrete pad structural support based upon equipment weight.

6.4 Intelligent Energy Center (IEC)

The Intelligent Energy Center will become the Microgrid main switchgear. Feeder protection relays and control logic will be integrated into the IEC.

The Microgrid PPC controller will actuate on the feeder protection relays associated to the DER's that are part of the MicroGrid. The SCADA system will communicate via Ethernet to the IEC for continuous monitoring of each of the system components and overall operation.

6.5 Microgrid controls and communication

The Microgrid system requires continuous remote communication. It should provide redundancy with two different technology carriers. All DER's shall provide ethernet connection ports for remote access monitoring.

There will be an intranet for communication equipment. The following networks are required:

1) DC Combiner Boxes network
2) SMA inverters network
3) BESS network
4) Intelligent energy center network

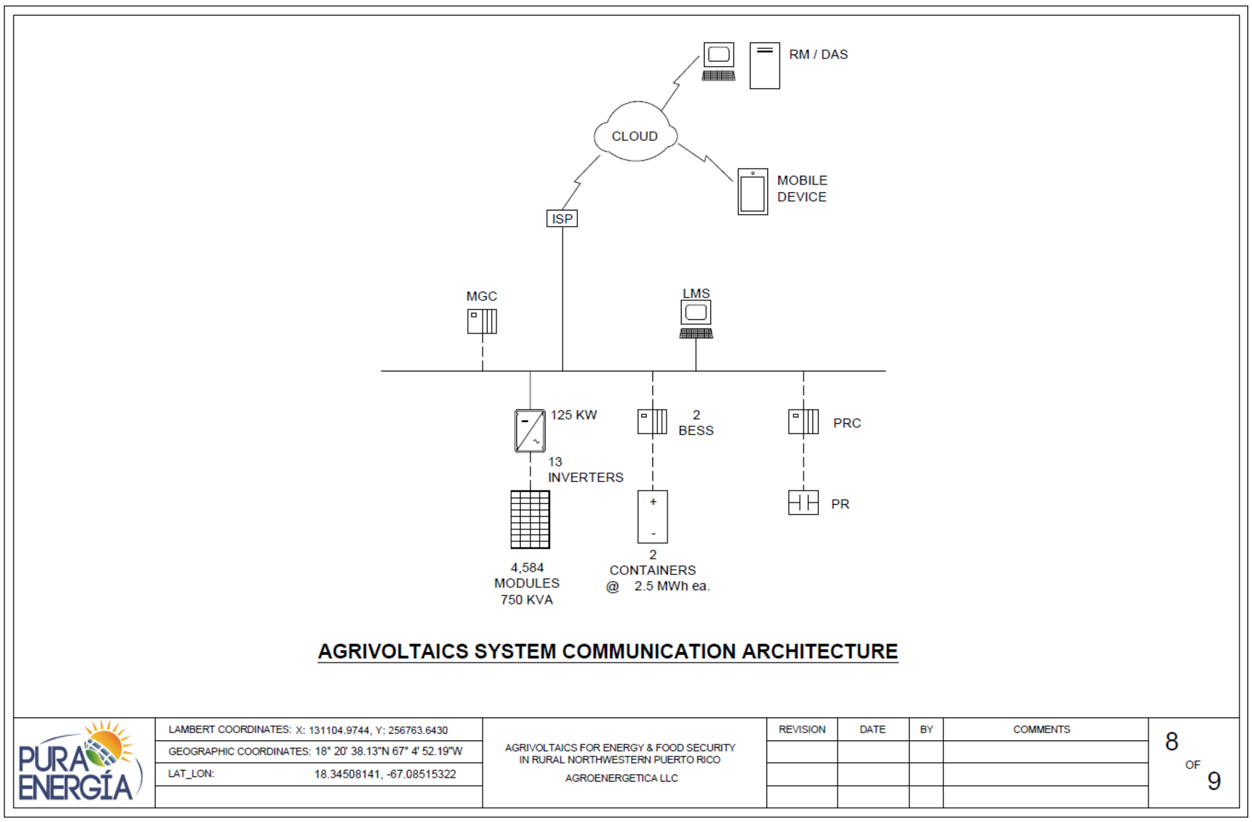


Figure 9: Communication layout and architecture.

6.6 Utility Point of Interconnection

Exported power to the utility is maintained at 750 KVA or under. That voltage level is suitable to be interconnected to distribution lines. The interconnection substation rated power is included 750 KVA. The transformer will serve as a voltage step-up from 480 VAC to 4,160 V.

The closest three phase line is approximately 2,500 ft from the Agrivoltaics Microgrid station or the interconnection substation. This project contemplates extending three phase lines from the nearest pole at coordinates 18.3416 N, 67.0736 W.

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Figure 10: Possible point of interconnection.

7. DOCUMENTATION AND TESTING

1.1 PV system commissioning test

The scope of the PV system commissioning is to demonstrate that wiring up to the combiner boxes and inverters are free of defects, open circuits or voltage arcs. Strings are tested to verify proper generation by string. Drop of AC voltage levels up to the switchgear, shall be maintained below 3%.

1.2 BESS Site Acceptance Test (SAT)

BESS tests will follow Tesla MegaPack 2 XL tests.

1.3 Documentation

Contractor will deliver the following documentation as part of the project:

- Design Specifications, schematics and system configuration documentation prior to installation
- Commissioning Acceptance Test document
- Agrivoltaics Microgrid System Manual

Grid transformation for the world's largest energy projects

- Best-in-class energy density and round-trip efficiency
- Industry-leading power electronics and thermal system performance
- Rapid and cost-effective deployment with factory-assembled and pre-tested solution

Scaled and rigorously tested product safety and reliability

- Comprehensive in-house reliability testing by the leading experts in the industry
- Engineered for safety and performance at every level
- Continuous improvement based on large-scale operational experience

Designed with flexibility and configurability in mind

- Modular architecture that allows for a range of configurations across multiple applications
- Industry experts available to identify site-specific needs
- Integrated solution that allows for battery augmentation over time

POWER AND ENERGY

Megapack duration is configurable. Standard configurations are 2-Hour and 4-Hour durations. Nominal energy is specified at 25°C (77°F).

	AC Power per Megapack	Energy per Megapack
2-Hour	1927 kW	3854 kWh
4-Hour	979 kW	3916 kWh

ELECTRICAL

Nominal AC Voltage	480 V AC 3-phase
Nominal Frequency	50 or 60 Hz
Inverter Power per Megapack[1]	2-Hour Max: 2400 kVA 4-Hour Max: 1320 kVA
Round-Trip Efficiency[2]	2-Hour: 92.0% 4-Hour: 93.7%

[1] Scalable from 400 kVA minimum in increments of 50 kVA

[2] Full-depth cycle including all power conversion and thermal system losses, at 25°C (77°F)

WARRANTY

Coverage	All-inclusive, equipment and energy retention
Term	15 years standard, extendable to 20 years

PART NUMBER

1848844-XX-Y Where X is a number between 0-9 and Y is a letter

MECHANICAL AND MOUNTING

Ingress Ratings	IP66/NEMA 3R (Main Enclosure) IP20 (Thermal System)
Enclosure Dimensions +/- 13 mm (½ in)	Width: 8800 mm (346 ½ in) Depth: 1650 mm (65 in) Height: 2785 mm (110 in)
Maximum Weight	38,100 kg (84,000 lb)
Operating Ambient Temperature	–30°C to 50°C (–22°F to 122°F)

REGULATORY

System is compliant to grid codes and safety standards of all major markets.

System	NRTL listed to UL 1973, UL 9540, UL 9540A, UL 1741 SB, IEC 62619, IEEE 1547
Cells	NRTL listed to UL 1642

CONTROLS AND COMMUNICATIONS

Protocols	Modbus TCP / DNP3 / REST API	
Core Control Modes	Direct Real Power Direct Reactive Power Frequency Support Virtual Inertia	Ramp Rate Control Site Control Power Factor Control Voltage Control

MONITORING

Powerhub	Free-to-use cloud monitoring portal