Power Plant Controller for Grid-Connected Solar Facility

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***Abstract*—Investors once avoided distributed energy resources (DERs) due to high costs, but thanks to technological advances and reduced expenses companies can now use solar photovoltaic (PV) systems to generate power, feed the grid, and earn revenue. With this advancement comes the necessity for a robust control system to optimize DERs to create reliable power systems and profitable generation. Such systems enable centralized inverter control, support grid frequency and voltage regulation, supplement load demand, maximize power export, and ensure compliance with power purchase agreements. To achieve these objectives, control systems must operate in multiple modes to regulate voltage, power factor, and reactive power while maximizing active power from DERs. They also include guard rails to keep setpoints safely within system limits and ensure proper antiwindup protection for power setpoints.**

This paper presents a real-world implementation of a power plant controller (PPC) for a solar farm, which has one utility tie line connection through a step-down transformer and an array of more than 20 PV inverters distributed over multiple PV collector feeders. All feeders and utility tie lines are connected to a medium voltage bus along with a shunt capacitor. The PPC was designed to meet the overall requirements of the solar farm owner in maximizing solar production while satisfying local grid operator requirements. The core of the PPC system is a substation-hardened controller that runs the main logic and provides communications interfaces to PV inverters, relays, data concentrators, meters, and remote terminal units.

***Keywords*—Power Plant Controller, Distributed Energy Resource, Inverter-Based Resource, Solar.**

I. INTRODUCTION

Power plant controllers (PPCs) are the central intelligence of modern power plants, balancing performance, stability, and economic efficiency [1]. These advanced control systems are designed to manage and coordinate the operation of generation assets, especially for plants incorporating distributed energy resources (DERs). PPCs play a critical role in ensuring that power plants operate efficiently, safely, and in compliance with grid requirements.

PPCs are needed to maintain stable plant operation by regulating key parameters, such as voltage, frequency, active power, and reactive power [2]. They enable cohesive integration of renewable resources like solar and wind, which are inherently variable, into the power system. Additionally, PPCs help optimize power output, support grid reliability through ancillary services, and ensure adherence to grid codes and power purchase agreements.

This paper presents an overview of a real-world implementation of a PPC for a facility in Eastern Canada, which was designed to export power to the utility grid while maintaining medium voltage (MV) bus voltage within the range of 0.95 to 1.05 pu and, when required by the grid, provide support by dispatching the inverters for both active and reactive power.

The functions included in PPC:

- Active power control: for utility interconnection through maximizing and curtailment of photovoltaic (PV) inverters.
- Reactive power control: via PV inverters and shunt capacitor (SC) reactive output regulation.
- Voltage control at the MV bus: effectively achieved via reactive power regulation.
- Ramp rate control: limits power fluctuations via active power control.
- Grid frequency support: provided by ensuring net power export from the plant using the available PV inverters.

Each section of the paper presents a specific component of the overall electrical system and control solution. Section 2 outlines the electrical system. Section 3 describes the implemented communications architecture. Section 4 details the functional overview of the PPC. Section 5 provides details for the approach to testing at different sites and their results.

II. POWER SYSTEM OVERVIEW

The facility has one high-voltage (HV) (230 kV) utility tie, which is connected to the MV (34.5kV) bus via a step-down transformer rated for approximately 55 MVA. In addition, there are three PV collector feeders and one SC feeder. All feeders and utility tie lines are connected to an MV bus through a combination of controllable circuit breaker and disconnect switch(es). The facility has a total of twenty-eight (18) PV inverters distributed across three (3) collector feeders and each PV inverter was rated at approximately 1925 kW. Figure 1 shows an overview of the power system.

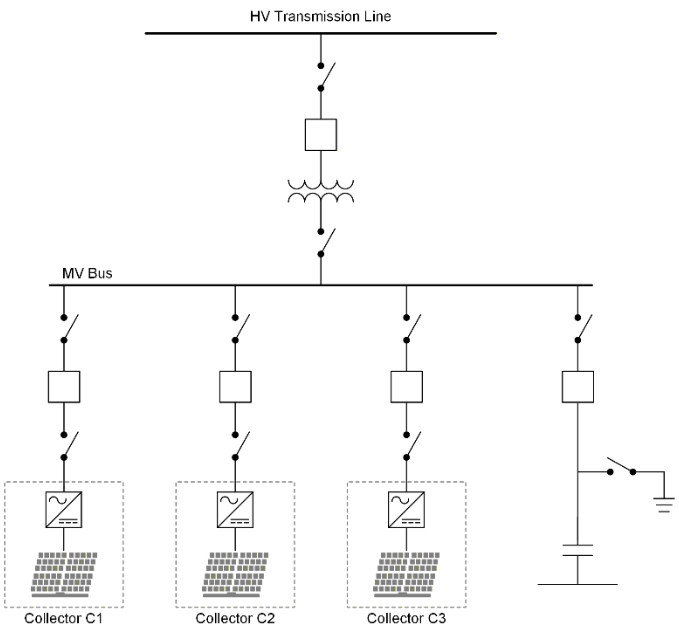

Figure 1 - Power system overview

III. Communications Architecture

Figure 2 shows an overview of how the PPC, relays, remote terminal unit (RTU), data concentrator (DCON), and PV inverters are connected to the Ethernet network, enabling the exchange of various data points. The PPC communicates with inverters and relays to control and monitor the facility, maintain the bus voltage in the range of 0.95–1.05 pu, and control the export active power across the point of common coupling (PCC). Each PV inverter communicates with the PPC using two different Modbus channels—one for sending status and monitoring data for supervision and a second for receiving control signals, such as state commands and dispatch setpoints.

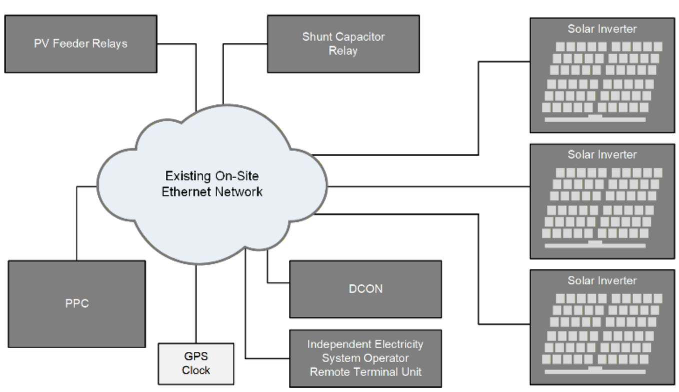

Figure 2 - Communications architecture

A brief description of each device involved in PPC system is as follows:

- Feeder relay(s): Provide two distinct functions of status and control. On one Modbus channel they send breaker and disconnect switch statuses as well as analog measurements for voltage, frequency, active, and reactive power. On the other Modbus channel, the relays receive control signals from the PPC for breaker open and close functions.
- RTU: Provides an interface between the PPC and Independent System Operator (ISO) and receives telemetry points from the PPC for monitoring purposes.
- DCON: Interfaces plant operations with the PPC, sending commands, setpoints, and measurements for control, while also receiving inverter status, alarms, and feedback for commands sent to the PPC. This device is the middle-man for all communications.
- PV Inverter: Receives set point commands from the PPC to achieve dispatch objectives and sends back PV state and output values.

IV. PPC – Functional Overview

The PPC is based on various function blocks developed in the IEC-61131-3:2025 environment using a rugged industrial controller. The implementation discussed consists of the following primary functions within the PPC.

A. *Active Power Control*

The power output of an inverter changes quickly when solar radiation varies. For example, when a cloud passes, some inverters suddenly produce less power, while others at the same facility may still have unused capacity.

The active power control algorithm monitors the changing power from individual inverters and adjusts others as available to deliver a stable, total power output at the PCC. It also ensures that any changes to the power limit follow the defined ramp rate of each inverter to mitigate harsh step-changes, so adjustments happen more smoothly. In this mode, inverter setpoints are being controlled via a proportional-integral (PI) controller. Figure 3 shows a simplified logic diagram for the active power control for this control sequence.

When the plant power is within a defined deadband of the target power flow across the PCC, the controller stops updating setpoints. It resumes adjustments only when target power flow across the PCC moves outside this deadband range. Table 1 lists out details of the main parameters used by the algorithm for active power control.

Table 1 - Parameters for Active Power Control

Parameter	Description
Active Power Target	PCC real power set point
Deadband	PCC power limit deadband
Kp	Proportional tuning parameter
Ki	Integral tuning parameter
Ramp Rate Up and Down	Plant power limit ramp rate (real power change/s). Setting to 0 will result in no ramp supervision

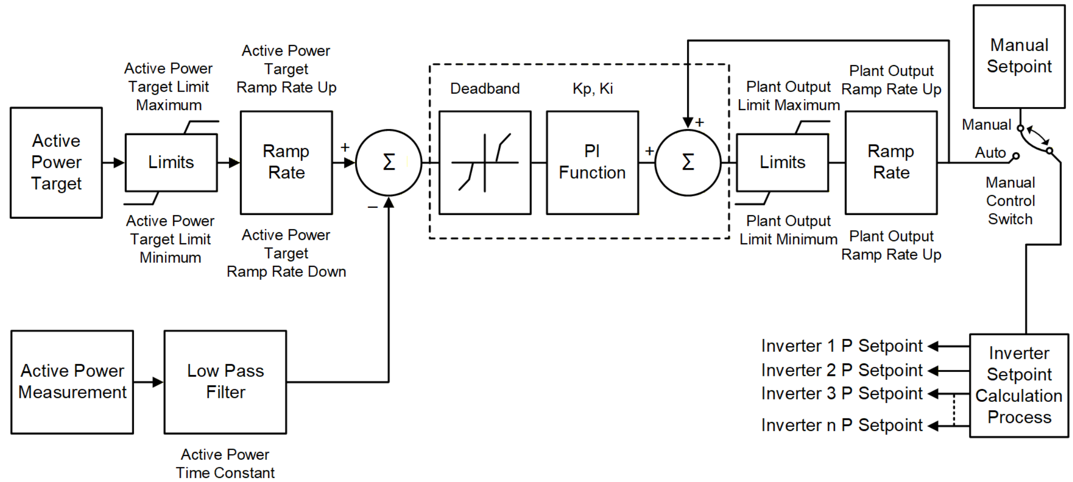

Figure 3 - Logic diagram for active power control (closed loop)

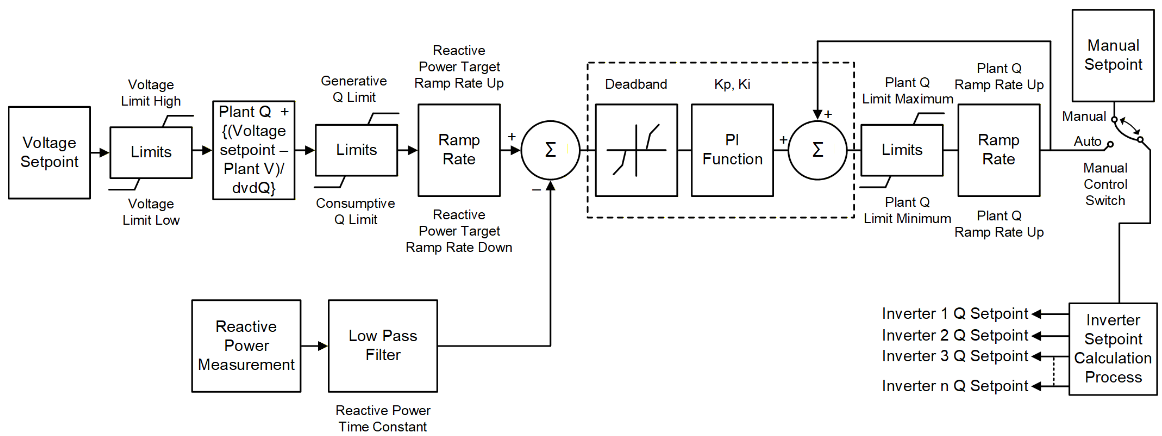

Figure 4 - Logic diagram for reactive power control (closed loop voltage control)

B. *Reactive Power Control*

In this mode, the PPC adjusts the VAR reference of the inverter to provide precise adjustment of the voltage magnitude at the PCC. The PPC uses a PI controller for these adjustments. Figure 4 shows a simplified logic diagram for closed loop voltage control for this control sequence.

For this mode to function properly, the inverter must be in VAR Control mode. If the inverter is not in VAR Control mode, the controller will periodically attempt to send a mode change control. The inverter is considered unavailable to the PPC if it is unable to change modes. Table 2 lists out details of the main parameters used by the algorithm for closed loop voltage control.

TABLE 2 - PARAMETERS FOR REACTIVE POWER CONTROL

Parameter	Description
Voltage Set Point	PCC voltage control set point
Deadband	PCC voltage control deadband
Kp	Proportional tuning parameter
Ki	Integral tuning parameter
dVdQ	PCC ratio of the expected change in voltage to a change in reactive power
Ramp Rate Up & Down	Plant reactive power ramp rate (reactive power change/s); Units are kVAR/s; Setting to 0 will result in no ramp supervision

C. *Frequency Regulation Function for Grid Support*

Frequency regulation is a function that supports grid stability by automatically adjusting the active power output of the PV inverters in response to frequency deviations. This function continuously monitors the grid frequency and, based on predefined droop characteristics, increases or decreases power generation to counteract imbalances between supply and demand. This function enables the plant to participate in primary and secondary frequency control, ensuring compliance with grid codes, improving system reliability, and preventing frequency excursions that could lead to equipment damage or system instability.

It is important to note that PV inverters are intermittent DERs and therefore cannot always guarantee power output when grid support is requested. Their ability to provide support depends on solar availability, particularly the time of day at which the grid support request occurs.

Figure 5 shows the characteristics followed by the frequency regulation function, and Table 3 shows the parameters that govern the frequency regulation function within the PPC.

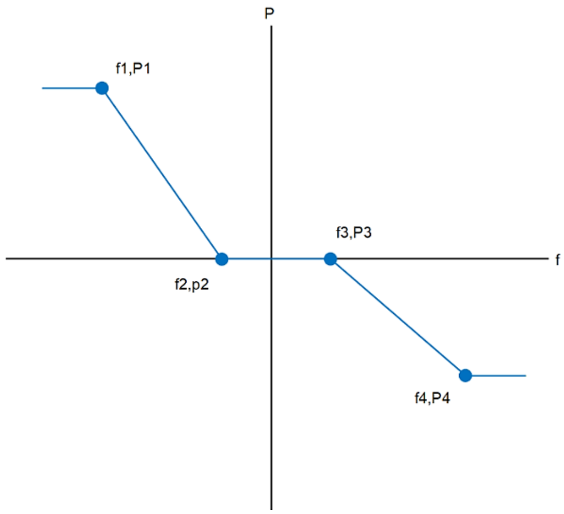

Figure 5 - PPC frequency regulation curve

TABLE 3 - PARAMETERS FOR FREQUENCY REGULATION FUNCTION

Parameter	Description
f1, P1	57.60 Hz, 100% of plant rating
f2, P2	59.95 Hz, 0% of plant rating
f3, P3	60.05 Hz, 0% of plant rating
f4, P4	62.45 Hz, -100% of plant rating
Droop	4%

V. SITE DEPLOYMENT

The site deployment for this PPC was executed by splitting the activities into precommissioning (sometimes referred to as non-invasive testing) and commissioning (sometimes referred to as invasive testing). As part of precommissioning, interfaces with all the devices (listed in Section 3) were established and verified.

The general activities for establishing successful interfaces included:

- Establishing Distributed Network Protocol (DNP3) and Modbus communications from end-to-end between the device, DCON, and the PPC
- Point-to-point mapping testing and verification of all signals
- Open-loop command and state verification
- Field data verification for live data

Figure 6 shows the open-loop testing of PV inverters, where manual setpoints were provided to the inverters in different steps (indicated by green line), and the corresponding response of the PV inverters power output (indicated by the red line). The time window used for this testing was selected during good sunlight and no cloud cover to minimize uncontrolled disturbances.

After precommissioning, the system became ready for testing the PPC algorithms and for NERC Modeling, Data and Analysis (MOD) testing, for compliance with ISO requirements.

The following tests were performed as part of commissioning:

- Active power, ramp rate control, and voltage control functionality test
- NERC MOD test
  - MOD25 – Active and reactive power capability test
  - MOD26 – Voltage control and speed of response test
  - MOD27 – Frequency droop and speed of response test

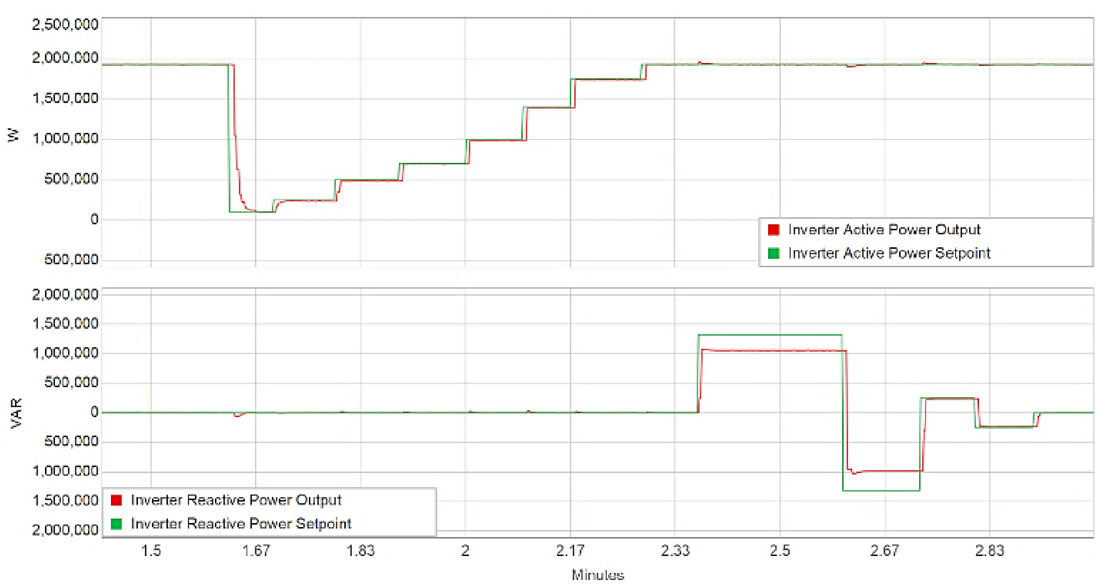

Figure 6 - Open-Loop active and reactive PV inverter response

Figure 7, Figure 8, and Figure 9 show the responses recorded for the active power limit test, voltage control functionality, and MOD27 (or frequency regulation) testing, respectively.

In addition to these major functionality tests, some basic PPC restart and time synchronization tests were also performed to ensure that the controller always retains the last known setpoints and commands to avoid malfunction upon restart, and that the Sequence of Events are recorded with the correct time stamping to facilitate effective and correct future analysis of PPC performance, when needed by the plant owner.

Below are few challenges and associated solutions that were related to site deployment of the PPC under discussion:

- The PPC hardware-supported high-sampling-rate synchrophasor-measurement-unit (PMU) enabled accurate recording of active and reactive power responses for both individual PV inverters and the overall plant.
- To meet the POI response time and performance requirements defined by MOD-26 and MOD-27 standards, the PID control loop gains were optimized.
- To satisfy the active power ramp rate requirement of 180 kW/s at the POI, the individual inverter ramp rate function was disabled, enabling near-instantaneous inverter response to setpoints. Consequently, the PPC served as the only adjustable control point and was tuned to achieve the desired ramp rate.

MOD-27 (frequency regulation) testing required varying the system frequency, which was not feasible on the live utility system. To facilitate testing, a simulated frequency mode was developed, allowing the measured frequency to be adjusted from 60 Hz to 62.437 Hz to verify the 4 percent droop response. An additional challenge was scheduling the test during peak solar irradiance to ensure all PV inverters could operate at maximum power output.

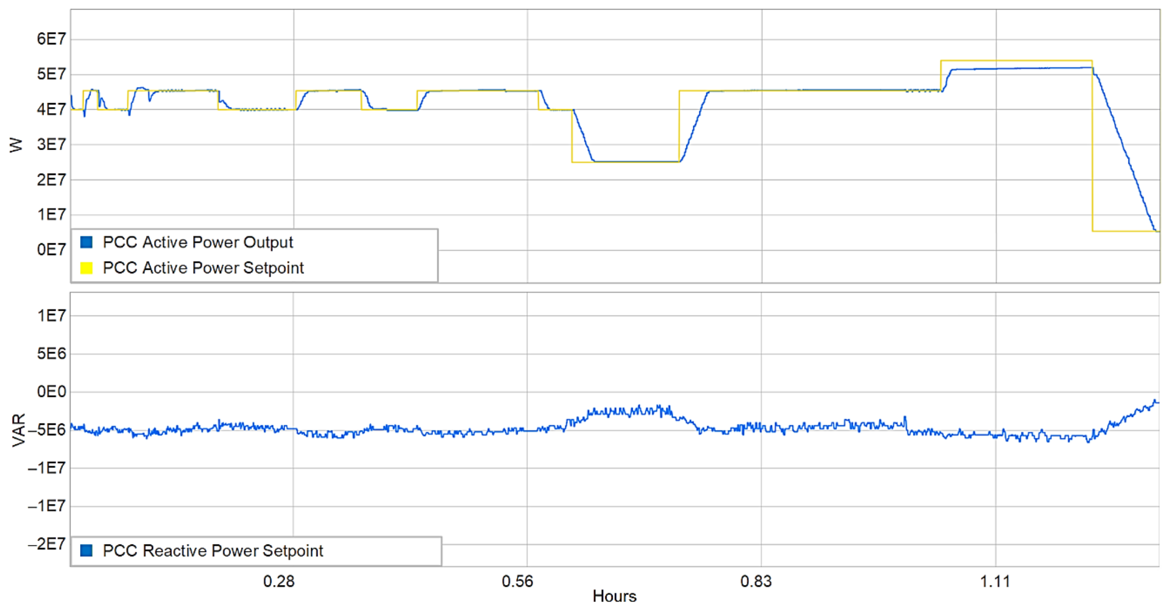

Figure 7 - Active power limit response

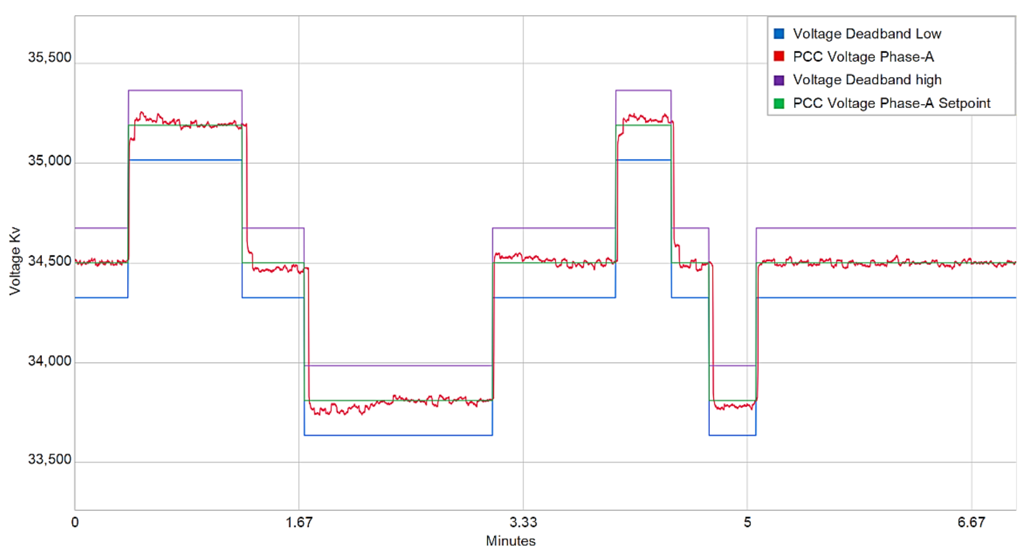

Figure 8 - Voltage control response

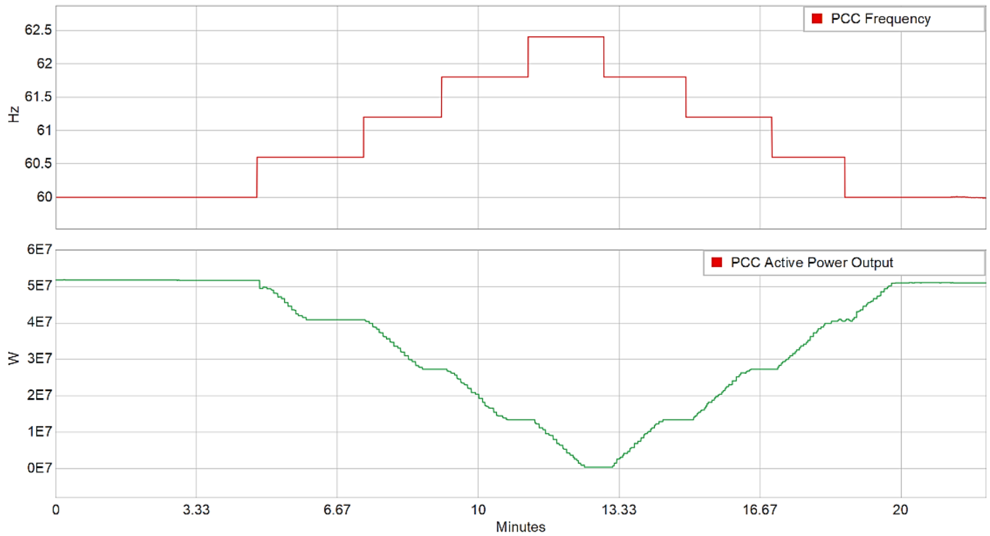

Figure 9 - Frequency regulation (above nominal)

VI. Conclusion

This paper demonstrates the practical implementation of a PPC for a grid-connected solar facility, highlighting the role of the PPC in optimizing power generation, while ensuring grid compliance. The PPC effectively coordinates active and reactive power control, voltage regulation, and frequency support across multiple inverters. Field deployment and testing confirmed reliable performance, smooth dynamic response, and adherence to operational and regulatory requirements. Overall, the solution shows how advanced PPCs enhance both system stability and economic efficiency in modern DER-based power plants.

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