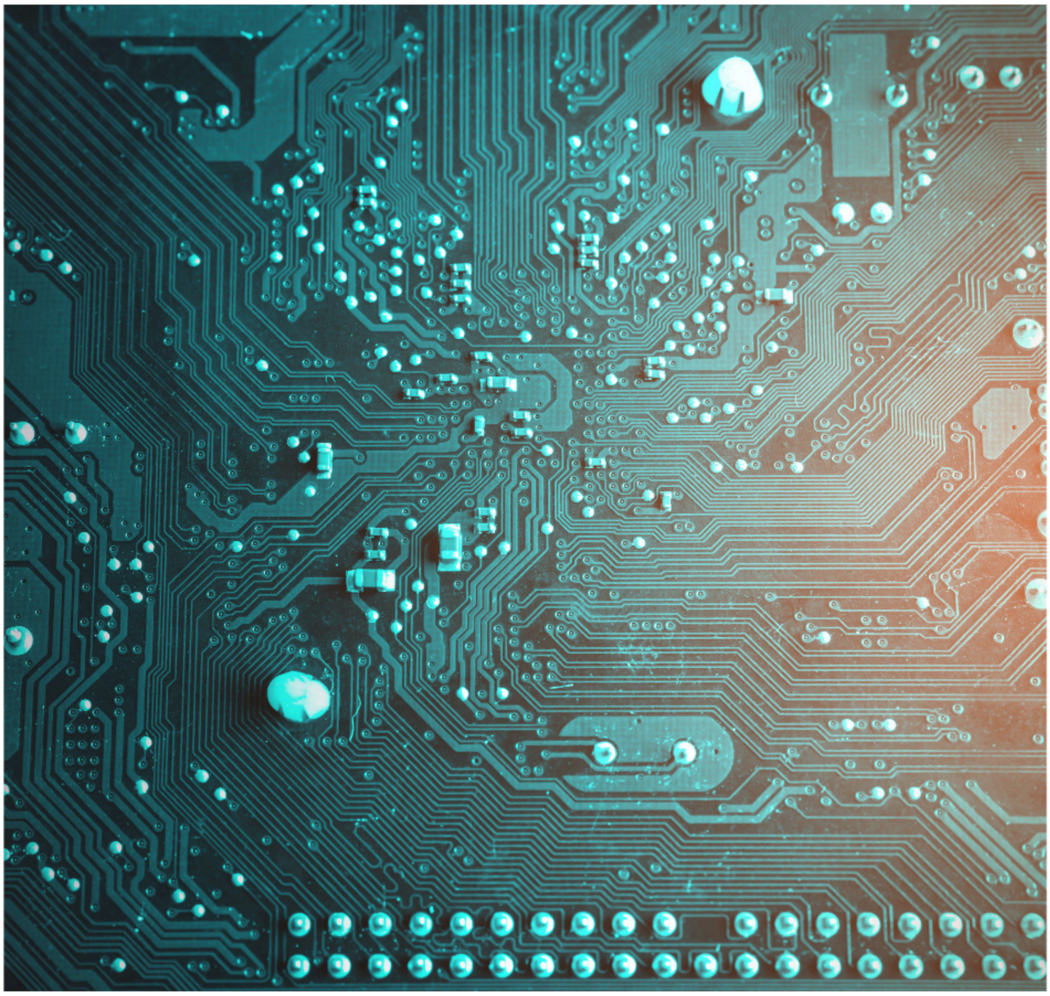
Silov Solutions
Incubated at Indian Institute of Technology, Delhi

PRODUCT MANUAL



V1.0 / 2025

HIGH POWER BIDIRECTIONAL GRID TIED INVERTER

SILOV SMINV-800/70

1. Introduction

1.1 Purpose of the Inverter

The SILOV SMINV-800/70 is an advanced, industrial-grade Bidirectional Three-Phase Grid-Connected Inverter designed and developed by Silov Solutions for high-efficiency power conversion between a high-voltage (700 V DC) battery system and the utility grid. This inverter enables bidirectional energy flow, charging the battery from the grid (Grid-to-Battery mode) and discharging the battery into the grid (Battery-to-Grid mode) with high accuracy using Id-Iq-based digital control algorithms.
Engineered for mission-critical applications, this inverter offers seamless grid interaction, excellent harmonic mitigation, and robust protection, all housed within a rugged industrial enclosure suited for field environments.

1.2 Document Overview

This manual provides comprehensive guidance on:

- Functional overview and technical specifications
- Installation requirements and electrical connections
- Operational modes and power flow control
- Precharge circuit operation and battery interfacing
- Communication options include RS-485 Modbus
- Fault logging and diagnostic capabilities
- Maintenance, safety, and troubleshooting procedures
- Compliance with IEEE 519-1992, IEEE 519-2014, and CEA harmonic limits

2. System Overview

2.1 General Description

The SILOV SMINV-800/70 is an industrial-grade bidirectional inverter that interfaces a high-voltage battery (approx. 700 V DC) with a three-phase AC network (nominally 400 VAC L-L, 50/60 Hz). It is rated for high power and is built for continuous duty in demanding environments. The inverter uses high-speed IGBT power modules and a robust cooling system to achieve high efficiency and high power density. It includes front-end and back-end protection circuits, a digital control board, and a TFT touchscreen HMI for local control.
By design, the SILOV SMINV-800/70 converts and controls power in both directions. In DC-to-AC mode (battery-discharge), it uses SPWM switching to create a stable three-phase AC output synchronized to the grid. In AC-to-DC mode (battery-charge), it actively rectifies grid power with power-factor correction to charge the battery. This bidirectional capability enables applications such as battery-based energy storage systems, microgrids, and Bi-directional EV charging (V2G). Bidirectional inverters provide efficient two-way power

conversion between AC and DC, enabling the system to charge batteries from both solar panels and the grid and supply power from batteries during outages.

2.2 Bidirectional Power Flow

The SILOV SMINV-800/70 supports four-quadrant power operation, meaning it can source or sink both real and reactive power. The power flow modes include:

- Battery-to-Grid (DC→AC): The inverter draws energy from the 700 V battery and generates AC to the grid or load. A SPWM-based inverter bridge converts DC to AC, while control loops ensure the AC voltage and frequency match the grid requirements. In this mode, the d/q current references are set to supply the required active power to the grid (ID on one axis, IQ often set to zero for unity PF, or nonzero for VAR support).

- Grid-to-Battery (AC→DC): The inverter functions as an active rectifier (charger). It takes three-phase AC from the grid and converts it to DC to charge the battery. This involves a controlled full-bridge rectification with active power-factor correction to optimize efficiency and minimize reactive draw. Charge currents are regulated to prevent overcharge or overdischarge and can be programmed by the user or controlled by an external BMS.

- Power Reversal: The transition between modes is seamless: if the battery is depleted or the application demands it, the inverter will switch to rectifier mode and vice versa. Anti-islanding detection is built in, so the inverter ceases power injection if grid loss occurs.

2.3 Key Features

- High Voltage, High Power: Designed for a nominal 700 V battery input, the SILOV SMINV-800/70 can deliver on the order of 50 kW continuous (model-dependent). Its modular IGBT bridge and DC bus capacitors are optimized for heavy-duty use.

- Digital Vector Control (ID–IQ): Implements field-oriented control (FOC) of currents. The three-phase currents are transformed into direct (d) and quadrature (q) axes, enabling independent regulation of active and reactive power. The d-axis typically regulates reactive power/voltage, while the q-axis handles real power (battery charging/discharging).

- Pure Sine-Wave Output: Uses high-frequency SPWM and LCL filtering to produce a clean sinusoidal waveform with low Total Harmonic Distortion (THD <3–5% at rated output). The output meets grid standards for harmonics IEEE 519-1992 & IEEE 519-2014, and CEA harmonic limits.

- Safety and Protection: Built-in protections include DC/ AC overvoltage and undervoltage trip, overcurrent and short-circuit shutoff, and thermal overload. The design follows inverter safety standards and includes a ground terminal for equipment earthing.

- Integrated Precharge: A front-end precharge circuit limits inrush current to the DC bus capacitors during startup, enabling safe hot-plug of the battery.
- User Interface: A front-mounted TFT color touchscreen HMI allows local monitoring, control, and parameter configuration. Providing quick operational feedback.
- Communications: Standard RS-485 interface for SCADA/PLC integration, an Ethernet port (via optional gateway) for Modbus TCP or remote access; supports external monitoring software (LabVIEW GUI) and can be integrated into building energy management systems.
- Robust Design: Industrial metal enclosure. High-quality fans and heat-sinks typically ensure operation at ambient temperatures.

2.4 Typical Applications

- Utility-Scale Energy Storage: In systems with large battery banks, the SILOV SMINV-800/70 provides bi-directional power exchange for load leveling, peak shaving, and renewable smoothing.
- Renewable Integration: Pairs with solar or wind installations to store excess generation and supply grid or local loads during deficits.
- Microgrids and Islanding: Used in microgrid controls, allowing battery systems to maintain local loads when disconnected from the grid.
- Vehicle-to-Grid (V2G) EV Charging: Allows electric vehicles or battery arrays to draw from or feed energy to the grid, supporting smart charging and grid services.
- Industrial Load Management: Absorbs peak loads or regenerates braking energy in large drives, improving overall energy efficiency.

3. Technical Specifications

3.1 Electrical Specifications

DC (Battery) Input

- Nominal Voltage: 700 V (e.g., operating range ~ 690–780 V by default, adjustable by parameters).
- Maximum DC Input Voltage: 800 V.
- Maximum Charging/Discharging Current: ~75 A RMS continuous.
- Precharge: Internal resistor precharge for DC bus.
- Input Overvoltage Trip: fixed at nearly 800 V.
- Input Undervoltage Trip: fixed at nearly 680 V.
- Input Overcharge Trip: adjustable from less than 790 V.
- Input Overdischarge Trip: adjustable from greater than 690 V to less than Overcharge.

AC Output (Grid Side)

- Configuration: Three-phase, three-wire (L1, L2, L3).
- Rated Output Voltage: 380–480 VAC L-L (nominal 400 VAC).
- Rated Frequency: 50 Hz or 60 Hz (selectable via settings).
- Maximum Continuous Power: ~50 kW.
- Peak Power: +5% overload for 30 s.
- Rated Output Current: ~50 A per phase at 400 VAC.
- Total Harmonic Distortion (THD): <3% at rated load (per IEC standards).
- Switching Frequency: 10 kHz.
- Inrush Limit: Soft-start control prevents AC surges.

Performance

- Efficiency: ≥97% at rated power, 50–100% load.
- Isolation: Isolation between control circuits and power circuits.

Control and Monitoring

- Control: Microcontroller-based ID IQ (vector) control loop.
- HMI: Touchscreen.
- RS-485: Modbus (8N1, up to 115200 baud); Ethernet (Modbus TCP with gateway).

Protection

- Overcurrent Protection: Fast current-limiting; IGBT desaturation detection.

- Active Discharge: By operating the system in open circuit mode after removing the DC supply and AC supply, we can safely discharge the DC bus voltage after shutdown. Make sure the open circuit mode is operated after removing the DC and AC terminals from the source or sink.

Communications:

- Protocols: Modbus (RS-485, optional TCP/IP), compatible with common SCADA systems.
- LabVIEW GUI: Supported (see Section 9.3).
- Firmware Updates: Via USB.

3.2 Mechanical Specifications

Enclosure:

- Material: Powder-coated Iron box.
- Cooling: Vented enclosure with forced-air cooling.
- Finish: Industrial gray; Left and right with handle/latch.

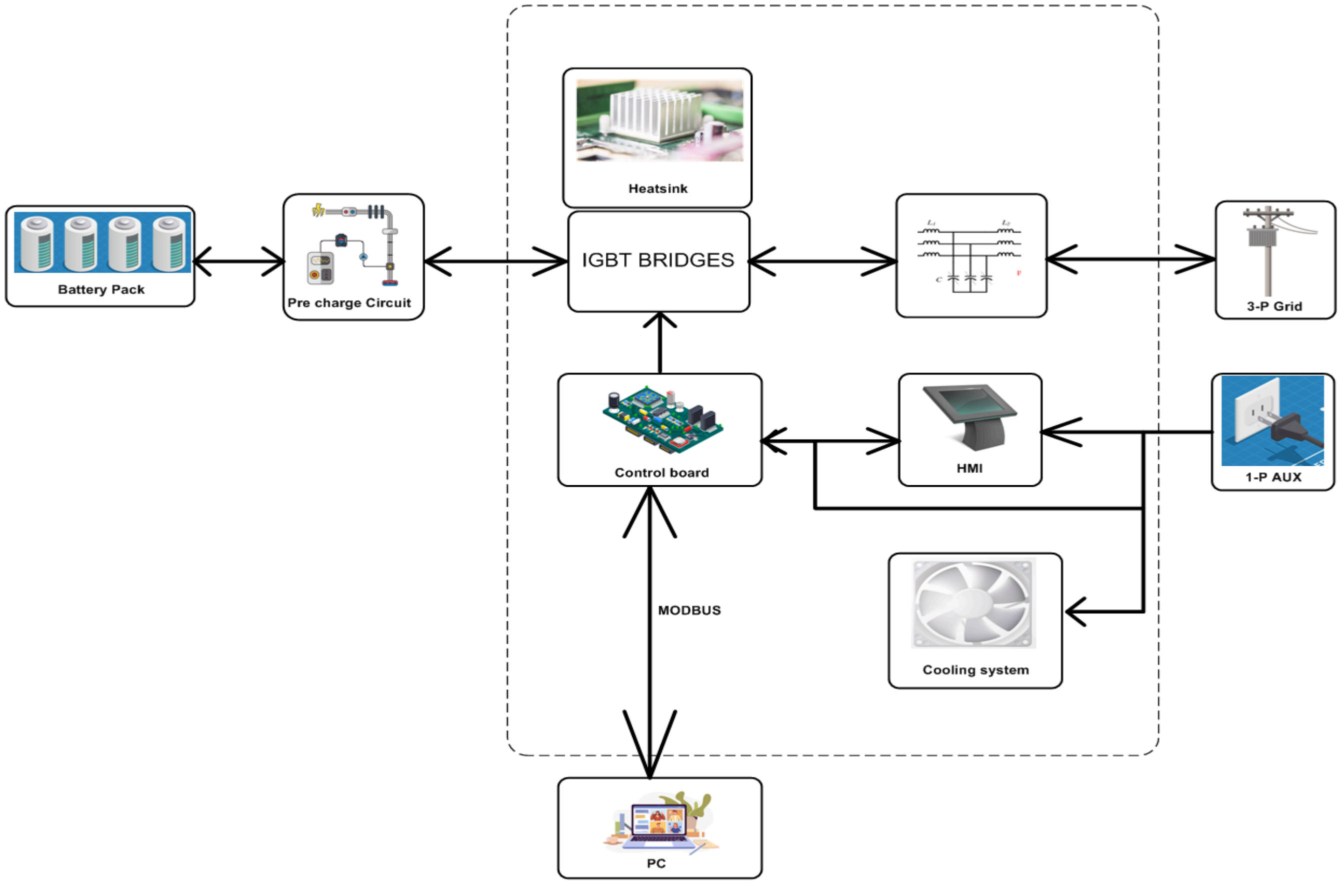
Physical:

- Ambient Noise: <60 dBA (fans running).
- Display: The Front panel door houses the HMI and status indicators.
- Maintenance Access: Top door opens, internal components accessible for cleaning.

3.3 Compliance and Standards

The SILOV SMINV-800/70 adheres to power quality standards, including IEEE 519-1992, IEEE 519-2014, and CEA harmonic limits, ensuring that harmonic injection is kept within acceptable thresholds (THD <5%).

4. System Architecture



BLOCK DIAGRAM

4.1 Power Stage

The power stage consists of:

- DC Link: The battery connects to the DC bus through fuses and a contactor. A pre-charge resistor limits inrush to DC link capacitors at startup.

- Inverter Bridge: A three-phase full-bridge (IGBT) converts the DC bus voltage to AC. The bridge is a four-quadrant converter, enabling bidirectional power flow. Each phase has high-current switches and freewheeling diodes.

- Output Filter: LCL filter on each phase attenuates high-frequency switching components, resulting in a near-sinusoidal output. This ensures compliance with grid harmonics standards. The filter also isolates switching noise from the grid.

- Sensing and Feedback: Hall-effect and current transformer sensors measure DC link current and each AC phase current. Voltage sensors measure DC bus and AC line voltages. These feed into the control system for regulation and protection.

- Auxiliary Power: The inverter includes a small internal power supply to provide 5 VDC/230 VAC for the Microcontroller, fans, and the HMI. This is isolated from the main power path.

The bridge is heat-sink cooled, with fans providing forced convection. Thermal sensors on heatsinks allow the control to derate power if overheating is detected.

4.2 Control System (ID–IQ)

The SILOV SMINV-800/70's control system is a digital vector (field-oriented) control implemented on a high-speed microcontroller. The main features include:

- PLL Synchronization: A Phase-Locked Loop locks the internal reference frame to the grid voltage. This generates angle information for the D-Q transformation.

- d-q Current Control: Three-phase voltages and currents are transformed into the rotating d-q frame. The controller independently regulates the d-axis and q-axis current. In the chosen frame alignment, the d-axis current governs reactive power (voltage control), while the q-axis current governs real (active) power. The user controls how much active or reactive current flows by adjusting ID and IQ references via parameter settings.

- Inner Control Loops: High-bandwidth controllers' algorithms regulate ID and IQ against their setpoints. A decoupling feedforward compensates for the D-Q cross-coupling. The outputs of the controllers and the harmonics rejection controllers give the phase voltage references for each axis.

- Pulse-Width Modulation: The reference voltages are converted into gating signals using SVPWM (Space Vector PWM) or sinusoidal PWM, modulating the IGBTs at ~10 kHz.

- Parameterization: The control firmware allows setting limits on ID and IQ (thus capping active/reactive power).

- Anti-Islanding / Ride-Through: Special algorithms monitor grid presence and apply voltage/frequency ride-through criteria. If an islanding condition is detected, the inverter shuts down per IEEE/UL requirements.

- By using digital vector control, the inverter achieves precise, decoupled regulation of active and reactive currents. The D-Q control governs the reactive power and voltage regulation [on the d-axis] and the real power [on the q-axis], enabling stable power exchange even under dynamic conditions.

4.3 Harmonic Filtering and Power Control

Each phase output passes through a low-pass LCL filter. This filter is tuned (along with PWM carrier) to ensure the line currents are essentially sinusoidal. The result is a pure sine-wave output with very low distortion, “crucial for protecting sensitive equipment from harmonics. The filter design ensures compliance with IEC/IEEE limits on harmonic injection. The inverter’s control also includes notch filters to minimize specific harmonics up to the 50th.

In summary, the power stage filter ensures clean output, and the vector control allows sophisticated reactive power support (as mandated by IEEE 1547-2018), solarbuildermag.com. These features enable the inverter to meet power quality and grid-support requirements.

5. Installation Guidelines

5.1 Site Requirements

- Environment: Install the inverter in a clean, dry, indoor area free from explosive dust or corrosive gases. The ambient temperature should be within –10°C to +50°C. Avoid direct sunlight and water spray. Ambient humidity should be <95% non-condensing.

- Clearances: Provide at least 300 mm clearance at the front (for the HMI door) and 100 mm on top for ventilation. Maintain ~150 mm on sides for airflow. Do not block air vents or fan outlets.

- Foundation: If floor-mounted, use a level surface capable of supporting the weight. For wall-mount, use sturdy structural supports (anchors for concrete or steel studs).

- Power Sources: Ensure the grid supply (voltage, frequency) matches the inverter specs before connecting. The DC battery or DC source must be isolated and switched (e.g., manual disconnect) adjacent to the inverter.

- Grounding: Install a robust protective earth connection to the inverter chassis (see Sec. 5.5). The local grounding system should comply with national standards (e.g., earthing rod with low impedance).

- Airflow/Ventilation: The location should have reasonable airflow and not accumulate heat. If ambient temperature over 45 °C is expected, provide additional cooling or derate the inverter output.

- EMI Considerations: Keep communication and signal cables away from high-current power lines. Use twisted/shielded pair for RS-485, grounded at one end to reduce interference.

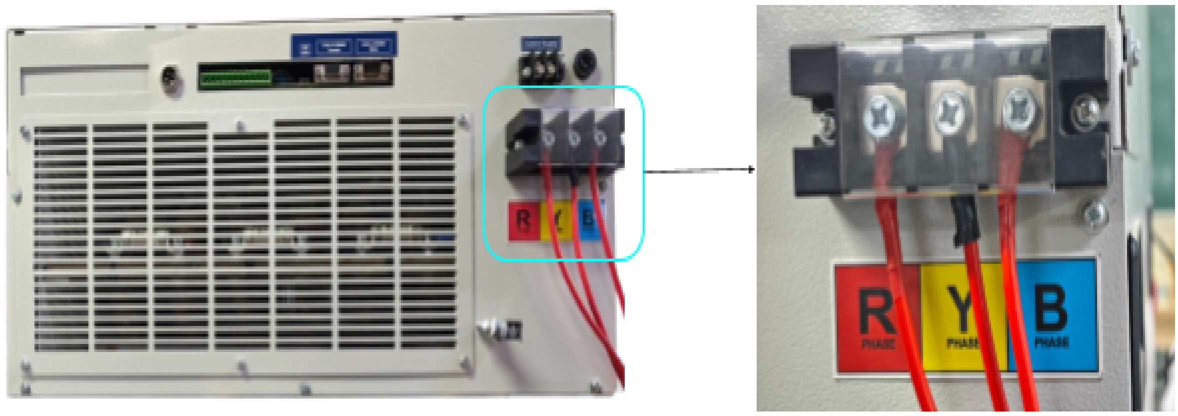
5.2 Electrical Connections

- DC Input (Front): The front panel provides connectors for Battery(+) and Battery(–). Route the battery (or DC source) cables from the bottom entry to these terminals. Observe polarity strictly: Reversing DC polarity will damage the inverter.

- Precharge Circuit: The inverter includes a pre-charge resistor and contactor. When the DC supply is first connected, the precharge limits inrush to the DC bus capacitors.

- AC Input/Output (Rear): The rear terminals include L1, L2, L3 (three phases). Connect these to the three-phase grid supply or load. Earth (PE) must be connected to the ground lug. Tighten AC terminals. Check the ‘+’ / ‘-’ markings on the hardware before connection.

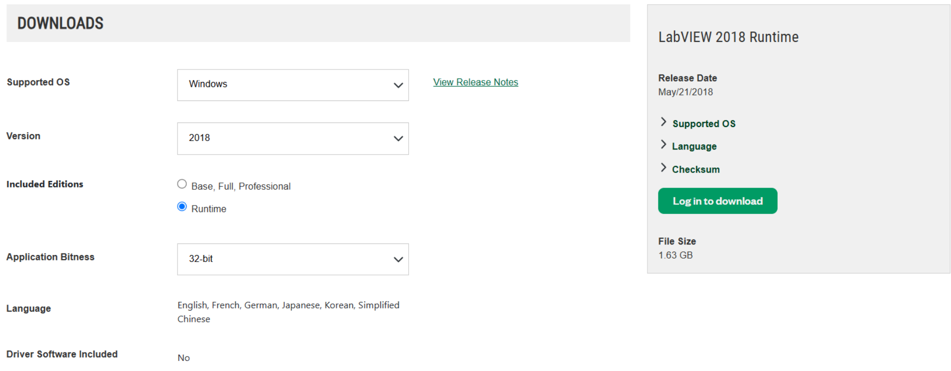
- Ensure correct phase sequence. The inverter's PLL has been designed such that it may detect incorrect phasing, but best practice is to verify L1-L2-L3 correspond to the



intended grid phases.

Auxiliary Supply: The inverter requires a separate auxiliary power 230 VAC for control electronics and HMI; connect it per the wiring diagram.

- Communications:
    - RS-485: Connect the RS-485 to the RS-485 to Ethernet converter, and also needs to give a DC power supply for the Ethernet converter. Observe polarity (A to A, B to B).
    - Ethernet cable: Connect the Ethernet cable between the RS-485 to the Ethernet port in the laptop.
    - Install the [LABVIEW Run time]() software from here. Make sure the download options are as in the image below, and then login and download the software.



    - Safety First: Before powering up, double-check all connections, ensure no exposed wires or tools are inside the enclosure, and confirm the area is clear of personnel.

5.3 Cooling and Ventilation

- Forced-Air Cooling: The inverter is cooled by internal fans. Keep all vents clear. Ambient airflow should be uninterrupted. If installed in a cabinet, ensure the cabinet is ventilated or air-conditioned.

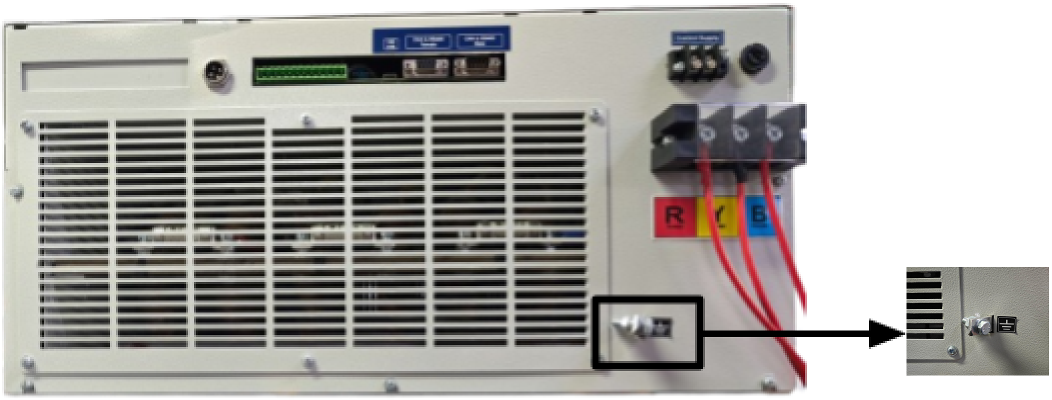
- Air Filters: In dusty environments, install intake filters. Check and clean/replace filters monthly or per site conditions to prevent dust buildup on heatsinks.

- Hot Spots: Do not install the inverter in full sun or near heat sources. High ambient (>50 °C) requires reduced load or external cooling to maintain a safe operating temperature.

- Positioning: Mount the unit horizontally. The design assumes cool air enters the bottom vents and exits the top.

5.4 Grounding

- Protective Earth: Connect the inverter's chassis/ground lug to earth ground via a thick copper conductor. This ground must be common with the building's electrical earth system. DO NOT rely on the conduit for grounding.
- Earthing Practices: The ground wire gauge should be as large as the largest AC phase conductor (or follow local codes).



- Lightning/Surge: For additional protection, surge arrestors (TVS or MOV) may be installed on the AC side (and DC side if needed) before the inverter.

6. Operation and Control

6.1 Power-Up and Shutdown Sequences

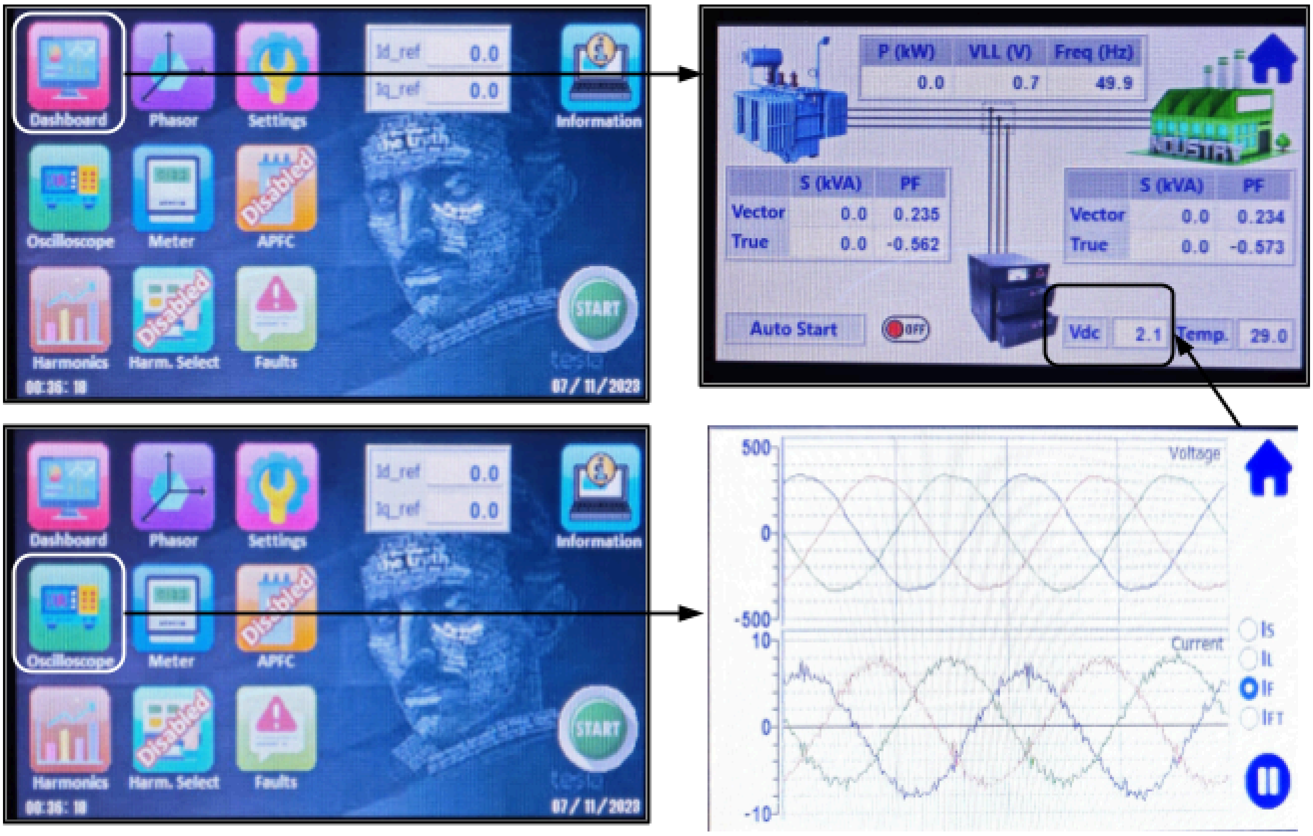
6.1.1 Startup Sequence

1. Initial Checks: Ensure AC and DC disconnects are open, and the inverter's internal switches are off (via HMI).

2. Apply Control Power: Energize the aux supply. The HMI power and control board will be powered on.

3. Make sure the fault option is not blinking in the HMI, or it is in red. Red indicates fault has happened.

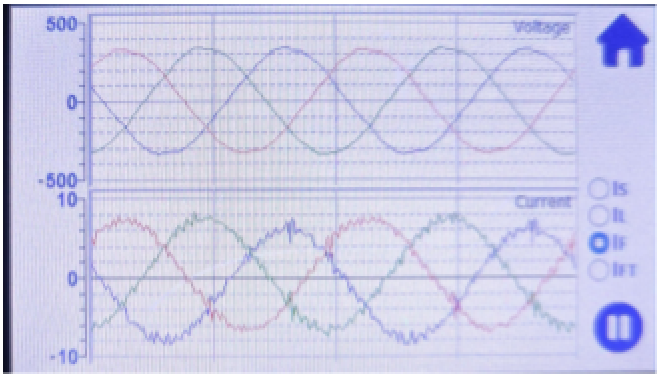
4. Enable the three-phase grid. Observe the DC voltage, which will be nearly 560 V in the Dashboard option in HMI, as shown in the image below. You can also observe voltage waveforms in the oscilloscope option in the HMI display.



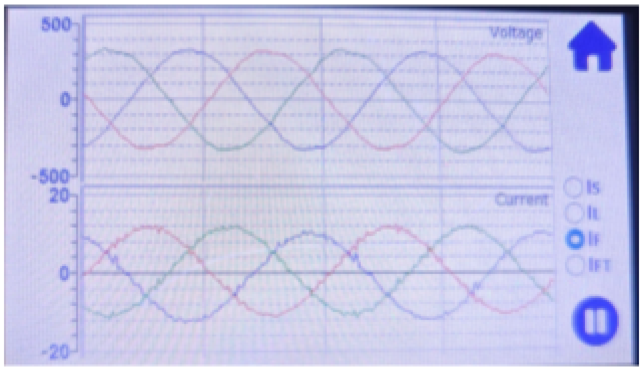
5. To successfully connect the DC source or battery to the inverter, first charge the DC bus to match the battery voltage using a resistor, which helps manage inrush current effectively. Once the DC bus reaches the battery voltage, activate the contactor positioned between the battery and the inverter to bypass the resistor. This step is essential to mitigate the risk of inrush currents flowing directly from the battery to the inverter during system startup. It is crucial to follow this procedure every time the system starts to ensure safe operation and maintain the integrity of the inverter, preventing potential damage.

6. Verify DC Voltage: Check on the HMI that the DC bus voltage in the dashboard is within the battery range. If not, investigate before proceeding.

7. Enable the system: On the HMI, click on the “Start” command. The inverter’s PLL will synchronize to the grid (watch the grid-current waveform lock).

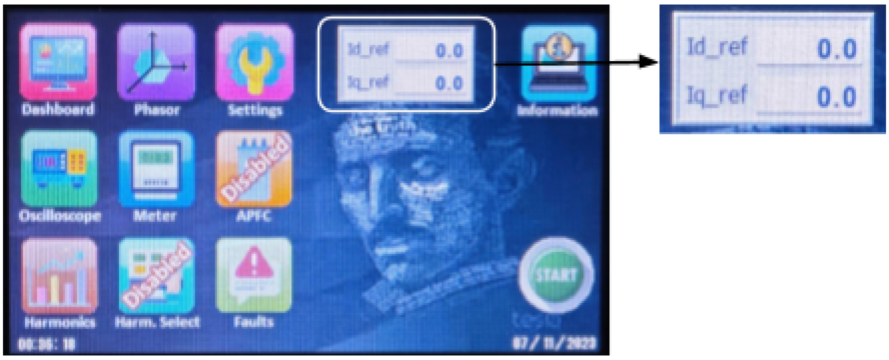


DC to AC

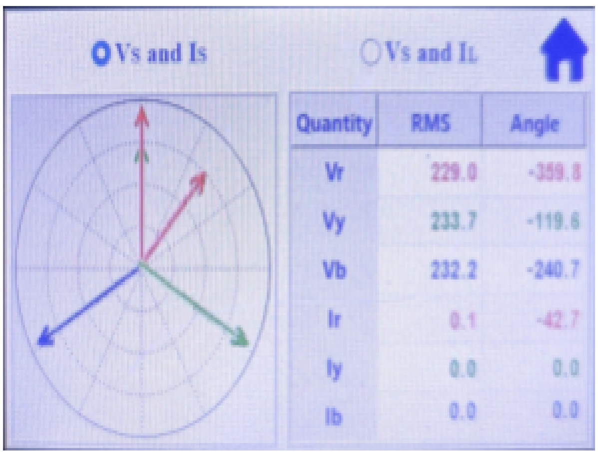


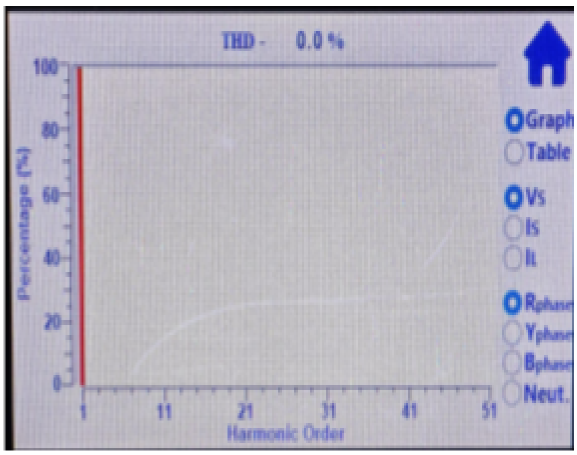
AC to DC

8. Set Output: Increase power output gradually by adjusting the ID reference or power setpoint. Observe grid voltage/current, ensuring stable power flow.



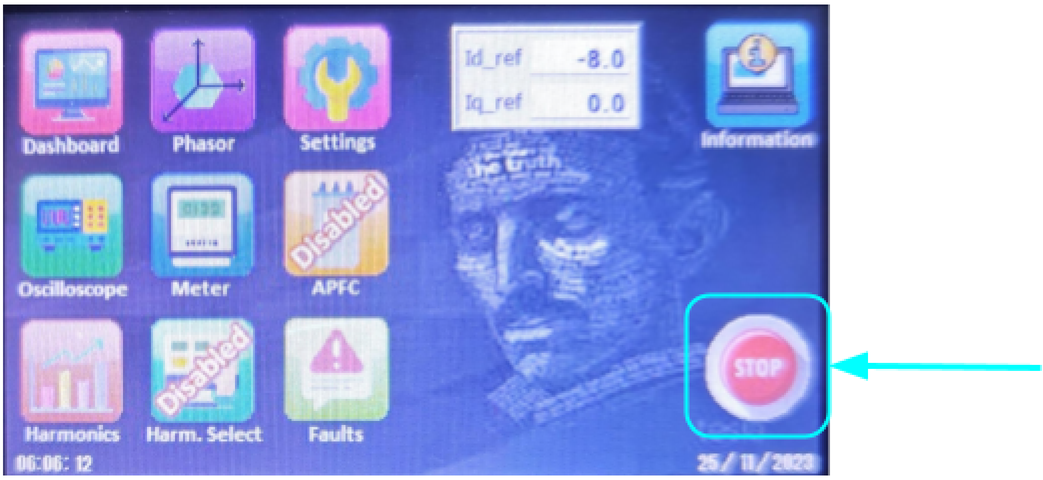
9. We can also observe additional options such as phasor diagrams and harmonic analysis for better performance evaluation and optimization.



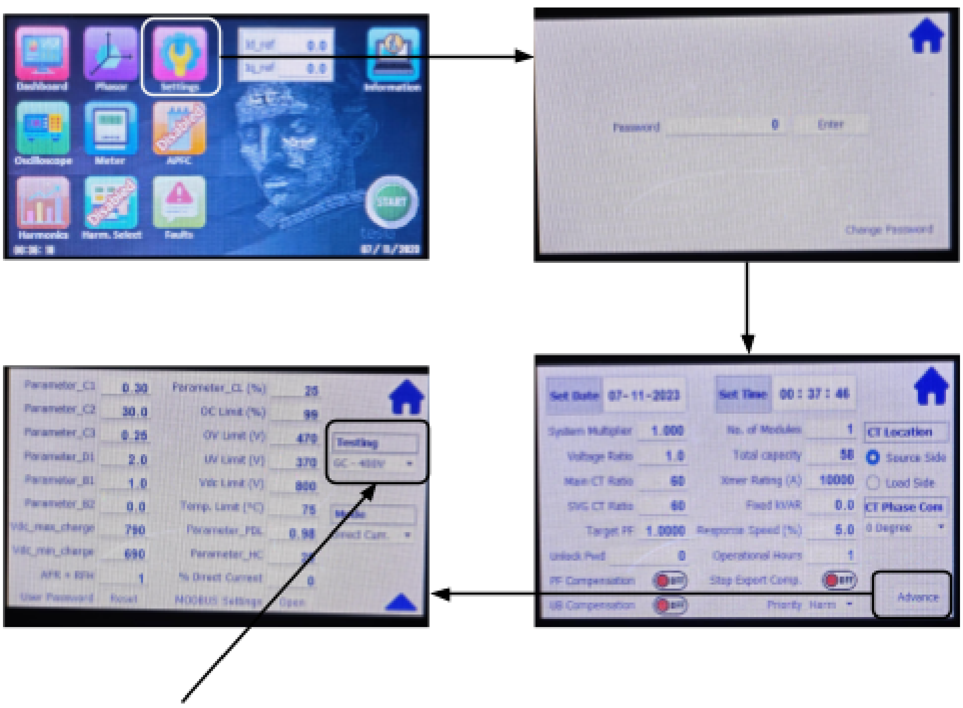


6.1.2 Shutdown Sequence

1. To perform a normal stop, press the “Stop” button on the main panel of the HMI to halt the power transfer from the inverter. After that, turn off the DC supply, followed by the AC grid supply. Please be aware that even after disconnecting both the AC and DC connections, the DC bus will not be fully discharged; it will take some time to discharge.



2. To effectively discharge the DC bus voltage, it is important to change the mode to open circuit and press the start button. Please note that this procedure should only be carried out when the DC bus and three-phase grid are completely disconnected, as this will allow the voltage to be discharged safely and quickly.
3. Refer to the images below to discharge the DC capacitor voltage by setting the GC-400 V mode to open circuit, then click the Start button on the HMI.



Change this to open circuit

4. Capacitor Discharge: After shutdown, wait for the DC bus indicator to go to 0 V. Do not touch the unit until capacitors are discharged (several minutes) if you are not discharged the capacitors through the open circuit mode.

6.2 HMI Interface and Menus

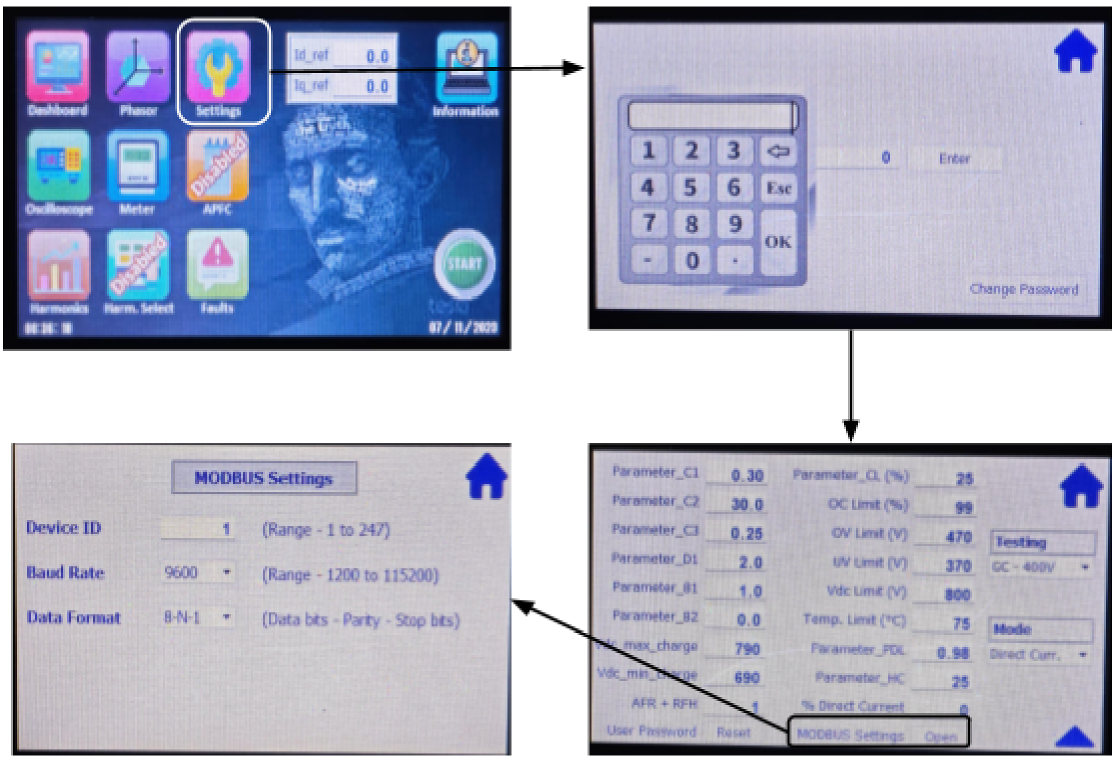
The front-panel HMI provides status, control, and configuration:

- Status Screen: Shows real-time voltages and currents (DC and AC).

- Menus: Password-protected menus allow parameter changes. Submenus include setting electrical parameters, protection thresholds, communication settings, and control setpoints (ID/IQ or power targets).

- Navigation: Use touch or buttons to navigate. The interface typically has an overview display.

- Control Commands: Using the HMI, the operator can start or stop the inverter, initiate a controlled shutdown, or reset faults in the fault settings. If a fault occurs, the system will blink the fault icon. By pressing the fault icon, the operator can identify the specific fault that has occurred as the green colour is shown in the status. This fault must be reset and cleared before restarting the system. If any troubleshooting occurs, restart the system, and it will automatically clear the fault.



6.3 Communication Interfaces

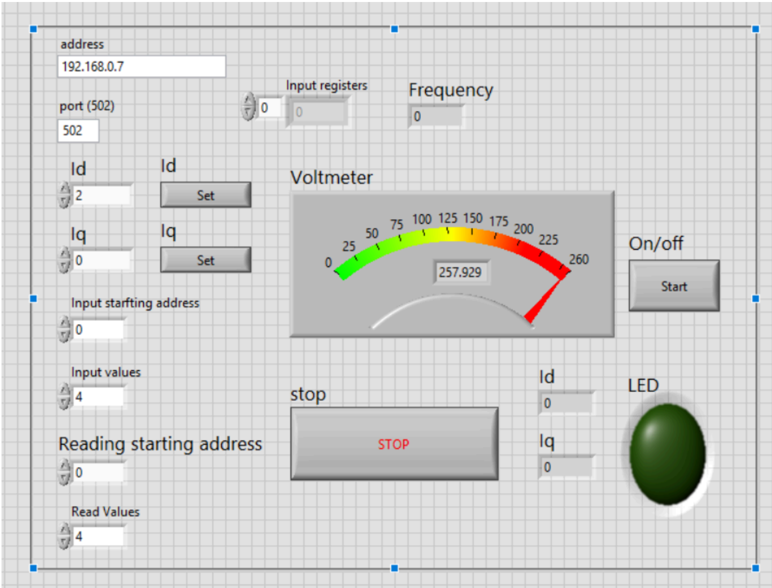
6.3.1 RS-485 (Modbus RTU)

A standard serial port implements the Modbus RTU protocol. Typical default settings are 19200 baud, 8 data bits, no parity, and 1 stop bit. Via RS-485, external devices (PLC or PC) can read measurements, monitor status, and write configuration parameters. You can also view this information by accessing the advanced options, as illustrated below.

An Ethernet (Modbus TCP) connection can be achieved using an RS-485 to TCP converter. This setup allows the inverter to function on TCP/IP networks and communicate using Modbus TCP/IP. To configure the network settings, such as the IP address and subnet mask, connect the inverter to the Modbus port located on the back panel and access the network address through your browser.

Protocol Mapping: A Modbus register map (Appendix C) details all accessible registers (voltages, currents, status bits, alarm flags, etc.).

Remote GUI: A LabVIEW-based PC application communicates via Modbus. It provides live displays of all inverter data and allows parameter editing (see Section 9.3).

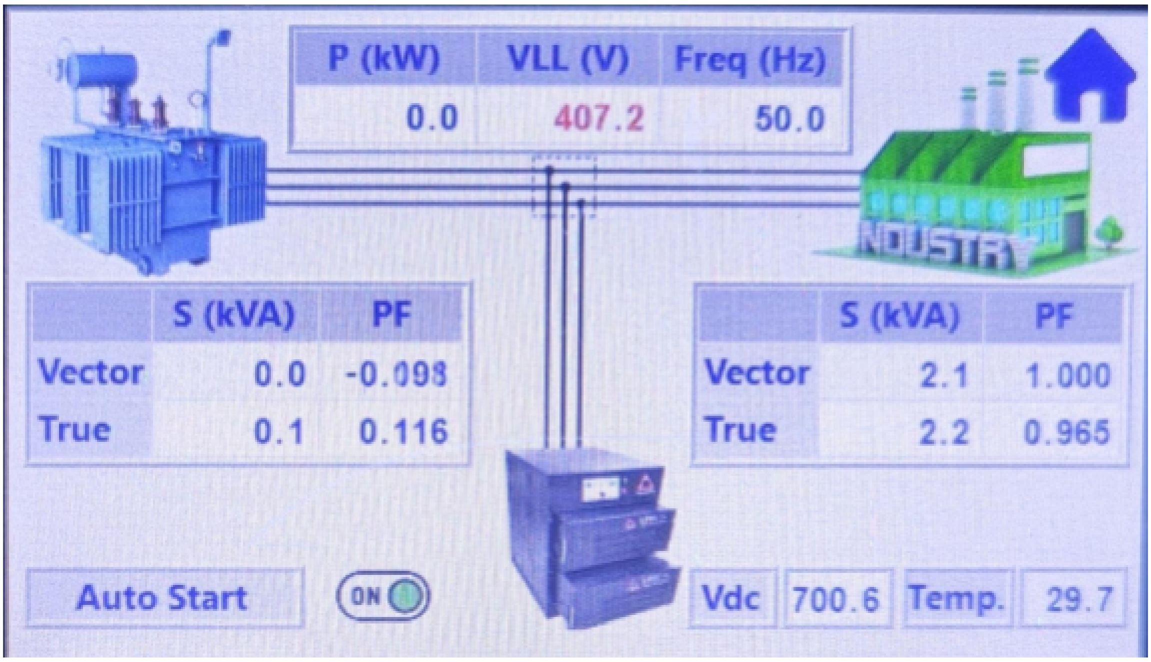


6.3.2 USB/ Serial

The model includes a port for direct PC connection for firmware update.

6.4 Operating Modes

- Charging Mode (Battery Charging): In this mode, the inverter draws power from the AC side to charge the battery. The HMI or remote command sets a positive d-axis reference (ID) corresponding to the desired charge current/power. The inverter regulates battery voltage and current to the setpoint. Typically, reactive current (IQ) is set to zero (unity PF), unless reactive support is desired.

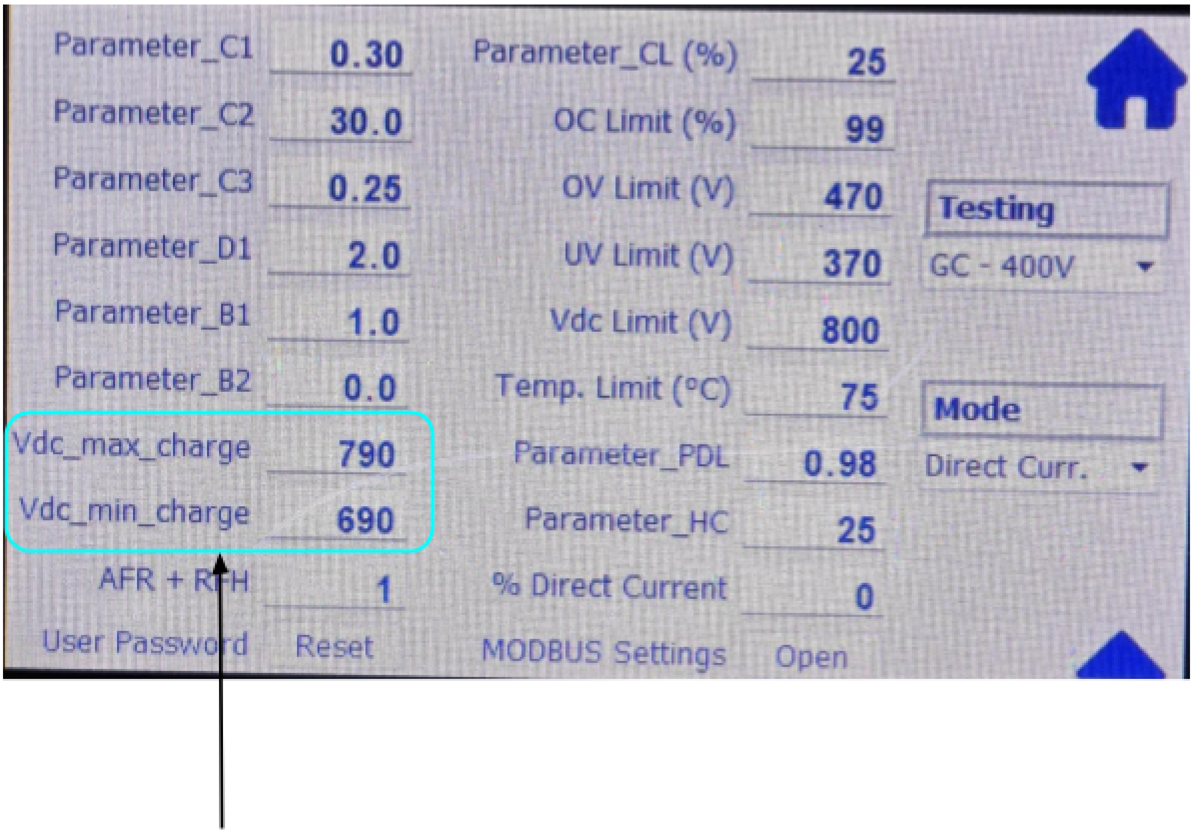


- Discharging Mode (Battery Discharge): The inverter sends power from the battery to the grid. Here, the d-axis current is set negative (ID reference drives AC output). The inverter ensures the DC bus remains regulated by draining battery energy. In discharging mode, the q-axis (IQ) can again be set to control PF or fixed.

- Idle/ Standby: The inverter can be commanded to standby, during which it maintains battery voltage and keeps essential controls alive but outputs no active power until we click on start.

- Automatic Transition: In systems with a supervisory controller or programmable logic, the inverter can switch between charge/discharge based on conditions (e.g., battery SoC, grid frequency, time-of-use). The transition is seamless if the DC bus stays within limits. This enables integrating a Battery using a Battery Control Unit (BCU) via Modbus.

- Safety Limits: We can modify the maximum charge/ discharge current limits to prevent the battery C-rate from exceeding a maximum of 70 A RMS. If battery voltage hits a limit, charging or discharging will taper off or stop. Similarly, the inverter will not export more than its rated power. <mention the limits in this system - maximum of 70A, where can this be set - show that part>


Parameter_C1
0.30
Parameter_C2
30.0
Parameter_C3
0.25
Parameter_D1
2.0
Parameter_B1
1.0
Parameter_B2
0.0
Vdc_max_charge
790
Vdc_min_charge
690
AFR + RFH
1
User Password
Reset
Parameter_CL (%)
25
OC Limit (%)
99
OV Limit (V)
470
UV Limit (V)
370
Vdc Limit (V)
800
Temp. Limit (°C)
75
Parameter_PDL
0.98
Parameter_HC
25
% Direct Current
0
MODBUS Settings
Open
Testing
GC - 400V
Mode
Direct Curr.

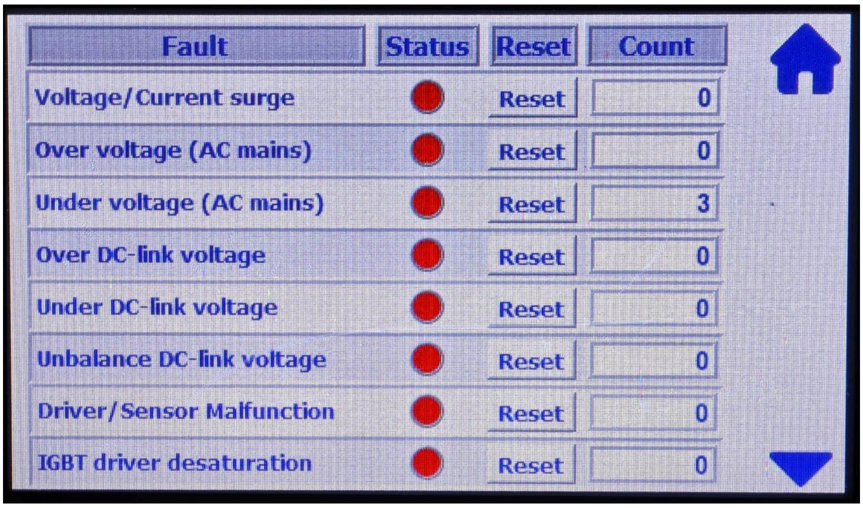
7. Protection and Safety

7.1 Overvoltage and Undervoltage Protection

- DC Overvoltage (Battery Overvoltage): If the DC bus voltage exceeds the upper limit of 790 V, the inverter will initiate an overvoltage cut-off. Charging will not be allowed, but discharge will be allowed. The inverter can automatically restart when the voltage returns to range. The contactor opens, and the inverter shuts down. The fault icon in the HMI blinks, and we can observe the fault by clicking on the fault icon. To recover, reduce the input voltage and reset the fault via HMI.

- DC Undervoltage (Battery Undervoltage): If the battery/ bus voltage drops below the lower threshold of 690 V, the inverter disconnects to prevent overdischarge (Battery operating limit of 690-790V). The inverter can automatically restart when the voltage returns to range.

- Overvoltage: If the voltage on the DC bus exceeds 800 V for longer than a few cycles, the inverter trips off (to protect loads and itself). The contactor opens, and the inverter shuts down. The fault icon in the HMI blinks, and we can observe the fault by clicking on the fault icon. To recover, reduce the input voltage and reset the fault via HMI.



- Undervoltage (Grid Loss): If grid voltage drops or is lost (phase dropout), the inverter ceases output (anti-islanding). This is required by grid codes. The contactor opens, and the inverter shuts down. The fault icon in the HMI blinks, and we can observe the fault by clicking on the fault icon. To recover, reduce the input voltage and reset the fault via HMI.

7.2 Overcurrent and Short-Circuit Protection

- AC Overcurrent: The inverter continuously limits output current to its rated value or stops the inverter. If the AC load causes a phase current to exceed the programmed threshold (99A) default for a sustained period, the inverter will fault (Voltage/Current surge). Rapid current limiting (adjusting or stopping PWM) also protects the power devices. We can change these threshold values in the HMI.

- Short-Circuit: In the event of a three-phase short on the AC side, the inverter's protection acts very quickly. IGBT desaturation detection or current threshold triggers are used to shut down the PWM and open the output contactor. The design can typically withstand a short for a few milliseconds without damage. The inverter will lock out and display "AC Short-Circuit".

- Thermal Protection: The inverter monitors the heatsink temperature. If the temperature exceeds safe levels (e.g.,>85 °C), it reduces output current or shuts down to prevent overheating.

- Fault Capture: If the circuit trips, the inverter control logs waveform data (similar to an oscilloscope capture) at the fault instant. The HMI or PC GUI can display these pre-fault waveforms for diagnostics, aiding troubleshooting.

7.3 Emergency Shutdown Procedure

In any emergency, immediately cut the AC supply, then the DC supply, and then use the E-Stop if further isolation is needed. Evacuate if necessary and follow safety protocols:

- Emergency Stop (E-Stop): A dedicated red E-Stop button on the front panel (or external circuit) will immediately shut off the inverter. This overrides all functions and opens the main DC and AC contactors. Use this in case of smoke, fire, or an immediate hazard.

- Grid Loss: If the grid fails or a major fault is detected (e.g., internal failure), the inverter automatically shuts down. Do not attempt to restart until the issue is resolved.

- Fire: If fire or electrical arcing occurs, cut both DC and AC supplies at the source. Use a Class C/CO2 fire extinguisher for electrical fires. Do not spray water on the unit.

- Post-Fault: After an emergency shutdown, the inverter must be manually reset via the HMI “Clear Fault” command and re-enabled following the normal startup sequence.

8. Commissioning and Testing

8.1 Pre-Startup Checklist

Before energizing the inverter, verify:

- Mechanical Installation: Unit is securely placed, enclosure is sealed, and all covers are in place.
- Wiring: Confirm all power and control wiring per wiring diagrams. Tighten all terminals. No loose conductors.
- Grounding: Protective earth is properly connected. Measure earth resistance (<1 Ω typical).
- Cabling: Correct gauges for DC and AC lines. Cable entries sealed.
- Disconnects: AC and DC disconnects are in place and open.
- Polarity: DC positive/negative correctly connected; AC phases to correct L1, L2, and L3.
- Control Power: An external AC auxiliary supply should be present before connecting anything else.
- Environmental: Ambient conditions within limits.
- Parameter Defaults: Check factory default parameters (HMI display) for key settings, rated voltage, and frequency.
- We will first turn on the AC grid, allowing the DC bus to be slowly charged to nearly 560 V through the precharge circuit.
- To successfully connect the DC source or battery to the inverter, first charge the DC bus to match the battery voltage using a resistor, which helps manage inrush current effectively. Once the DC bus reaches the battery voltage, activate the contactor positioned between the battery and the inverter to bypass the resistor. This step is essential to mitigate the risk of inrush currents flowing directly from the battery to the inverter during system startup. It is crucial to follow this procedure every time the system starts to ensure safe operation and maintain the integrity of the inverter, preventing potential damage.

8.2 Parameter Configuration

Use the HMI to enter system-specific parameters before operation:

- DC Voltage Limits: Set the minimum and maximum DC bus voltages according to the battery spec (e.g., 690 V min, 790 V max). This protects the battery and prevents trips.

- Setpoints: The inverter uses direct ID/IQ current references. For simplicity, set a maximum active power (kW) and leave IQ=0 for unity PF by default.

- Protection Setpoints: Overvoltage (OV) and undervoltage (UV) thresholds on DC are fixed at 680 V min and 800 V max.

- Protection Battery Setpoints: Overcharge (OV) and Overdischarge (ODC) thresholds on DC are adjustable up to 680 V min and 800 V max.

- Communications: Assign Modbus ID, baud rate, and enable communication ports as needed.

- Control Mode: Typically starts in standby (no power flow). I.e, id = 0 and iq = 0.

- Anti-Islanding: grid protection features per local grid code.

8.3 Functional Tests and Validation

Perform these tests to ensure correct operation:

- Power Delivery Test: Set id and iq values and use a power analyzer to verify the inverter delivers the correct real power, frequency, and PF to the grid. Verify AC voltages remain within tolerance.

- Recharge Test: Set the inverter to charge mode at a moderate rate (id = 10 A). Verify that DC current flows into the battery (or a DC load bank).

- Discharge Test: Set the inverter to charge mode at a moderate rate (id = -10 A). Verify that DC current flows into the grid.

- Overcurrent Trip Test: (Caution!) With a known load, deliberately increase the load to trigger the inverter's overcurrent protection. Confirm that the inverter trips cleanly and displays the correct fault code.

- Over/Under Voltage Trip Test: Raise/lower the AC voltage (using a source or autotransformer) to trigger UV/OV trips and verify alarms. Similarly, adjust battery voltage to trigger DC UV/OV.

- Communication Test: Use the Modbus client or LabVIEW GUI to read parameters. Verify all values match the HMI.

- Control Response: Use the HMI to change a setpoint (e.g., increase power) and observe the smooth response of the inverter (no oscillations).

- After testing, the system can be put into normal operation. Record all test data for future reference.

9. Monitoring and Diagnostics

9.1 Real-Time Monitoring Parameters

On the HMI and remote interface, the following key parameters are available in real time:

- DC Measurements: Battery/ DC voltage, battery SOC (if BMS-connected), DC power.
- AC Measurements: Line-to-line voltages, phase currents, frequency.
- Derived Values: Total energy throughput (kWh), efficiency (from power readings), THD% on currents (if measured).
- Alarms: fault code and description (e.g., " Overvoltage").
- Logs/History: Time-stamped records of fault events, start/stop events, and parameter changes.
- External Data: If integrated with a battery BMS, it may display battery pack data (e.g., cell voltages, battery temperature) on the LABVIEW application.
- Remote monitoring via Modbus or LabVIEW GUI can retrieve some of the data. We can monitor voltage, frequency, ID, and IQ. Additionally, we can set parameters such as ID and IQ, as well as start and stop commands, along with an indication of whether the inverter is on or off.

9.2 Fault Logging

The inverter maintains a fault log that records the last N fault events:

- Fault Codes: Each error has a text description and indication (e.g., "Over DC-link voltage", "IGBT driver desturation").
- User Response: When a fault occurs, the inverter usually disables power output. To clear a fault, conditions must return to normal, and the user must reset the fault via HMI.
- Diagnostic Data: Every fault automatically triggers data capture. For example, if an under-voltage (AC mains) fault occurs, the inverter stores a short waveform history around the event for analysis. This can be accessed on the oscilloscope option in the HMI screen.

9.3 Remote Monitoring via Modbus/LabVIEW GUI

Silov provides software for remote monitoring and data logging:

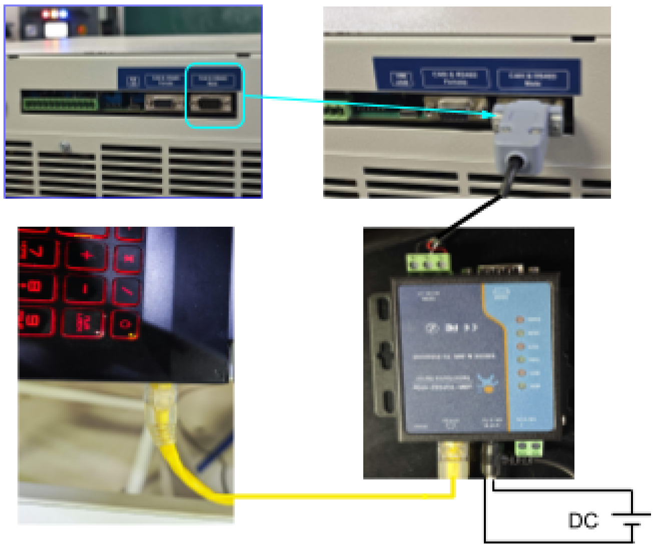
- Modbus Integration: Using the inverter's Modbus interface, SCADA systems can continuously poll all measurements and status registers. A Modbus register map will be provided (Appendix C placeholder).

- LabVIEW GUI: A Windows-based application shows live dashboards of voltages, currents, and alarms. It allows reading/writing parameters via an RS-485/USB or Ethernet connection.

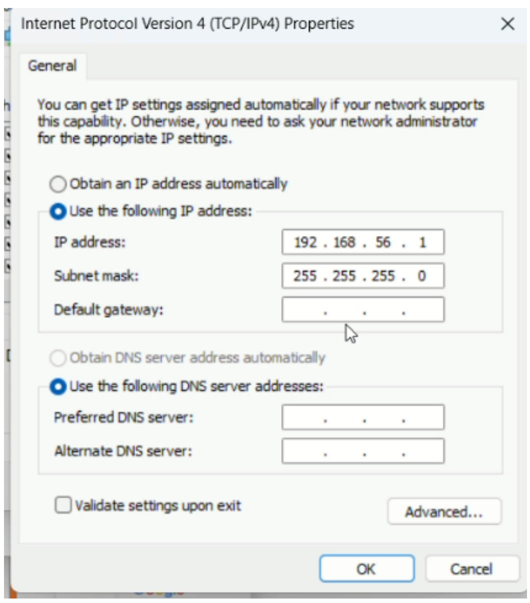
- Data Logging: The remote software can log historical data for analysis (CSV export). Useful for performance verification or diagnostic review.

- LabVIEW Integration: For custom systems, the Silov solutions will provide a Windows application for controlling the inverter via Modbus. This application will serve as an intuitive interface for managing the inverter's operations effectively, as it already implements the inverter's Modbus protocol. See Appendix C for register details (to be provided).

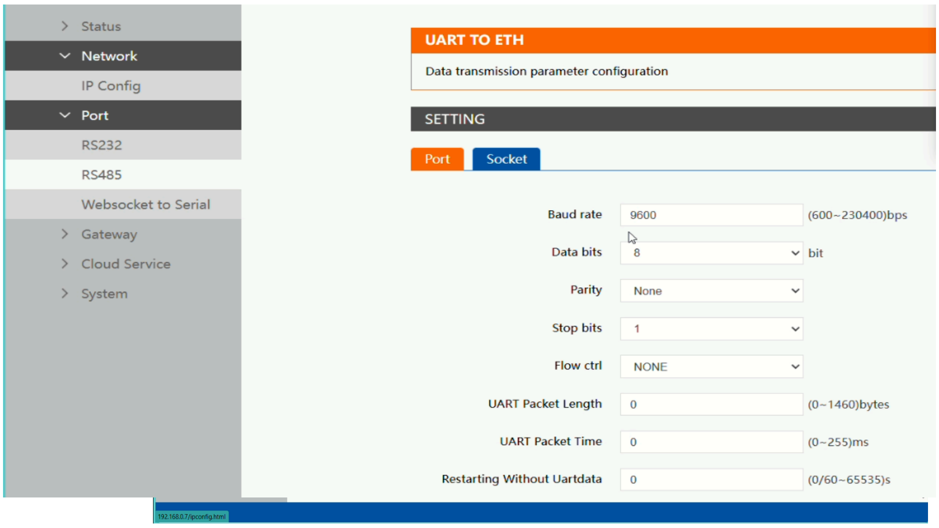
  Make the connections as shown below:



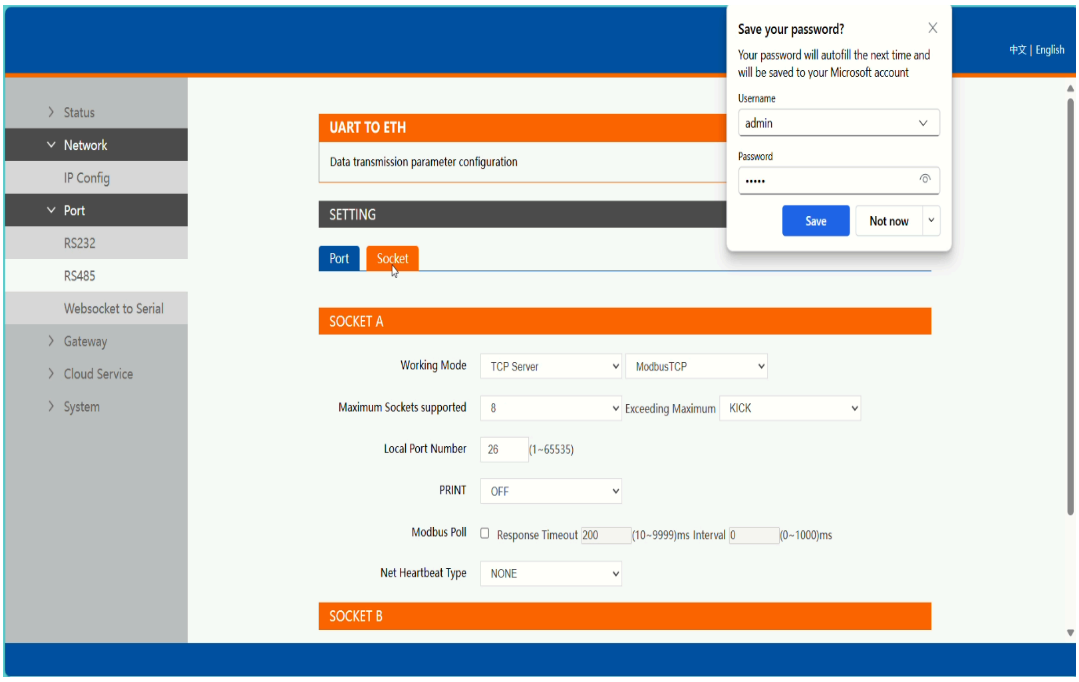
  - First, we need to make some changes to the converter by using the local address(192.168.0.7) method once. This adjustment is only required once for the Modbus to Ethernet converter. Follow the steps below to implement these changes.
    1. Establish the connection.
    2. Go to network connections using search and then right click on the Ethernet port and select the properties.
    3. Click TCP/IPv4 properties and then click on properties.



4. Change the IP address to 192.168.0.1. The subnet mask will be automatically created, and then click on OK.
5. Open your web browser.
6. Enter 192.168.0.7 in the address bar.
7. A pop-up window will prompt you for a username and password.
8. Type "admin" for both the username and password fields.
9. You will be directed to the settings for the Modbus to Ethernet converter.
10. Make the necessary changes according to the provided images below.



11. After making the change, click on save and reopen to check if anything else needs to be changed.



10. Maintenance and Service

10.1 Routine Inspection Checklist

Perform regular inspections (e.g., monthly) to ensure reliable operation:

- Visual Inspection: Look for loose connections, burnt marks, or corrosion on terminals. Check that the indicator LEDs and display show normal status.
- Cooling System: Ensure fans are running quietly. Clean any dust from fan blades, heatsinks, and vents using dry air or a vacuum. Replace air filters if present.
- Tightness: Check the tightness of all power and grounding terminals with a torque wrench (per spec). Vibration can loosen connections over time.
- Environment: Confirm ambient conditions still meet requirements (no new obstructions, temperature/humidity within spec). Check that ventilation is unobstructed.
- Ground Continuity: Verify the earth connection with a multimeter (should be $<0.5\,\Omega$).
- Function Test: Test the E-Stop and verify the inverter stops safely. Cycle the inverter off and on to ensure it restarts cleanly.
- Labeling: Ensure warning labels and document ID on the inverter are legible and updated.
- Battery Interface: If the inverter is part of a battery system, check battery terminals and BMS connections.

10.2 Firmware Updates

- New Versions: Firmware updates from Silov Solutions will be announced whenever an update is available. Updates may improve performance or add features.
- Procedure: Use the USB port and the Silov update tool to load new firmware. Ensure the inverter is off-load (no power transfer) during the update.
- Verification: After the update, reboot and check the version displayed on the HMI. Perform key functional tests to verify normal operation.
- Precautions: Do not interrupt power or communication during firmware flashing. If the update fails, do not operate until the firmware is restored to a stable release.

10.3 Spare Parts and Accessories

Recommended spare parts to have on hand:

- Power Modules: Spare IGBT/MOSFET modules for the inverter bridge (if user-serviceable in the field).
- Fans: Replacement cooling fans (match size and spec).
- HMI/Display: Spare touchscreen or LCD module (if detachable).
- Fuses/Breakers: AC and DC fuses or breakers of correct ratings.
- Wiring: Extra terminal blocks, cable glands, and connectors.
- Aux Power Supply: If an external 24 V supply is used, a spare power brick is required.

Documentation: Copies of the manual, wiring diagrams, and parameter sheets.
All spare parts should be procured from Silov or approved vendors to ensure compatibility. Using non-approved parts may void the warranty and compromise safety.

11. Appendices

11.1 Glossary of Terms

- AC (Alternating Current): Electric current that periodically reverses direction (e.g., grid power).
- DC (Direct Current): Electric current flowing in one direction (e.g., battery output).
- ID/IQ (Direct/Quadrature Current): Components of AC in a rotating reference frame. ID controls one power component, IQ controls the other.
- PF (Power Factor): The ratio of real power to apparent power. A PF of 1.0 means the current is in phase with the voltage.
- PLL (Phase-Locked Loop): A Control algorithm that synchronizes the inverter’s frequency and phase to the grid.
- SPWM (Sine Pulse-Width Modulation): Technique of switching power transistors on/off to synthesize AC voltage.
- HMI (Human-Machine Interface): The touchscreen display and controls on the inverter.
- THD (Total Harmonic Distortion): Measure of waveform distortion. Lower THD = cleaner sine wave.
- IGBT (Insulated-Gate Bipolar Transistor): A semiconductor switch used in power electronics.
- Modbus: A serial communication protocol commonly used in industrial devices.
- IEEE (Institute of Electrical and Electronics Engineers): An Organization that sets many technical standards (e.g., IEEE 1547).
- RS-485: A standard for differential serial communication over twisted pair.
- Inverter: A device that converts DC to AC power. (Here, bidirectional also performs rectification.)
- Rectifier: A device that converts AC to DC power.
- Four-Quadrant Operation: Capability to source or sink active (±P) and reactive (±Q) power.
- Vector Control (FOC): A Control method that separates AC currents into orthogonal components for precise control of motor/inverter performance.

- Grid Code: The rules and standards governing how devices connect to the utility grid.
- Derating: Reduction of maximum power capability under certain conditions (e.g., high temp or altitude).

11.2 Modbus Register Map

Starting Register	**Ending Register**	**No of bytes**	**Register type**	**Name**
0000	0001	2	Read input register	Frequency
0002	0003	2	Read input register	Voltage
0000	0001	2	Read holding register	Id
0002	0003	2	Read holding register	iq
0000	—----	1	Write single coil	Start/stop
0000	0001	2	Write holding register	Id
0002	0003	2	Write holding register	Iq