

PV SCADA™

◆ ◆
Solar Plant Control & Monitoring Solution

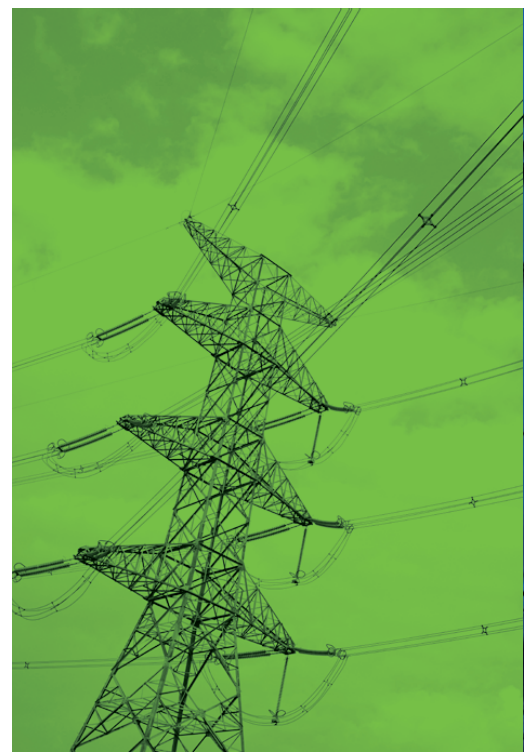


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A. Product Overview

PV SCADA system is a critical part of a PV solar power plant. The well designed PV SCADA system will ensure the operational stabilities and reliabilities of the power plant during its life circle.

PV SCADA system will perform all data acquisition, monitoring and control functions of power plant. All necessary information concerning process behavior, instrument and integrity controller, sequential control and alarm function shall be immediately available at the operation consoles.

ATS solution of the PV SCADA System assures to fully supports both national and international grid codes, thus enabling grid-compliant feed-in from PV systems at high-voltage levels worldwide. The high-performance system provides a wide range of features for active and reactive power control, which guarantees grid stability – in fact manufacturer independent. Modularity and scalability allow customized plant control and provide the necessary flexibility in order to meet the needs of the high diversity of grid connection requirements. The Human-Machine Interface (HMI) visualizes all measured values locally and in real time, allows technical operation management for PV power plants on site.

In order to obtain a high availability and reliability of the PV power plant, the SCADA system also will be built with a high availability. This shall be achieved by using a single-fault-tolerant design for the centralized components and important devices and redundant configuration.

ADVANTAGES

- ◆ Compliance with national and international grid codes.
- ◆ High flexibility in system design and PV system technology.
- ◆ Wide compatibility thanks to interface and protocol variety.
- ◆ Able to connect and control several types of inverters: Central or String Inverters or both.
- ◆ Reduction of commissioning costs and also maintenance cost of PV power plant.

MAIN FEATURES

- ◆ Provide fully features of PV SCADA system for data acquisition, monitoring and control of PV plant in accordance with national and international grid codes.
- ◆ Modular, scalable architecture and manufacturer independence, suitable for controlling PV Power Plant with different Inverter vendors.
- ◆ De facto Historical Information System (HIS) in popular use worldwide.
- ◆ Multi-protocol speaking: Modbus Serial/TCP, IEC61850, SEL Fast-Message, DNP3, IEC 62056/IEC61107, IEC-60870-5-104,... (can be extended upon users' requests).
- ◆ System sizing support over 2000 IEDs, controller and monitor, and can handle 256,000 datapoints.
- ◆ User-friendly graphic interface allowing operators to perform their tasks with minimal computer knowledge and reducing "start-up" time.
- ◆ Ready for future utility interface bus integration.

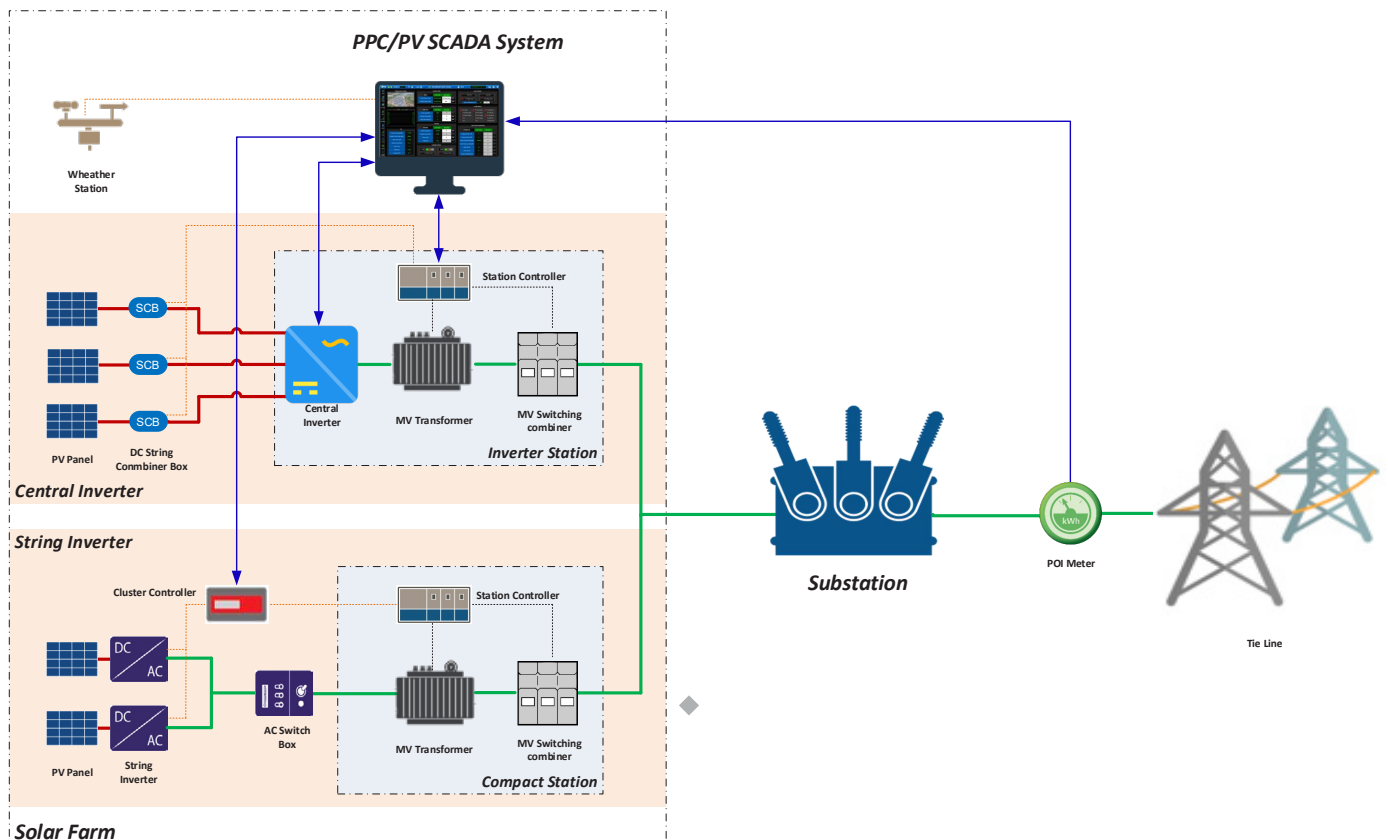


Figure 1. Overview of PV SCADA system

1. HARDWARE STRUCTURE

Main Components of PV SCADA system:

- ◆ At each inverter station:
 - * Station controller with analog, digital input/output and support protocol converter function to collect all monitoring and control data of PV power plant from DC combiner box monitors, Inverters, MV transformer, RMU panel, protection relays, multifunction meters, auxiliary systems, weather stations.
 - * Weather stations to acquire meteorological information for performance evaluation and generation prediction of PV power plant. These weather stations will be connected to data acquisition devices at Inverter stations.
- ◆ At operator control room:
 - * Redundant Power plant control and SCADA servers for data acquisition, data processing, historical data storage, monitoring and control of whole the PV power plant. These devices are manufactured according to industrial standards, open

architecture, networking capable, compatible with standard protocols, ensure that any failure devices does not affect to monitoring control process of power plant.

- * Human – Machine Interface function (HMI), support operator to perform all monitoring and control function for the PV power plant.
- * History database server for data storage and historical data mining applications; engineering applications for building, configuring and maintaining PV Plant SCADA system.
- * Satellite-Synchronized Clock for time synchronization of all equipment in the PV SCADA system.
- ◆ Multi meter installed at substation to collect measurement data (U/I/P/Q) at POI, provide data input for PPC system.

SCADA signals of PV power plant will be integrated into Substation SCADA Gateway servers and connect to SCADA systems at the Load Dispatching Centers (such as NLDC, SRLDC, EVNSPC,...)

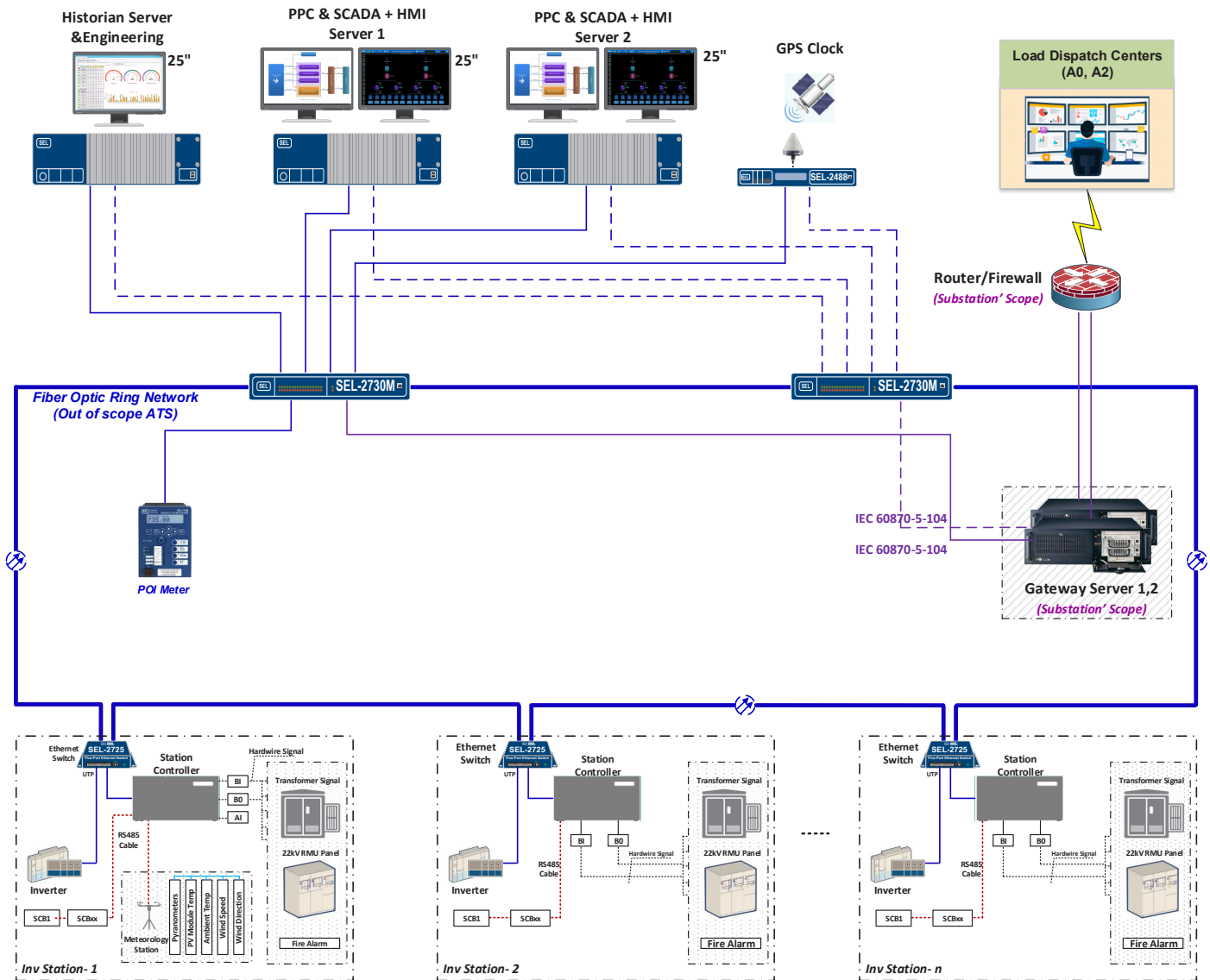


Figure 2. PV SCADA hardware system

B. Technical Highlights

2. SOFTWARE DESCRIPTION

2.1. Software architecture

The PV SCADA system is provided with the data acquisition, processing, presentation and storage functions to be performed at the power plant. The primary data acquisition, control and processing tasks shall be performed via the redundant power plant control and SCADA Server with appropriate protocol via the Ethernet LAN or dedicated serial communication system.

Main software modules of the PV SCADA system include:

- ◆ Data Acquisition module (DA)
- ◆ Real-time Database (RTDB)
- ◆ Historical information system (HIS) and applications
- ◆ Power plant control module (PPC)
- ◆ Human – Machine Interface module (HMI)
- ◆ Intelligent energy management system (iEMS)
 - * PV power generation predicting function
 - * PV power plant analysis and failure detection function

2.2. Supported communication protocol

Here are some of the communication protocols system supports:

- ◆ Modbus Serial/TCP (DC String combiner boxes, Inverters, Weather stations, Inverter station controller, Multi-function meter, IO devices...)
- ◆ IEC61850, SEL Fast Message, DNP3 ... (Relay, IO devices, Grid analyzer...)
- ◆ IEC 62056/IEC61107 (Tariff meter)
- ◆ ...

2.3. System sizing

The PV SCADA system can support sizing capacity for over **2.000** IEDs, controller and monitor, and **256.000** data points. This sizing ensures to meet all requirements of PV plant and can be extended in the future without having to upgrade any of the control system components.

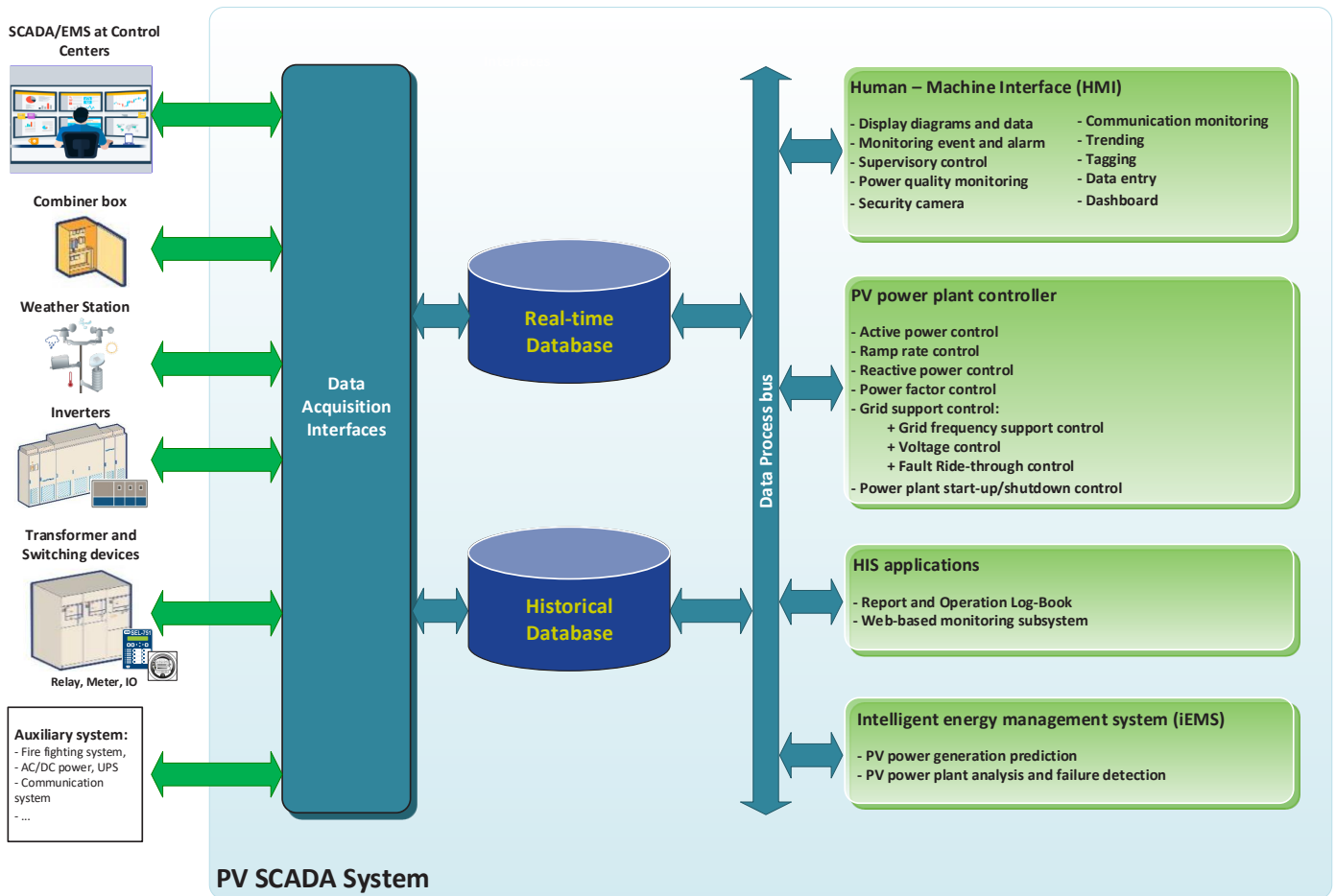


Figure 3. PV SCADA software system

2.4. Software Modules

2.4.1. Data acquisition (DA)

The SCADA system will acquire all available analog data, status data and perform control signal from PV power plant apparatus through DC string combiner boxes, Inverter controllers, Inverter station controllers, relays, Common IO devices, Meteorological station, Multi-function meters, 22kV RMU panel. A local data repository is built up at Power plant controller for real-time data; the historical data will be integrated in the Substation historian database.

DA module process following data types:

- ◆ Analog data
- ◆ Status indications and alarm signal
- ◆ Time stamped status and SOE
- ◆ Manually entered data
- ◆ Oscillograph information
- ◆ Disturbance and [Power Quality] Information
- ◆ Control command...

Data acquisition from main PV power plant devices:

- ◆ DC string combiner boxes located throughout the solar field
- ◆ Inverters located in Inverter Station
- ◆ MV transformer 0,6/22kV
- ◆ 22kV RMU panel located in Inverter/Transformer Station
- ◆ Weather station

2.4.2. Historical Information System (HIS)

Smart Historical Information System (SmartHIS™) developed by ATS is used for the historical repository of all information coming from the PV power plant operation, generated under normal operating conditions or during disturbances. The SmartHIS™ is designed with the client-server architecture, non-SQL database technology, Time-series data archiving to collect, process, store, manage and retrieve data.

The difference between SQL and Non-SQL database is summarized as follow:

SQL Database	No-SQL Database
Use predefined schemas to determine the structure of data, a change in the structure would be both difficult and disruptive to whole system.	Has dynamic schema for unstructured data, and data is stored in many ways. So you can add fields as you go.
Data tables have complex relation, so the data reading and writing processing is not fast.	Data structure allows to retrieve all information of specific item in a single query, data reading and writing is faster than SQL Database.
Sequence data query, performance is slow.	Ad-hoc data query, fast accessing historical data at a timestamp.
Built on the idea of "one size fit all", when the database is bigger, reading and writing performance is slower, require a larger hard disk volume for storage.	Built on the idea of "one size does not fit all", there is no problem when database is bigger, data can be stored on different partitions.
Consistent with the static data which has specific structure and relationship.	Data store with key-value structure, suitable for time series data type.

Table 1. Comparison between SQL and No-SQL Database

Benefits of Historical Information System:

- ◆ **Data Infrastructure base for advanced applications:** like Solar power generation prediction, PV power plant analysis and failure detection...
- ◆ **Massive scalability and performance:** the database can be scaled to support millions of devices or time series data points in continuous flow and perform real-time analysis.
- ◆ **Reduced downtime:** the architecture of a database that is built for time series data ensures that data is always available even in the event of network partitions or hardware failures.
- ◆ **Lower costs:** Fast and easy scaling using commodity hardware reduces the operational and hardware costs of scaling up or down.
- ◆ **Improved business decisions:** analyze data in real time and make faster and more accurate adjustments for energy consumption, device maintenance, infrastructure changes, or other important decisions that impact the business.

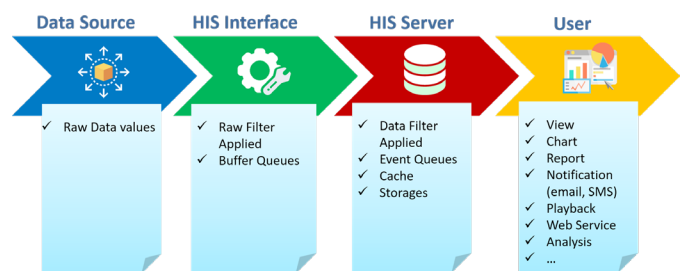


Figure 4. SmartHIS™ system overview

B. Technical Highlights

2.4.3. PV power plant control (PPC)

PV Power Plant Controller (PPC) is an intelligent vendor-independent system for dynamic PV power plant control and grid code compliance, customizable to satisfy any grid requirement while ensuring interoperability with plant SCADA systems.

Our solution is based on IEC 61131-3 logic software system and suitable for controlling PV Power Plant with different Inverter vendors (such as ABB, SMA, Huawei, TMEIC, Sungrow, etc.) for both of string and central inverters. The PV plant controller will be implemented at plant-level logic and utilized closed-loop control schemes. Real-time commands will be sent to each inverter via industrial protocols such as Modbus RTU, DNP3, IEC 61850, IEC 60870-5-104, etc... to achieve fast and reliable regulation of PV power plant generation.

The main PV power plant control functions:

- ◆ **Active Power Control:** Hold the output at fixed commanded Setpoint or react to curtailment commands by operator and the Load dispatching center. Ensure that output of PV power plant does not exceed specified limit.
- ◆ **Ramp rate control:** Limit a smooth active power ramp rate must be followed in the output to the grid, ensure not to cause to the system instability at the grid connection point.
- ◆ **Reactive Power Control:** Used to hold the plant at a specific reactive power output.
- ◆ **Power Factor Control:** Allow the plant to maintain a desirable power factor at the point of connection.
- ◆ **Grid support control:**
 - * Grid frequency support control: Automatic regulate the active power delivered based on the instantaneous frequency deviation of the Grid.
- * **Voltage Control:** Allows the plant to dynamically provide reactive power support, based on system voltage.
- * **Fault Ride-through capability:** do not trip off during system disturbances such as specific low and high voltages or low- and high-frequency circumstances and continue to provide power when the grid needs it.
- ◆ **Power plant start-up/shutdown:**
 - * If a planned outage is needed, operations should have a way to take the plant offline in a controlled manner by one click activity. Similarly, after the outage period; the plant needs to come up smoothly.
 - * When a shutdown request is provided along with required confirmation, the active power of plant will ramp generation down all the way to 0MW. Inverters will then be stopped. Likewise, when a startup command is issued, each inverter will be started and ramped up to the plant level setpoint.
 - * Operator can configure automatic start-up power plant at setting time or at the beginning of solar radiation intensity of shutdown power plant at the end of solar radiation intensity.
- ◆ **RMU panel control function:**
 - * Remote control of 22kV RMU panel at each Inverter stations with Interlocking Logic via Relays and Bay Control Units in specific conditions such as maintenance and repair process or in fault isolating and recovering process.

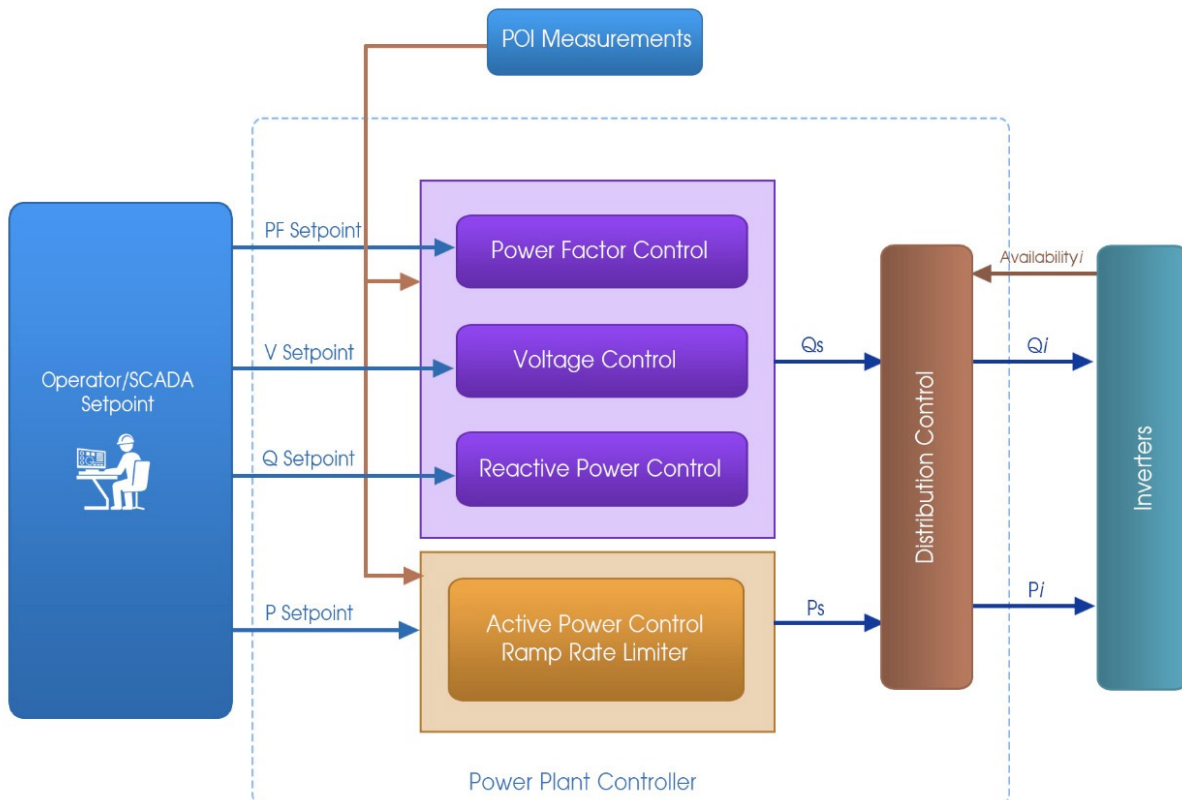


Figure 5. PV power plant control function block diagram

2.4.4. Human-Machine Interface (HMI)

User Interfaces can be understood as communication path between user and monitoring, controlling programs of the PV SCADA system as well as other applications. User interfaces allow to monitoring, controlling all primary device in power plant, access to storage data simply and friendly.

- ◆ The design of Screen can be simply modified and reused.
- ◆ User Interface can immediately reflect by light and sound indication corresponding with event of operator or primary devices.
- ◆ The operator can implement every controlling action exclude automatic controlling functions. All message or warning signals will be unlimited follow time sequence. All signals of operation process will be collected and continuously warn to operator at Alarm screen.
- ◆ At central control room, the HMI system will be built in the unified way, include all supervisory and control function of both PV power plant and Substation.

(1). Supervisory control

The supervisory control commands shall be enterable at the Operator's request, via tabular and graphic displays, will be processed by the Power plant controller and sent to the Inverter controller, relay, BCU only after the command has been validated. The control sequence shall be predicated on the "select and check before operate (SBO)" philosophy in order to ensure the operation security.

The supervisory control step sequence is provided as follows:

- ◆ Display schematic diagram or tabular display on displays.
- ◆ Select the device for remote control by means of cursor positioning.

- ◆ Invalid requests shall result in a message showing the reason for rejection and the cancellation of the point selection – the ability shall be provided for the Operator to insist on the request in case of predefined non-critical situations.
- ◆ Change the color and blinking attribute of the affected device or function on the schematic diagram if the operation has been performed.

a) PV power plant control functions:

- * Dynamic voltage and/or power factor, reactive power regulation of the solar plant at the point of interconnection (POI) to Grid support.
- * Active power output control with fixed setpoint or curtailment command of the solar plant when required so that it does not exceed an operator specified limit.
- * Frequency control to lower plant output in case of over-frequency situation or increase plant output (if possible) in case of under-frequency.
- * Support incorporate fault ride-through capability is that they do not trip off during system disturbances such as over – under voltage, over – under frequency but continue to provide power when the grid needs it.
- * Start-up and shut-down control of whole power plant.

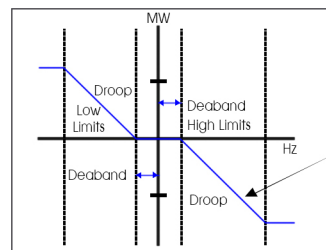


Figure 6. Frequency droop parameters

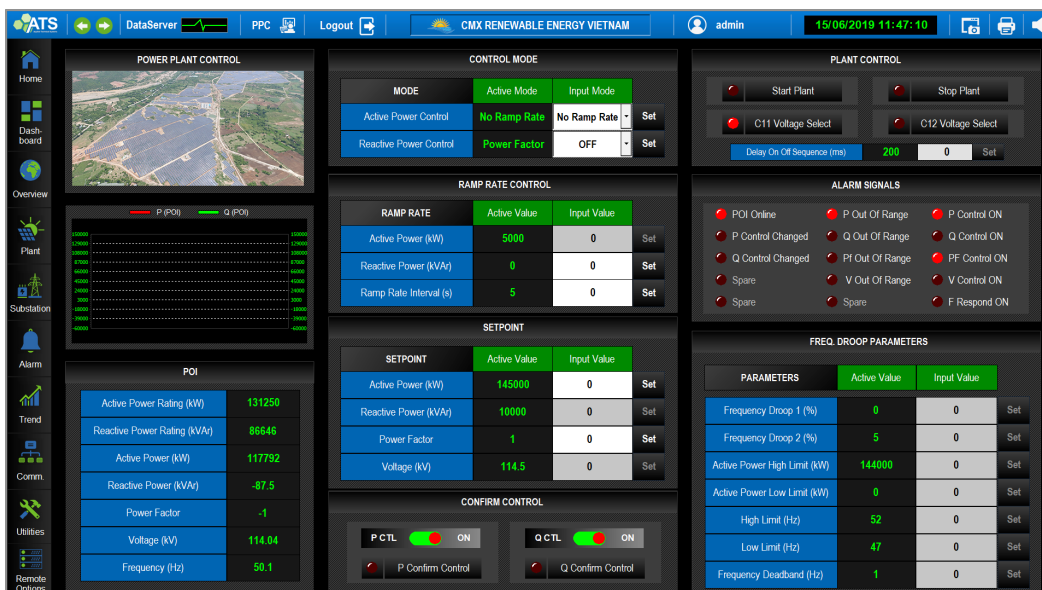


Figure 7. Power Plant Control Screen

Company Overview

b) 22kV RMU panel devices control functions:

Device Control – The capability to control devices shall be enabled in accordance with the pre-defined areas of responsibility; control commands entered by non-authorized users shall be inhibited (Figure 8).

(2). Monitoring

a) PV power plant monitoring

The HMI function is designed with multi-layer architect, more lower layer more detail information (Figure 9-16).

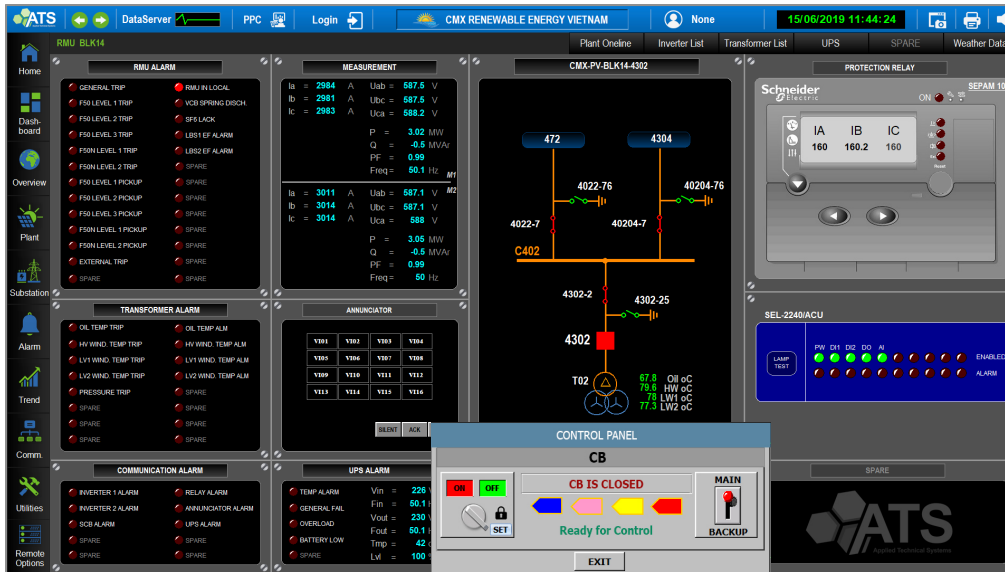


Figure 8. 22kV RMU Breaker control



Figure 9. Power Plant Dashboard

Display plant dashboard with current generation parameters (3 phase currents, voltage, active power, reactive power, power factor and frequency); total plant daily, weekly and monthly yield; current weather parameters...

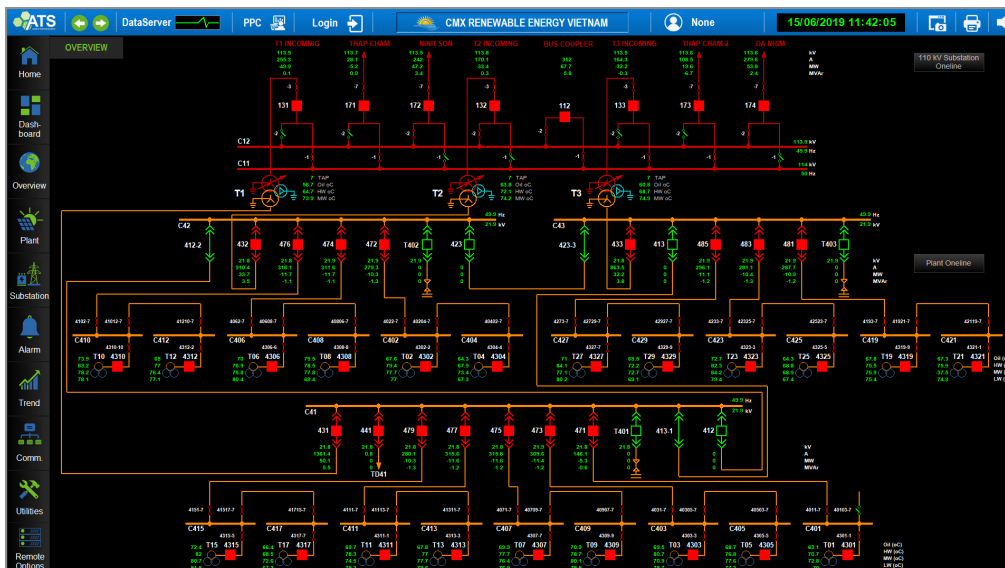


Figure 10. PV power plant Single Line Diagram

Display solar power site online diagram with main devices and operation parameters

Display operation parameters, status signal, alarm and protection signal of each Inverter station. The system is able to connect and control several types of inverters: Central or String Inverters or both.

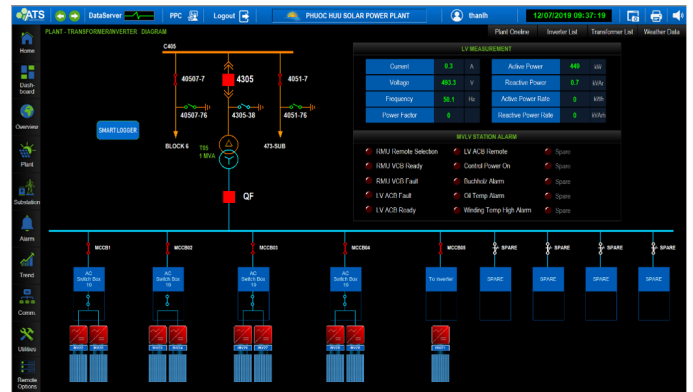
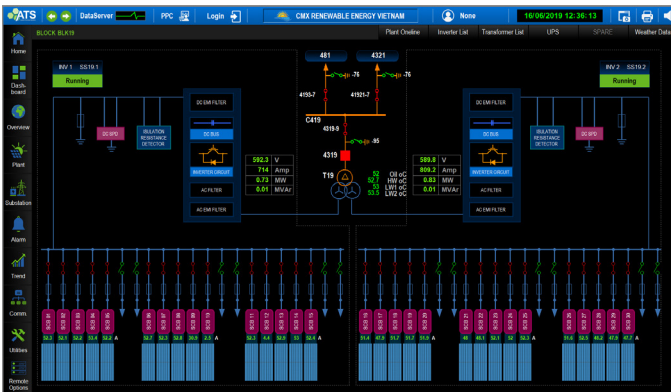


Figure 11. Central & String Inverter Station Screen



Figure 12. PV Inverter data monitoring and control

Display analog parameter such as input current, input voltage, output current, output voltage, output power, power factor, frequency, operation time; status, alarm, protection signal of input and output switching devices of each Inverters...



Figure 13. MV transformer monitoring

Display operation signal of MV transformer such as tap position, temperature, alarm and protection signal...

B. Technical Highlights



Figure 14. PV String Monitoring

Display all analog parameter such as: current, voltage and power of each solar string, surface temperature and evaluate efficiency and operation time of each PV string

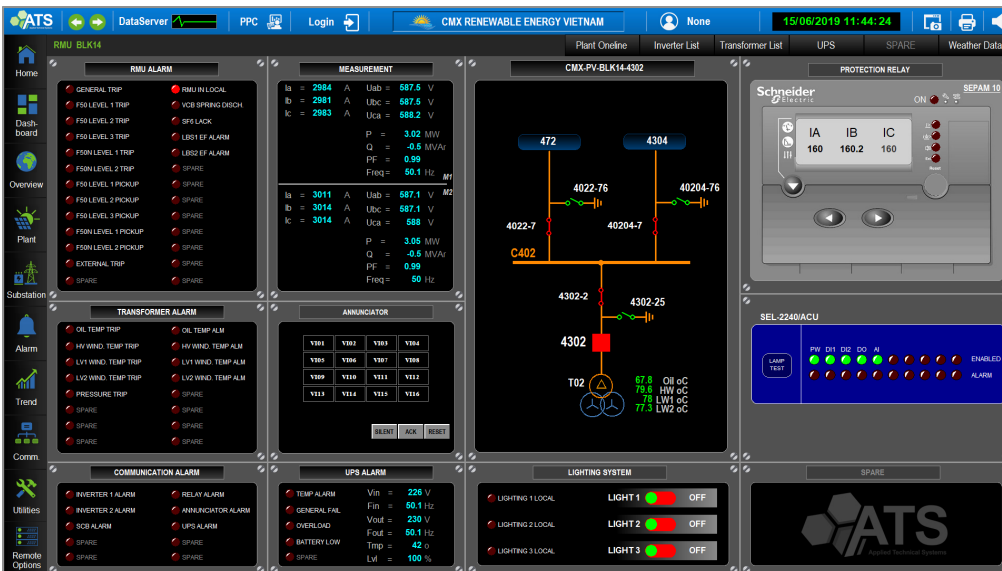


Figure 15. RMU Monitoring

Display operation parameter, status signal, alarm and protection signal of RMU panel devices such as circuit breaker, load break switch...



Figure 16. Weather conditions Monitoring

Display current value of weather conditions such as solar radiation, atmospheric pressure, wind direction and speed, humidity, ...

b) Power quality monitoring

Monitor power quality parameters at output of power plant to analysis and evaluate generation efficiency and quality of PV power plant and substation. The main parameters to be measured and recorded are:

- * Voltage sag, swell, and interruption (VSSI)
- * Harmonic distortion to the fiftieth order
- * Voltage fluctuation
- * Voltage unbalance
- * Power factor
- * Frequency variation

(3). Alarm processing

The monitoring of alarms coming from the equipment operation has a major importance in the power plant operation, especially during significant events such as total or partial system outages. An event is defined as any change in the power plant operation. An alarm is a subgroup of events. Any unsolicited status change or violation of any allowable limits of the power system variables shall initiate an alarm.

As a minimum, the following information shall be included for each alarm:

- ◆ Date and Time
- ◆ Substation Name
- ◆ Element Identifier
- ◆ A brief description of the alarm condition

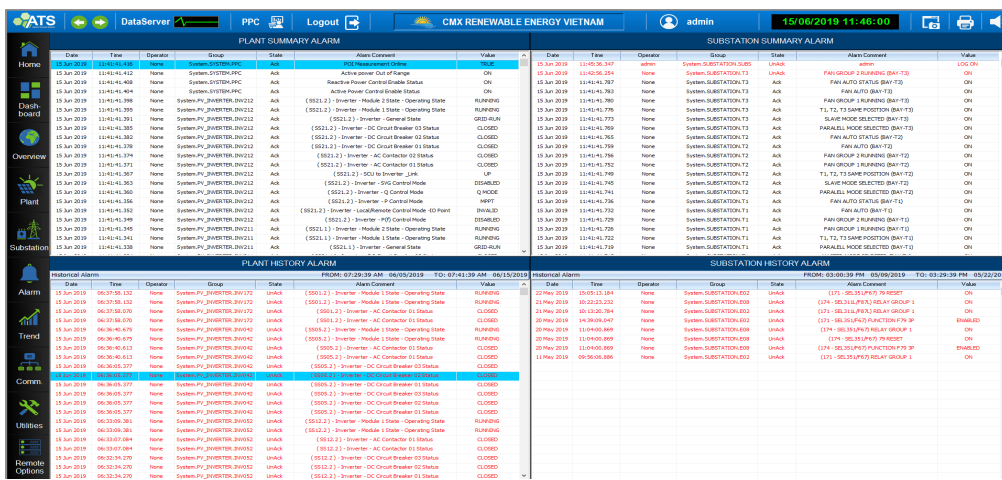


Figure 17. Alarm presentation window



Figure 18. Trending window

(4). Trending

The PV SCADA system shall incorporate trending functionality. It shall be possible to represent trends both from historical data, using the information stored in the HIS, and with real-time data.

There are some trend types the SCADA system can support:

- ◆ Electrical parameters trending (U, I, P, Q, Hz, PF...)
- ◆ Temperature trending (Ambient temperature, Room temperature, PV panel temperature, Inverter temperature, Tie transformer temperature...)
- ◆ Auxiliary parameters trending...

(5). Tagging

Tagging of the circuit breakers and disconnector switches, inverters... for maintenance, hot line work or automatic re-closing is an important part of the PV SCADA system design criteria. This will be accomplished by using as one input in interlock condition.

The Tagging function also allows the user to enter the following tag information:

- ◆ Job/Permit Number
- ◆ Date
- ◆ Purpose
- ◆ "Tagged by" and "Tagged for" Information

B. Technical Highlights

(6). Communication Monitoring and Diagnostic

The following communications monitoring and diagnosis facilities shall be provided.

- ◆ *Communications Monitoring:*
 - * Interactive access to the parameters of the communication links database
 - * Maintenance of the data links elements in the same database
 - * Monitor all operational status of Network devices including switches, computers and IED ports
 - * Failures detection and recovery management
 - * Graphic display of the status and activity of the communication devices
- ◆ *Channel and Interface Diagnostics* – including channels selection, diagnostic message generation, establishment of communication

sessions with other elements, and presentation of information displays

- ◆ *Monitoring and Diagnostics of IEDs Communications* – For the particular case of the data acquisition and communications servers, the corresponding operating system shall provide the programming facilities for the supervision of the behavior and diagnosis of the interfaces and communication channels with the installed IEDs in the substation.

(7). Power plant auxiliary monitoring

The PV SCADA system will monitor all necessary information related to plant auxiliary system or Inverter station auxiliary system like AC and DC, UPS, etc.

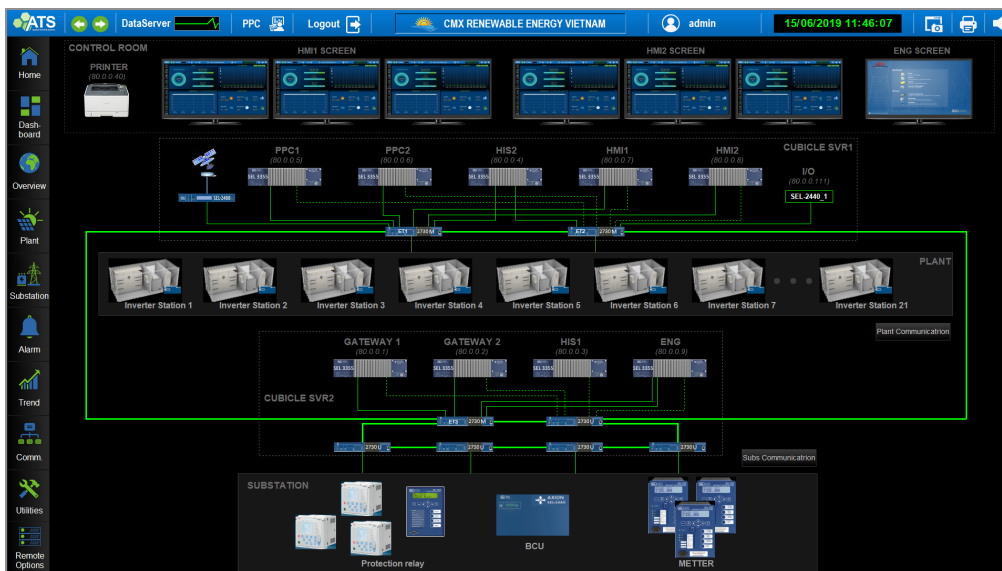


Figure 19. Communication Monitoring

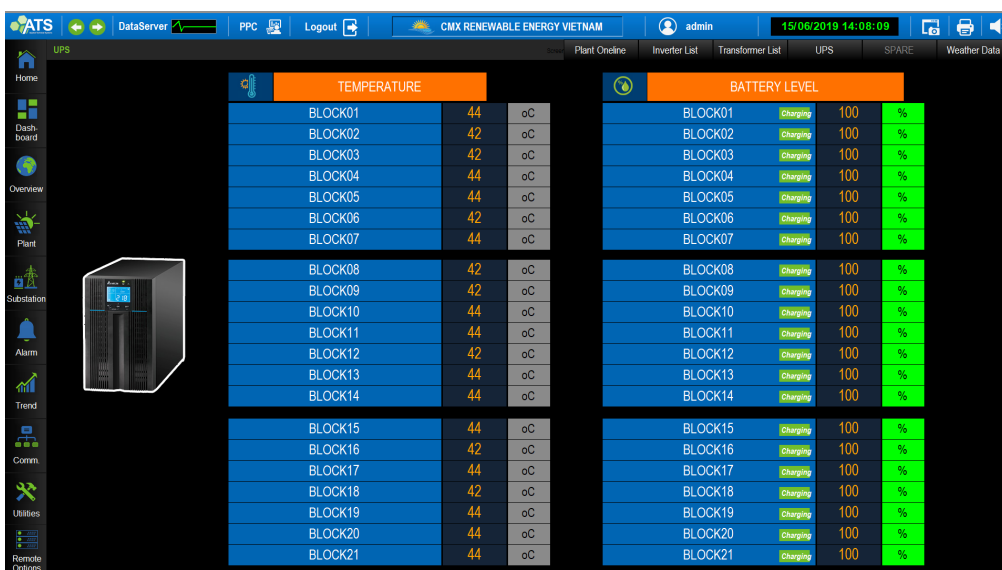


Figure 20. UPS Monitoring

2.4.5. HIS Applications

(1). Report and Operation Log-Book

- Reports can be built using ATS Data Link tool (an add-in for Microsoft Excel). This add-in can allow data to be retrieved directly from within the spreadsheet program. You can create complex reports and graphs using current or historical data from the HIS (Figure 21).
- Data Link includes a tag search dialog, a dialog for viewing point configuration, a dialog for managing connections to multiple HIS, and support for login security to the HIS.

(2). Web-based monitoring subsystem

This application subsystem can allow external users retrieve real time data and historical data.

The benefit of web-based interface includes:

- Using new technologies (HTML5, CSS3, SVG, etc.)
- Need only web browser from client side for accessing (PC, laptop, tablet, smartphone, etc.)
- Ensure reliability and security
- Allows for connection from multiple users at the same time
- HIS data will be available for display in tabular, graphic, chart and gauges.
- Any quality code, tag, timestamp or data value for any HIS data value will be displayable.
- Allows for display of any report in real time mode and historical mode.
- Export and download report to local computer (Microsoft Excel format or pdf format).
- Allows for notification of any alarm and report through SMS, Email.
- Users can query historical data with SMS query command.

2.4.6. Intelligent energy management system (iEMS)

The intelligent energy management system (iEMS) allows the operator to evaluate in detail all operating status of the power plant and find out the optimal, safe, reliable and economical operating procedures of the power plant.

Input data of iEMS module are operation real-time data and historical

data archived in HIS database of PV power plant such as:

- Voltage, current, power of PV strings and PV panel temperature.
- Input and output current, voltage, power, power factor, frequency, energy of inverters.
- Total output power, power factor, frequency of whole power plant.
- Current and predicting weather data: solar radiation, ambient temperature, wind direction and speed etc.

Functions of the iEMS include:

- PV power generation prediction
- PV power plant analysis and failure detection

(1). PV power generation prediction

- Summary results:
 - System production
 - Performance ratio
 - Array losses
 - System losses
- Hourly input/output trending of each inverter
- Hourly Energy yield injected into grid
- Hourly PV string voltage
- Detailed system losses
- Detailed inverter losses
- Economic evaluation
- And the aging of PV panel, Inverter

(2). PV power plant analysis and failure detection

- If the differential deviation of validating and evaluating process exceeds pre-set margin of error, the system will initiate alarm to operator. This result and other signals in the system support operator to determine exactly location of error devices or predict degradation devices can affect efficiency of the power system and create profiles about actual error for evaluating process at the next time.
- If the differential deviation value is in allowed margin, this measured value will be stored in HIS database for validating and evaluating processing at the next time.
- Evaluating process with data for a long duration will support operator to analysis and determine the aging of each PV string.

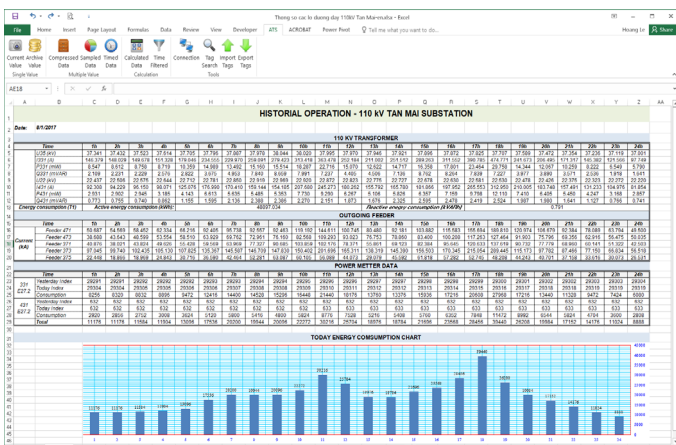


Figure 21. Operation Report

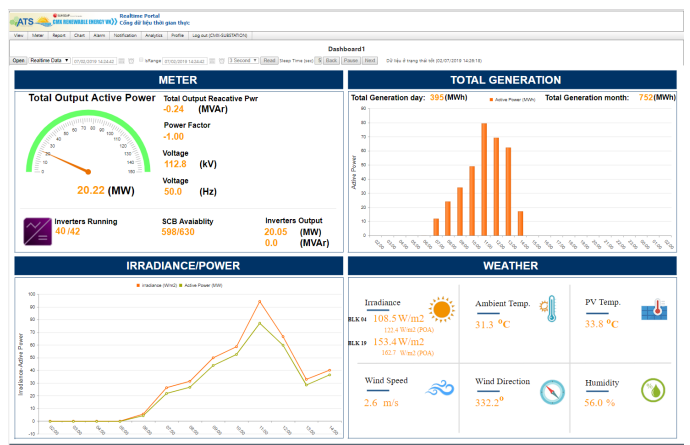


Figure 22. Web-Based monitoring

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