ATS
Leading of Integration

PV SCADA & PPC

Solar Plant Control & Monitoring Solution

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Table of Content

A. Product Overview

ATS's PV SCADA & PPC system offers full control and supervision functions for PV solar power plants. The well-designed PV SCADA system will ensure the operational stability and reliability of the power plant during its life circle.

PV SCADA & PPC System can 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.

Our solution for PV SCADA & PPC 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 for customized plant control and provides the flexibility needed in order to meet the needs for high diversity of grid connection requirements. The Human-Machine Interface (HMI) visualizes all measured values locally and in real time, and allows for technical operation management of PV power plants on site.

In order to ensure operational reliability for PV power plants, the PV SCADA & PPC system is also built with high availability by using a single-fault-tolerant design for centralized components and important devices as well as redundant configuration.

ADVANTAGES

- Compliance with national and international grid codes.
- High flexibility in system design in accordance with PV system technology.
- High compatibility thanks to interface and protocol variety.
- Ability to connect with and control various types of inverters: central and/or string Inverters.
- Reduction of commissioning and maintenance cost of PV power plants.

MAIN FEATURES

- Provide full features of PV SCADA & PPC system for data acquisition, monitoring and control of PV plant in accordance with national and international grid codes.
- Modular, scalable architecture and manufacturer independent, suitable for controlling PV Power Plants using inverters from different 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, etc. (can be extended upon users' requests).
- System sizing support over 2000 IEDs, controllers and monitors; can handle up to 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.

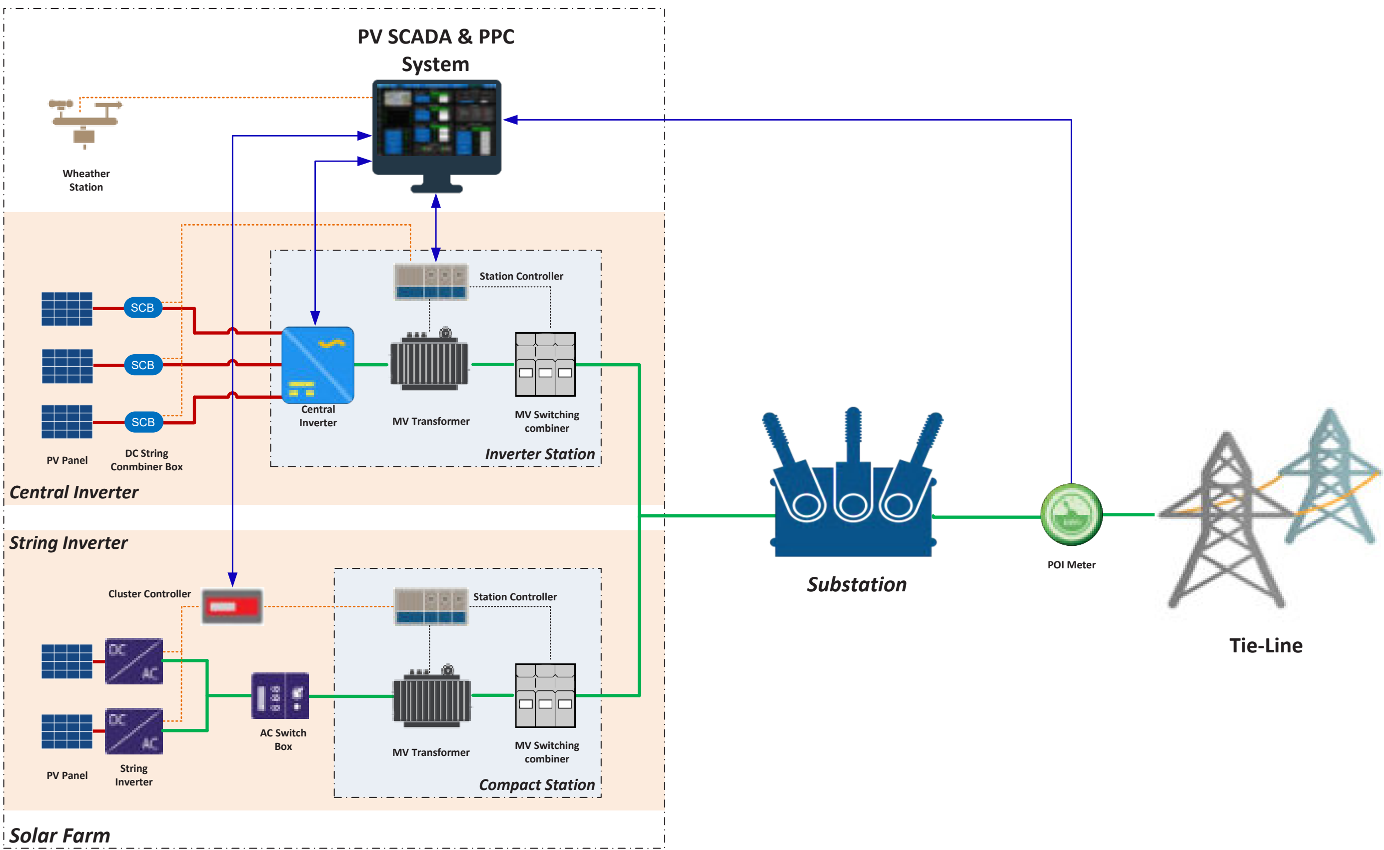

Figure 1. Overview of PV SCADA & PPC system

1. HARDWARE STRUCTURE

Main Components of PV SCADA & PPC 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, and 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 the whole of PV power plants. These devices are manufactured according to industrial standards with open architecture, networking capability, and standard protocols compatibility, ensuring that any single device failure shall not affect the monitoring and control process of the power plant.
  - * Intuitive Human – Machine Interface function (HMI) that allows operators to perform all monitoring and control functions for the PV power plant.
  - * History database server for data storage and historical data-mining applications; engineering applications for building, configuration and maintenance of PV Plant SCADA system.
  - * Satellite-Synchronized Clock for time synchronization of all equipment in the PV SCADA & PPC 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 can be integrated into Substation SCADA Gateway servers and connect to SCADA systems at the Load Dispatching Centers (such as NLDC, SRLDC, EVNSPC, etc.)

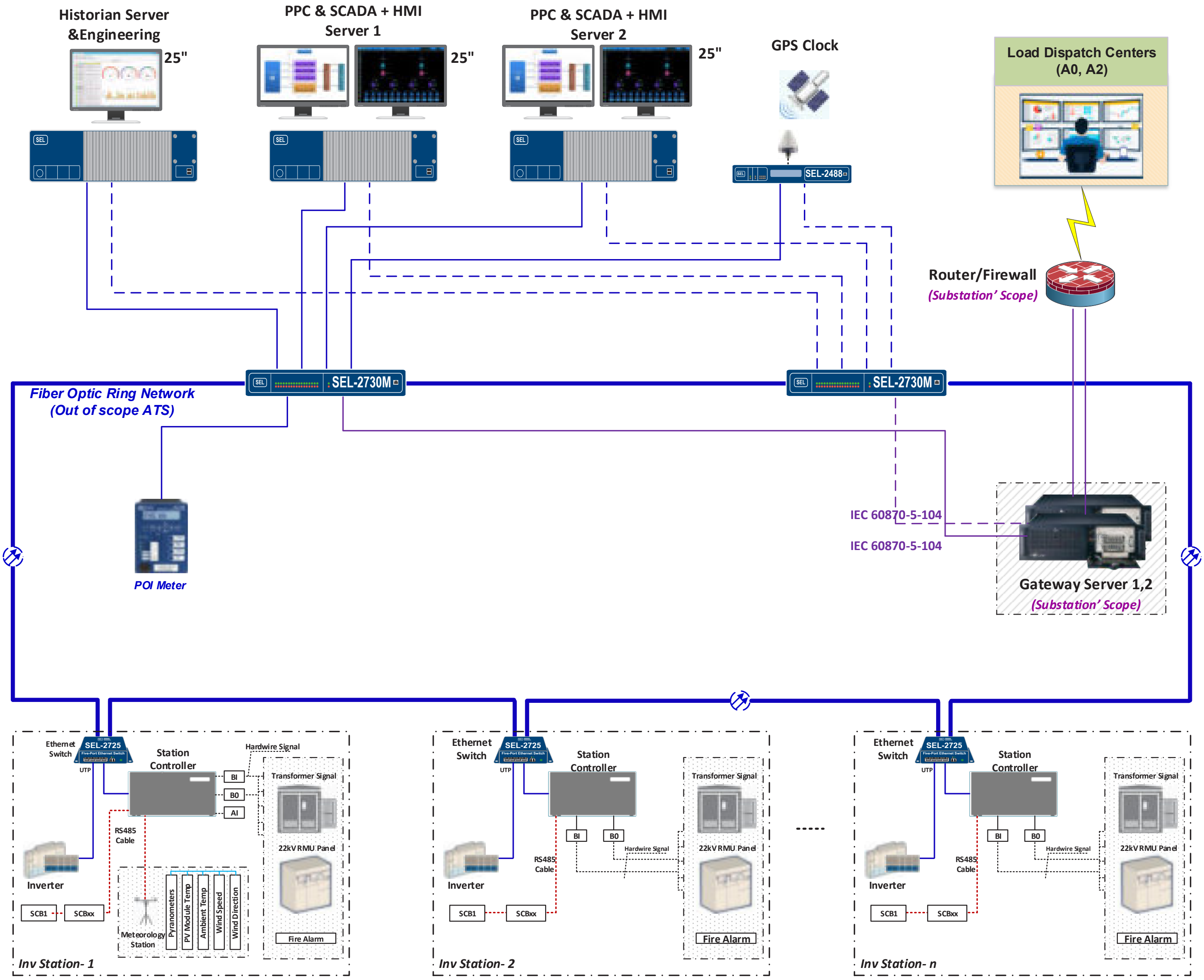

Figure 2. Typical PV SCADA & PPC Hardware System

B. Technical Highlights

2. SOFTWARE DESCRIPTION

2.1. Software Architecture

The PV SCADA & PPC System is provided with 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 & PPC system include:

- **Standard modules:**
  - Data Acquisition (DA)
  - Real-time Database (RTDB)
  - Time-series Historical Information System (HIS)
  - Power Plant Control (PPC)
  - Human – Machine Interface (HMI)
- **Advanced modules:**
  - HIS applications (Web-based monitoring and report)
  - Intelligent Energy Management System (iEMS)
    - PV Power Generation Forecast
    - PV Power Plant Analysis and Early Failure Warning

2.2. Supported Communication Protocol

Supported communication protocols include:

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

2.3. System Sizing

The PV SCADA & PPC system can support over **2.000** IEDs, controllers and monitors, as well as **256.000** data points. This capacity can meet all requirements of any PV plant and can be extended in the future without having to upgrade any of the control system components.

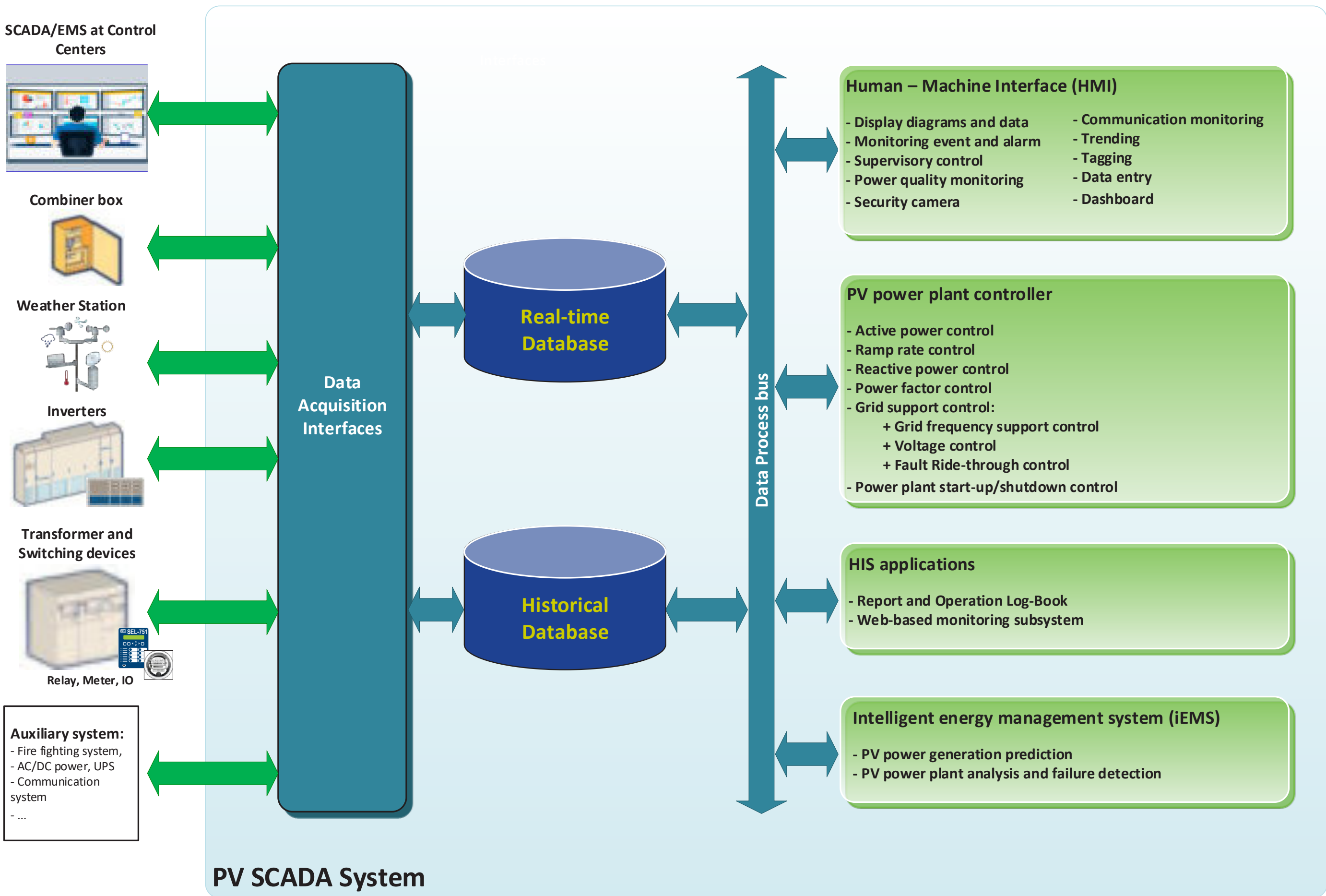

Figure 3. Typical PV SCADA & PPC Software System

2.4. Standard Software Modules

2.4.1. Data Acquisition (DA)

The SCADA system will acquire all available analog data, status data and control signals from PV power plant devices such as: DC string combiner boxes, Inverter controllers, Inverter station controllers, relays, Common IO devices, Meteorological station, Multi-function meters, RMU panels, etc. 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 supports the 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, etc.

Data acquisition from main PV power plant devices:

- DC string combiner boxes located throughout the solar field
- Inverters located in Inverter Station
- MV transformer
- RMU panel located in Inverter/Transformer Station
- Weather station

2.4.2. Time-series 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 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 per Table below:

Benefits of Historical Information System:

- Data Infrastructure base for advanced applications: such as Solar power generation forecast, PV power plant analysis and failure detection, etc.
- Scalability and performance: the database can be scaled to support millions of devices or time-series data points in continuous flow as well as performing real-time analysis on these data.
- 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.
- Optimized 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.

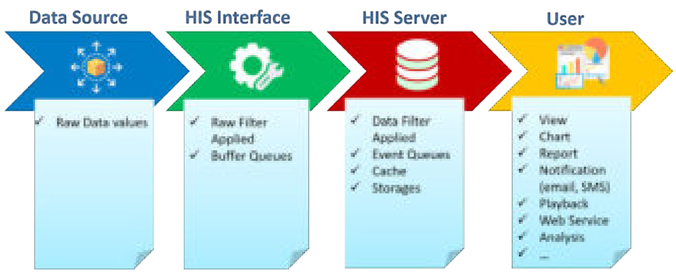

Figure 4. SmartHIS™ System Overview

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. Data can be stored in various ways, with additional fields can be added later.
Data tables have complex relation, therefore data reading and writing processing is not fast.	Data structure allows for retrieval of all information on specific item in a single query. Data reading and writing is faster than SQL.
Sequence data query. Performance is slow.	Ad-hoc data query. Fast access to historical data at any timestamp.
Built on the idea of "one size fit all". When the database gets larger, reading and writing performance is slower and also requires larger hard disk volume for storage.	Built on the idea of "one size does not fit all". When database becomes larger, data can be stored on different partitions.
Consistent with static data which has specific structure and relationship.	Data stored with key-value structure, suitable for time series data type.

Table 1. Comparison between SQL and No-SQL Database

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 is suitable for controlling PV Power Plants using Inverter from various vendors (such as ABB, SMA, Huawei, TMEIC, Sungrow, etc.), including both string and central inverters. The PV plant controller will be implemented at plant-level logic and utilize 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.

Main PV power plant control functions:

- Active Power Control: Keep output at fixed commanded Set- point or react to curtailment commands by operators and the Load dispatching center. Ensure that output of PV power plant does not exceed specified limit.
- Ramp rate control: Limit change to ramp rate to avoid causing to system instability at grid connection point.
- Reactive Power Control: Used to keep 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: Automatically regulates 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: Ensures system do not trip off during system disturbances, such as specific low and high voltages or low- and high-frequency circumstances, and can continue to provide power when the grid requires.
- Power plant start-up/shutdown:
  - If a planned outage is needed, operations should be able to take the plant offline in a controlled manner. Similarly, after an outage period, the plant should be restarted 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 for power plant at set time or when specific condition of solar radiation intensity is met.
- RMU panel control function:
  - Remote control of 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 fault isolation and recovery process.

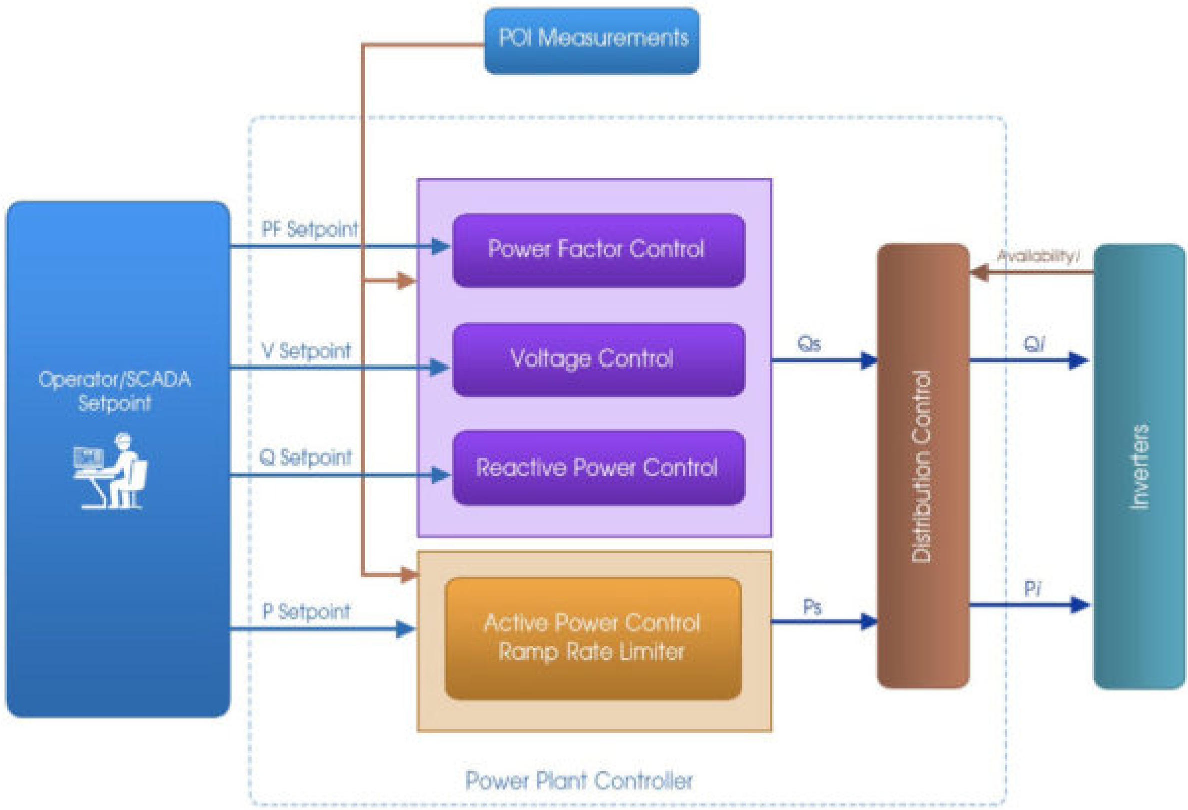

Figure 5. PV Power Plant Control Function Block Diagram

2.4.4. Human-Machine Interface (HMI)

Human-Machine Interfaces can be understood as communication path between user and monitoring & control programs of the PV SCADA & PPC system as well as other applications. User interfaces allow for simple and user-friendly monitoring and control of all primary devices in power plant, with access to data storage.

- Screen display can be easily modified.
- HMI can immediately notify by light and sound indication corresponding to events created by operator or primary devices.
- Operators can implement every control actions excluding automatic control functions. All message or warning signals will be unlimited and follow time sequence. All signals of operation process will be collected and continuously alerted to operators via Alarm screen.
- At central control room, HMI system is built in a way that unify all supervisory and control functions 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, and will be processed by the Power plant controller and sent to the Inverter controllers, relays, and BCUs only after the command has been validated. The control sequence is predicated on the "select and check before operate (SBO)" philosophy in order to ensure operation security.

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.
* 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 incorporation of fault ride-through capability so that the system does not trip off during system disturbances, such as over – under voltage or over – under frequency, but continues to provide power when the grid requires.
* Start-up and shut-down control of the entire power plant.

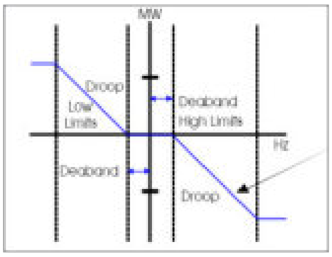

Figure 6. Frequency Droop Parameters

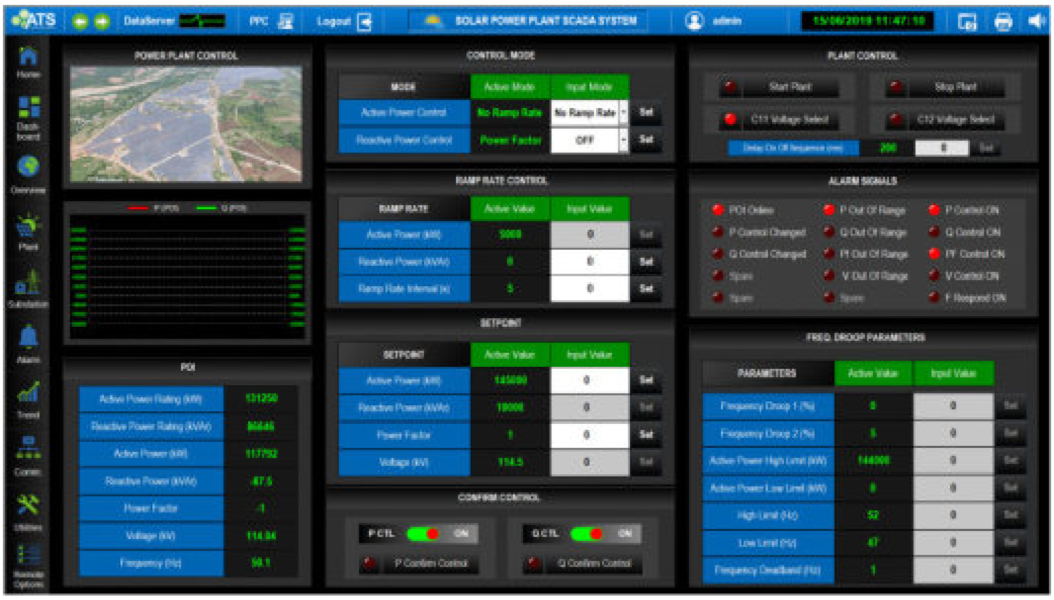

Figure 7. Power Plant Control Screen

Company Overview

b) RMU Panel Device 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 architecture. The lowerthe layer, the more detailed information is available (Figure 9-16).

Figure 8. 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, etc.

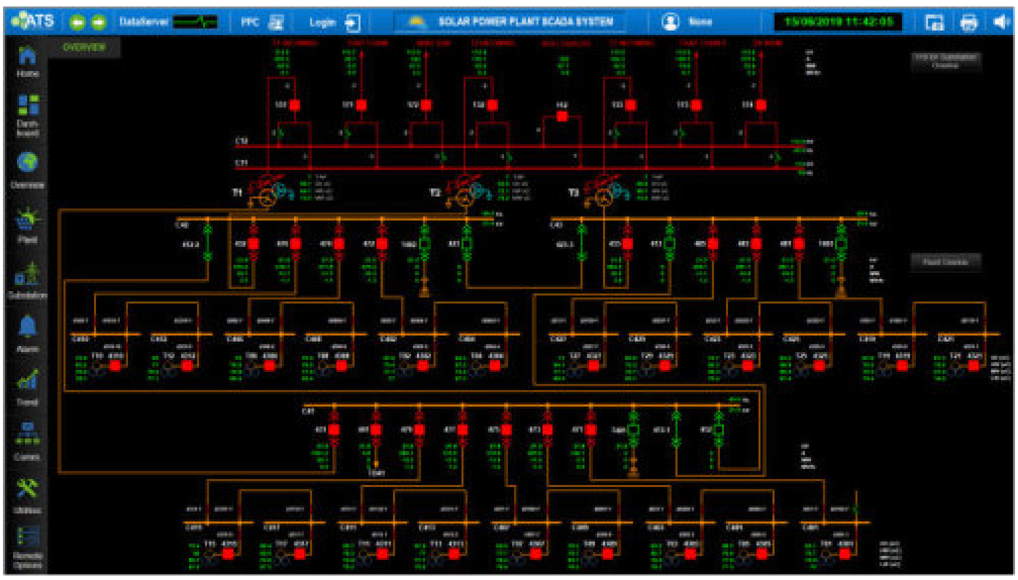

Figure 10. PV Power Plant Single Line Diagram

Display one-line diagram of solar power plant 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 and/or string inverters.

Figure 11. Central & String Inverter Station Screen

Figure 12. PV Inverter Data Monitoring and Control

Display analog parameters such as input current, input voltage, output current, output voltage, output power, power factor, frequency, operation time; status, alarm, protection signals of input and output switching devices of each inverter, etc.

Figure 13.MV Transformer Monitoring

Display operation signals of MV transformer such as tap positions, temperature, alarms and protection signals, etc.

B. Technical Highlights

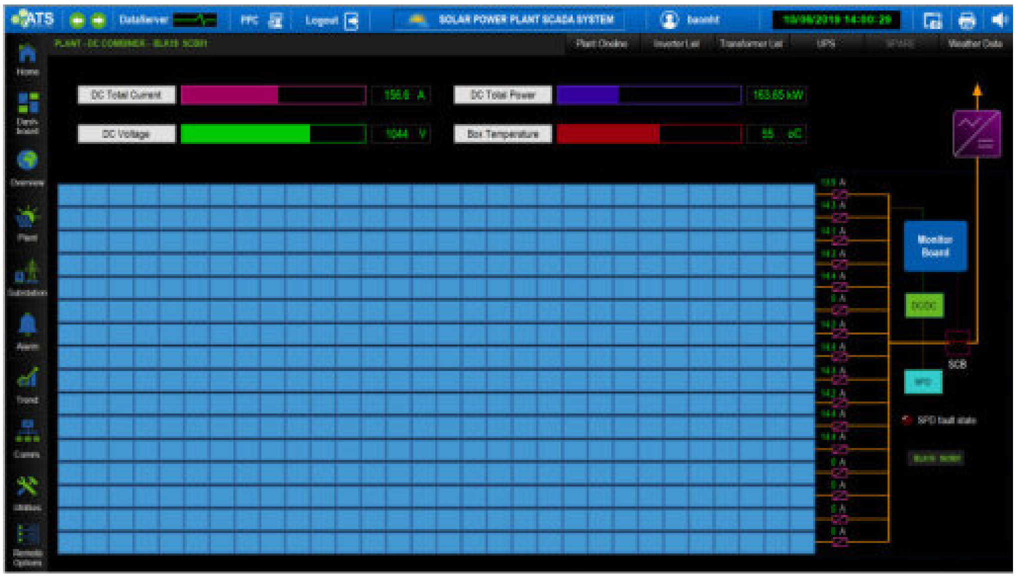

Figure 14. PV String Monitoring

Display all analog parameters such as: current, voltage and power of each solar string, surface temperature; evaluated efficiency and operation time of each PV string, etc.

Figure 15. RMU Monitoring

Display operation parameters, status signals, alarms and protection signals of RMU panel devices such as circuit breakers, load break switch, etc.

Figure 16. Weather Conditions Monitoring

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

b) Power Quality Monitoring

Power quality parameters at output of power plant is monitored for analysis and evaluation of 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 is of high importance for the operation of power plant, 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.

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

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

(4). Trending

The PV SCADA & PPC 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.

Some trend types that the system can support include:

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

(5). Tagging

Tagging of the circuit breakers, disconnector switches, and inverters, etc. for maintenance, hot-line work or automatic re-closing is an important part of the PV SCADA & PPC system design criteria. This will be accomplished being used 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

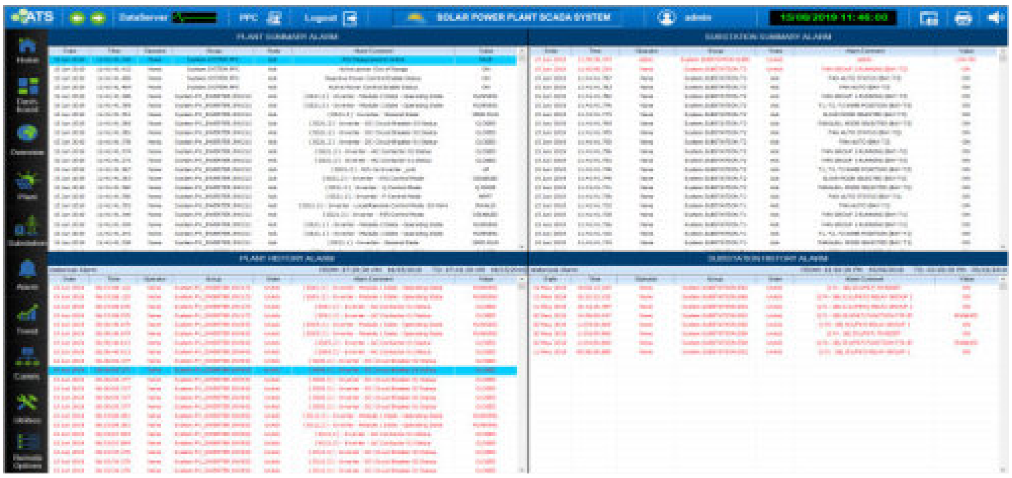

Figure 17. Alarm Presentation Window

Figure 18. Trending Window

B. Technical Highlights

(6). Communication Monitoring and Diagnostic

The following communications monitoring and diagnosis functions 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
  - Monitoring of all operational status of Network devices including switches, computers and IED ports
  - Failure detection and recovery management
  - Graphic display of statuses and activities of 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 & PPC system will monitor all necessary information related to plant auxiliary system or Inverter station auxiliary system such as AC and DC, UPS, etc.

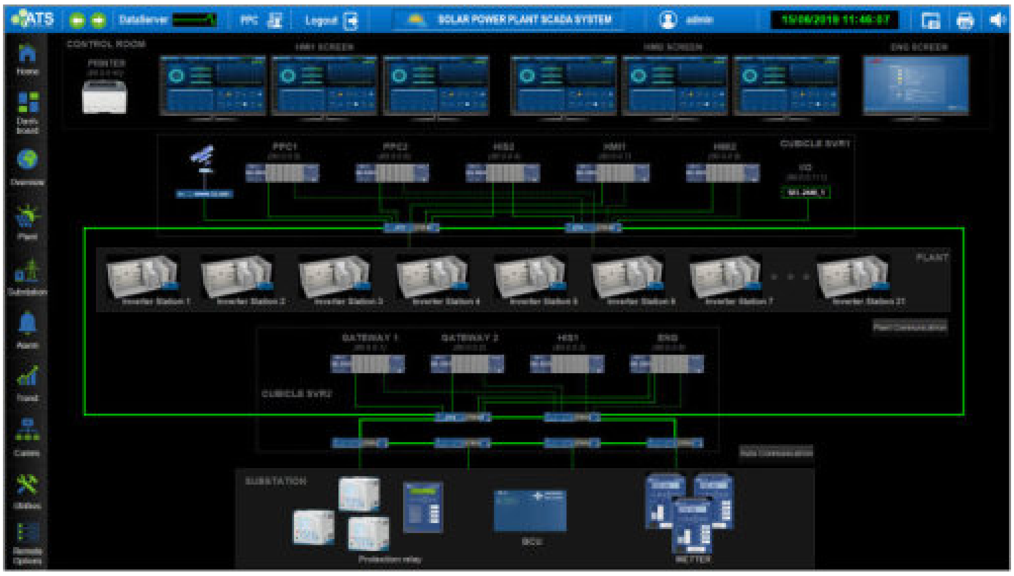

Figure 19. Communication Monitoring

Figure 20. UPS Monitoring

2.5. Advanced Software Modules

2.5.1. HIS Applications

(1). Report and Operation Log-Book

- Reports can be built using ATS Data Link tool (an add-in for MS 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 to retrieve real time data and historical data from web-browser.

The benefit of web-based interface includes:

- Uses latest technologies (HTML5, CSS3, SVG, etc.)
- Only requires web browser from client side for access (PC, laptop, tablet, smartphone, etc.)
- Ensures reliability and security
- Allows for connection from multiple users at the same time
- Availability of HIS data for display in tabular, graphic, chart and gauges
- Allows for display of any quality code, tag, timestamp or any HIS data value
- Allows for display of any report in real time and historical modes
- Allows for export and download of reports to local computers (Microsoft Excel or pdf format).
- Allows for notification of any alarm, report though SMS or Email
- Users can query historical data with SMS query command.

2.5.2. Intelligent Energy Management System (iEMS)

The Intelligent Energy Management System (iEMS) allows operators to evaluate in detail all operation statuses of the power plant and to determine the optimal, safe, reliable and economical operating procedure for 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 forecast weather data: solar radiation, ambient temperature, wind direction and speed, etc.

Functions of the iEMS include:

- PV Power Generation Forecast
- PV Power Plant Analysis and Early Failure Warning

(1). PV power Generation Forecast

- Forecast result summary:
  - 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 aging of PV panels and inverters

(2). PV Power Plant Analysis and Early Failure Warning

- If the differential deviation of validation and evaluation exceeds pre-set margin of error, the system will initiate alarm to operators. This result and other signals in the system support operator to determine the exact location of faulted devices or predict the extent the degradation of devices can affect efficiency of the power system and create profiles on the actual error for evaluation.
- If the differential deviation value is within allowed margin, this measured value will be stored in HIS database for validation and evaluation next time.
- Evaluation using data from long operation duration will support operators to analyze and determine the aging of each PV string.

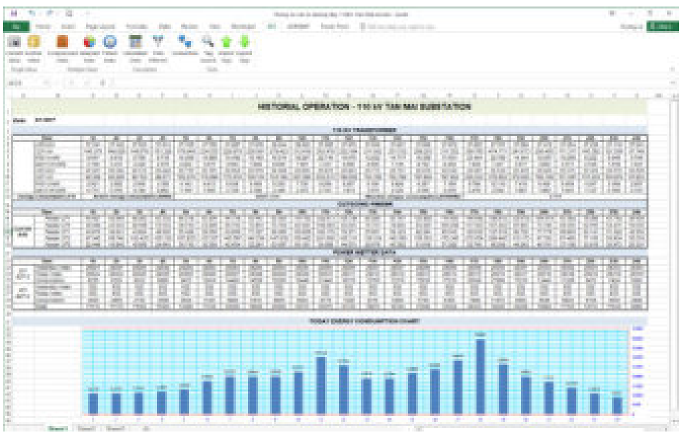

Figure 21. Operation Report

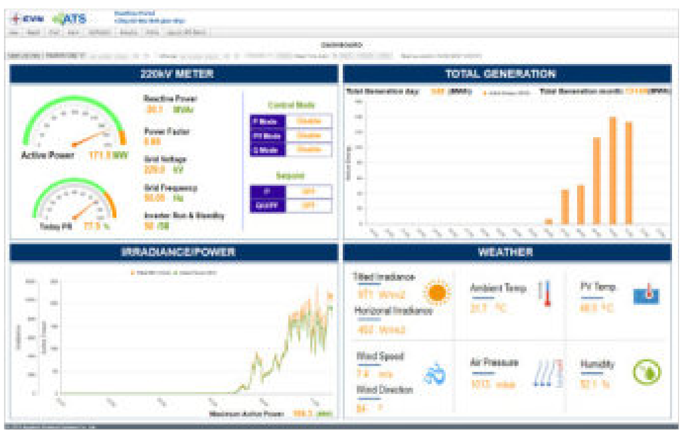

Figure 22. Web-Based Monitoring

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