Leading of Integration

@ReHybrid™

Renewable Power Plant Control & Monitoring System (SCADA & Hybrid PPC)

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A. Product Overview

ATS's @ReHybrid™ solution (Renewable Power Plant Control & Monitoring System - SCADA & Hybrid PPC) offers full control and supervision functions for power plants. The well-designed system will ensure the operational stability and reliability of the power plant during its life cycle.

@ReHybrid™ can perform all data acquisition, monitoring, and control functions of power plants. All necessary information concerning process behavior, instrument and integrity controllers, sequential control, and alarm function shall be immediately available at the operation consoles.

@ReHybrid™ fully supports both national and international grid codes, thus enabling grid-compliant feed-in from power plant 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 provide the flexibility needed to meet the 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 power plants on site.

In order to ensure operational reliability for power plants, @ReHybrid™ is also built with high availability by using a single-fault-tolerant design for centralized components and important devices as well as redundant configuration.

ADVANCE FEATURES

- Compliance with national and international grid codes.
- High flexibility in system design in accordance with power plant 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), wind turbines, and BESS.
- Reduction of the commissioning and maintenance costs of power plants.

MAIN FEATURES

- Provide full features of SCADA & Hybrid PPC for data acquisition, monitoring, and control of power plants in accordance with national and international grid codes.
- Modular, scalable architecture, and manufacturer-independent, suitable for controlling Power Plants using inverters/BESS/wind turbines from different vendors.
- The de facto Historical Information System (HIS) is in popular use worldwide.
- Multi-protocol speaking: Modbus Serial/TCP, IEC61850, SEL Fast-Message, DNP3, IEC 62056, IEC-60870-5-104, MQTT, IEEE C37.118, etc. (can be extended upon users' requests).
- System sizing supports over 2000 IEDs, controllers, and monitors and can handle up to 256,000 datapoints.
- A user-friendly graphic interface allows operators to perform their tasks with minimal computer knowledge, reducing "start-up" time.
- Ready for future utility interface bus integration.

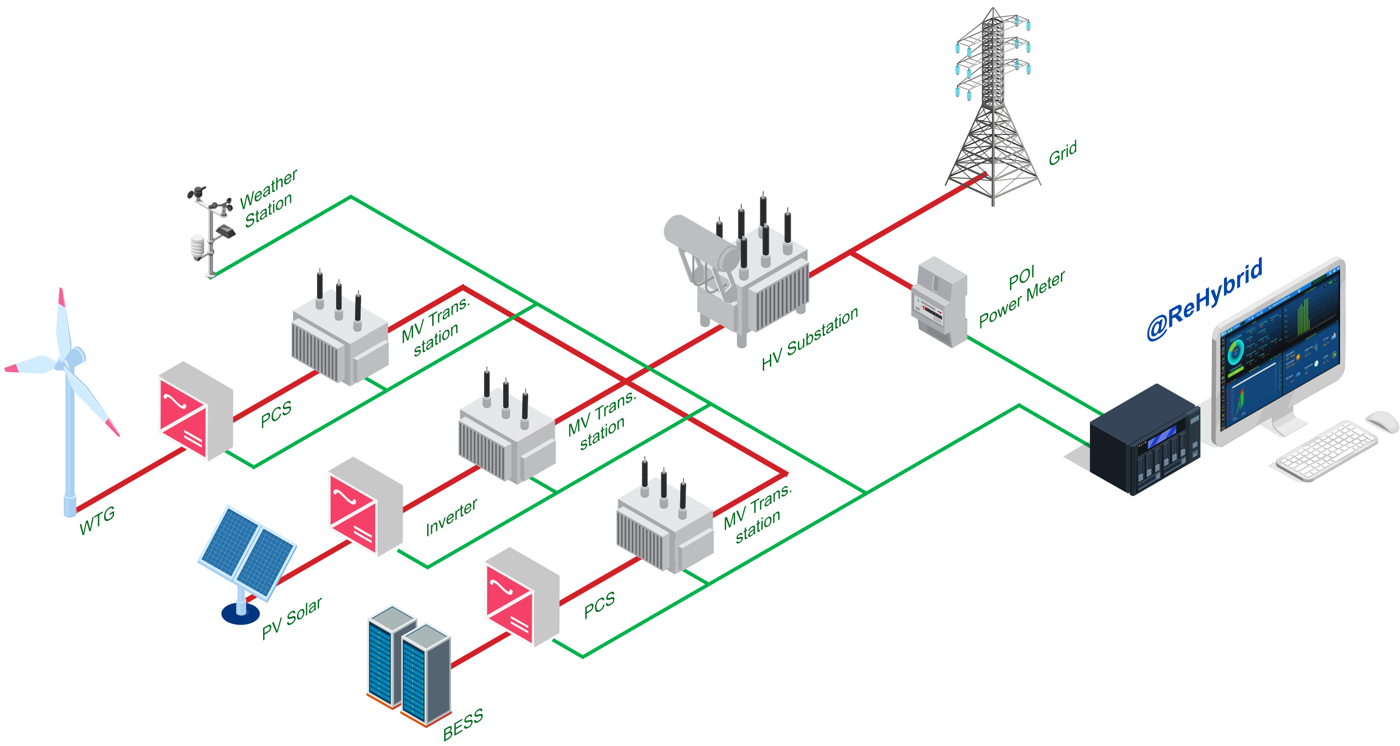

Figure 1. Overview of @ReHybrid™

1. HARDWARE STRUCTURE

Main Components of @ReHybrid™:

- At each compact station:
  - Station controller with analog, digital input/output and support protocol converter function to collect all monitoring and control data of the power plant from DC combiner box monitors, Inverters, Wind Turbines, Battery storage systems, MV transformers, RMU panels, protection relays, multifunction meters, auxiliary systems, and weather stations.
  - Weather stations to acquire meteorological information for performance evaluation and generation prediction of power plants. These weather stations will be connected to data acquisition devices at Inverter stations.
- At the operator control room:
  - Redundant Power plant control and SCADA servers for data acquisition, data processing, historical data storage, monitoring, and control of the whole power plant.
  - These devices are manufactured according to industrial standards with open architecture, networking capability, and standard protocol 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 power plant.
  - Intuitive Human – Machine Interface function (HMI) that allows operators to perform all monitoring and control functions for the power plant.
  - History database server for data storage and historical data mining applications; engineering applications for building, configuring, and maintaining SCADA system.
  - Satellite-Synchronized Clock for time synchronization of all equipment in @ReHybrid™.
  - Multi-meter installed at substation to collect measurement data (U/I/P/Q) at POI and provide data input for the PPC system.
  - SCADA signals of power plant can be integrated into Substation SCADA Gateway servers and connect to SCADA systems at the Load Dispatching Centers/Control Centers (such as NLDC, SRLDC, EVNSPC, etc.).

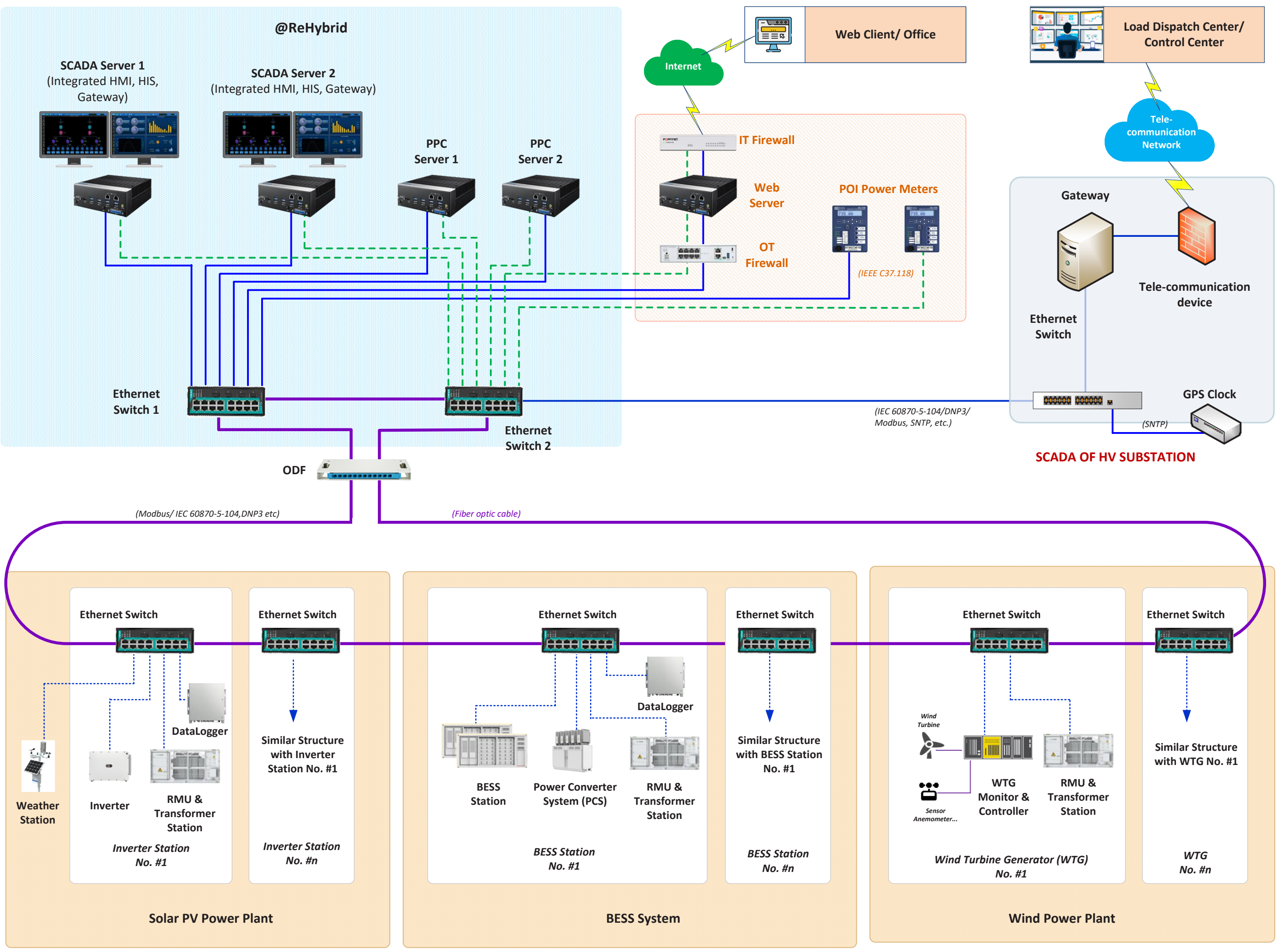

Figure 2. Typical Hardware System

B. Technical Highlights

2. SOFTWARE DESCRIPTION

2.1.Software Architecture

@ReHybrid™ is provided with data acquisition, processing, control, 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 protocols via the Ethernet LAN or dedicated serial communication system.

The main software modules of @ReHybrid™ include:

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

2.2. Supported Communication Protocol

Supported communication protocols include:

- Modbus Serial/TCP (DC String combiner boxes, Inverters, Wind turbine controllers, Battery controllers, Weather stations, Inverter station controllers, Multi-function meters, IO devices, etc.)
- IEC61850, SEL Fast Message, DNP3, IEEE C37.118, etc. (Relay, IO devices, Grid analyzer, etc.)
- IEC 62056 (Tariff meter)
- OPC, ODBC, XML Web Service, MQTT, Application Programming Interface (API), API RESTful (exchange data with other databases), etc.

2.3. System Sizing

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

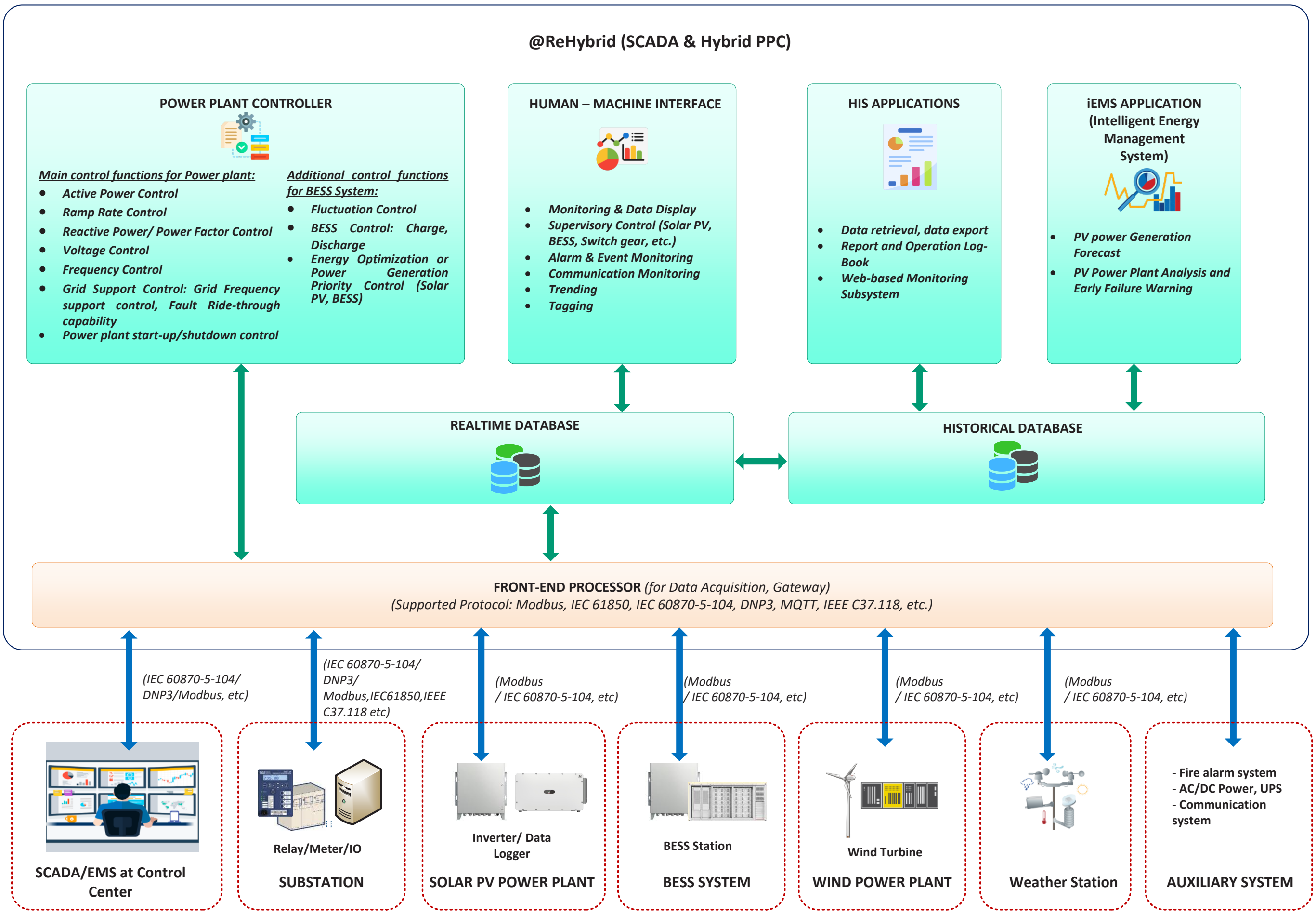

Figure 3. Typical Software System

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 power plant devices such as: DC string combiner boxes, Inverter controllers, Inverter station controllers, relays, wind turbines, Battery, Common IO devices, Meteorological station, Multi-function meters, RMU panels, etc. A local data repository is built up at the power plant controller for real-time data; the historical data will be integrated into the Substation historian database.

The DA module supports the following data types:

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

Data acquisition from main power plant devices:

- DC string combiner boxes located throughout the solar field
- Inverters are located in the inverter station.
- Wind turbines
- BESS
- MV transformer
- RMU panel located in Inverter/Transformer Station
- Weather station

2.4.2. Time-series Historical Information System (HIS)

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

Benefits of the 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 perform 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.

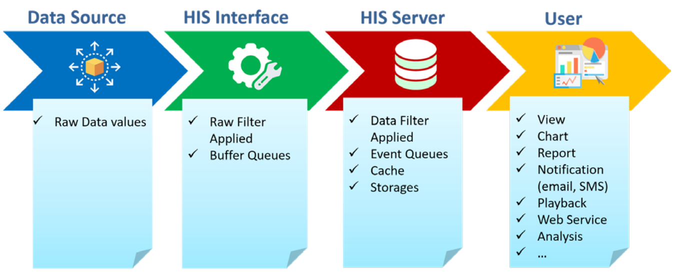

Figure 4. SmartHIS™ System Overview

SQL Database	No-SQL Database
Use predefined schemas to determine the structure of the data. A change in the structure would be both difficult and disruptive to whole system.	Has a 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.	The data structure allows for retrieval of all information on a 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 the 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

B. Technical Highlights

2.4.3. Hybrid Power Plant Controller (A-PPC)

Renewable energy has transformed into the next generation of the hybrid system, where a mixed type of technology wind, solar, battery or hydro generations share same Point-of-interconnection (POI). The complexity of plant controller and energy management is increasing concerns from project owners, network regulators...etc. much more than the past controller for a single type of renewable power. The Advanced Power Plant Controller was developed to integrate all renewable energy generations into one completed larger plant.

Worldwide Grid code compliance!

ATS Advanced Power Plant Controller was designed with passion in fulfillment of worldwide grid codes. The high penetration of inverter-based-resources (IBRs) together with the retirement of traditional coal/gas generators accelerate the risks to the security of the power system. A reduced power system inertia could result in more volatile system frequency; while low system strength could make the voltage more vulnerable to the grid disturbances. In parallel with the increasing development of grid forming technology for inverters, the power plant controller is also seeing a more important role in meeting new requirements of world grid codes, such as:

- Australia grid code (AEMC NER 196)
- Vietnam grid code (25/TT-BCT, 30/TT-BCT)
- Etc,

Supported Power System Models

Grid connection studies require accurate electrical modeling of plant controller and IBRs for more assurance of grid code compliance, power system stability, and security. At ATS, we developed novels of modeling technique "digital twins" that the EMT models (PowerFactory, PSCAD) run the same source code and the hardware product. AAdditionally, our unique solution in the world allows the power system IBRs to run in sub-realtime mode in DigSilent, interfacing with hardware-in-loop PPC. The PPC model also supports the RMS platform in PSSE which is popularly used by power system engineers and authorities around the world.

Main power plant control functions:

- Active Power Control: Keep output at the user commanded Setpoint or react to curtailment commands by operators and the Load dispatching center. Ensure that the output of power plant does not exceed specified limit.
- Ramp rate control: Limit changes to ramp rate to avoid too fast power injection to the network at grid connection point, which might cause system instability.

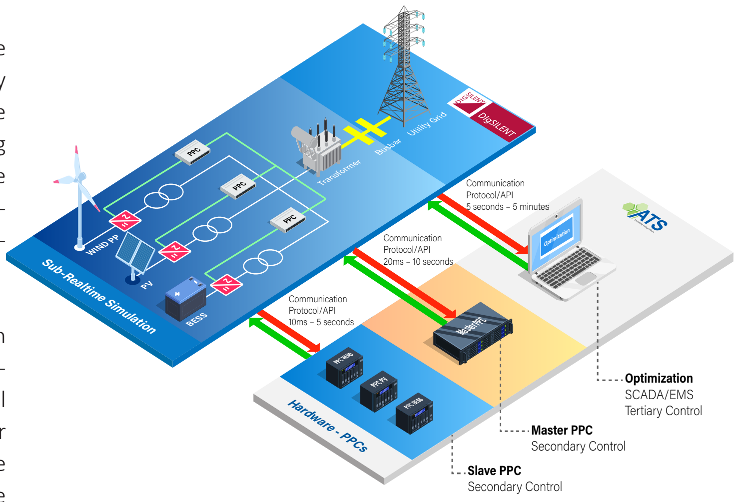

Figure 4. Hardware-in-Loop co-simulation with DigSilent in sub-realtime mode

- Reactive Power/Power Factor Control: To maintain reactive power, follow the user according setpoints at Point-of-Connection.
- Voltage Control: Allows the plant to dynamically provide reactive power support, based on system voltage and droop settings.
- Energy Optimization or Power Generation Priority Control: Allows grouping source devices into different groups and configuring priority control levels for each group. Optimal Energy Allocation (P-Q) among sources in the system.
- Fluctuation control: Keep the fluctuation of output following a specified value during a specified time interval.
- Grid support control:
  - Grid frequency control: Automatically regulates the active power delivered based on the instantaneous frequency deviation of the Grid & droop settings.
  - Fast frequency support: Send fast frequency power command & flag signals to IBRs if there is a frequency event happened.
  - Fault Ride-through capability: Assist IBRs to ensure 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.

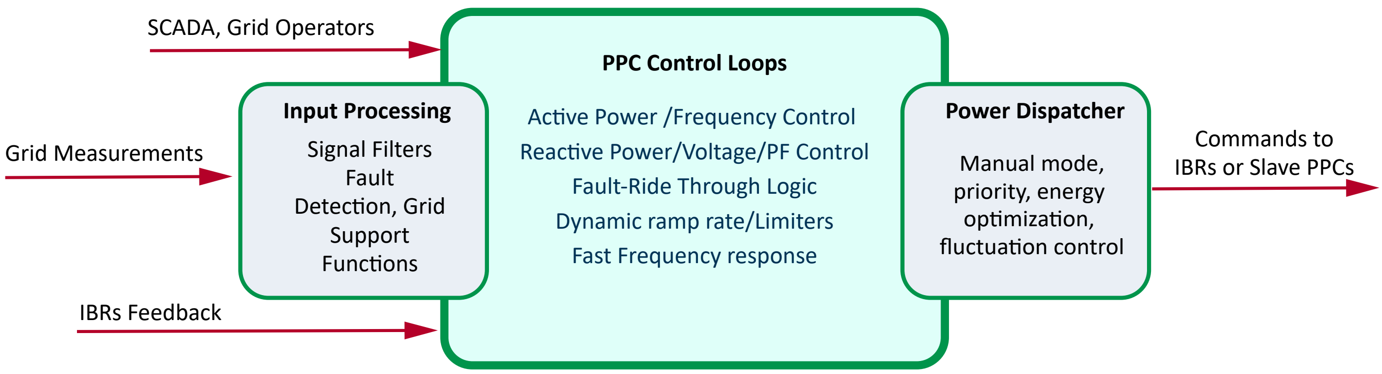

Figure 6. Advanced PPC Software Core Functions

Versatile Controller for Adaptable and Integrated Solutions!

In contrast to the old-fashioned renewable plants, where most of the inverters are supplied by the same manufacturer; the hybrid power plants consist of multiple vendors with different types of technology. It triggers the requirements for the integrity of these equipment to communicate and exchange data, thanks to in-house development solution for industrial protocols such as Modbus RTU, DNP3, IEC 61850, IEC 60870-5-104, IEEE C37.118, etc. This communication capability allows our APPC to work with most inverter suppliers in the market from various vendors such as ABB, SMA, Huawei, TMEIC, Sungrow for solar generation; Vestas, GE, Goldwind for wind turbine manufacturers.

Fast, Scalable Controller for Large Renewable Projects!

Our Power Plant Controller deployed a high computing industrial PC with the most efficiency Real-time embedded system OS bring high processing capability. A fast-sampling time of 20ms is guaranteed for both active power and reactive power control loops. Additionally, the deployment of an advanced power meter module allows our system to record all transient events on the network as fast as 10ms samples. As a result, our PPC system could even trigger all fault ride-through and smart grid support logic are well implemented to support IBRs during critical contingency network events.

Our rich experience of SCADA and software for power system allow us to build open architecture control platform for PPC system. The control loops are flexible and replicate to eight (8) parallel loops for expandable projects. It can also be configured in redundancy working mode for a more reliable backup system.

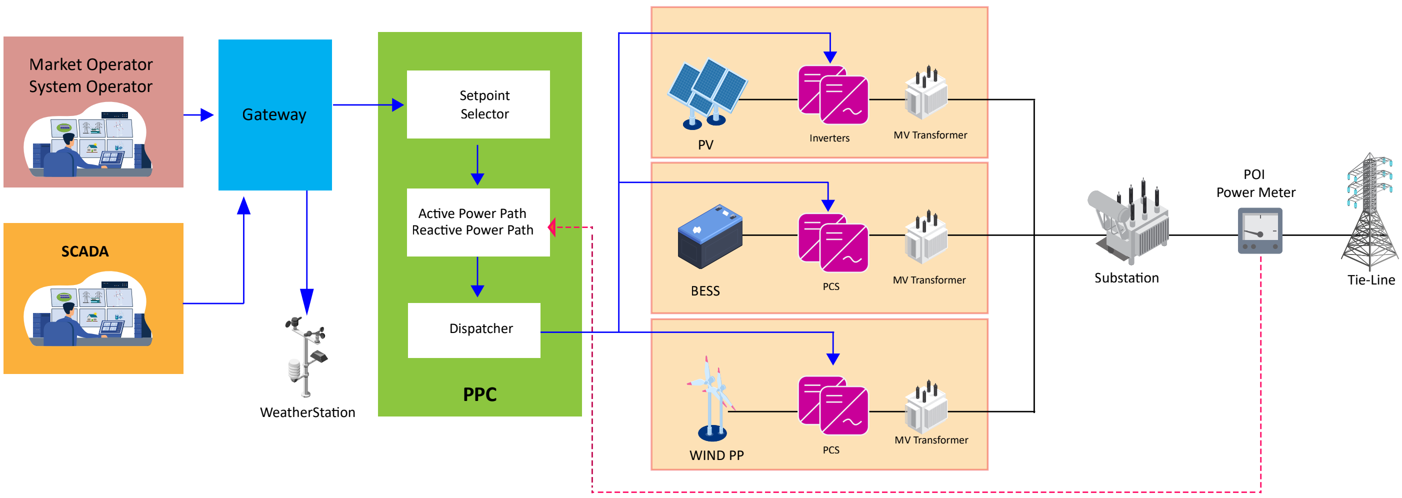

Figure 7. Typical SCADA & hybrid PPC Configuration (No PPC Slave)

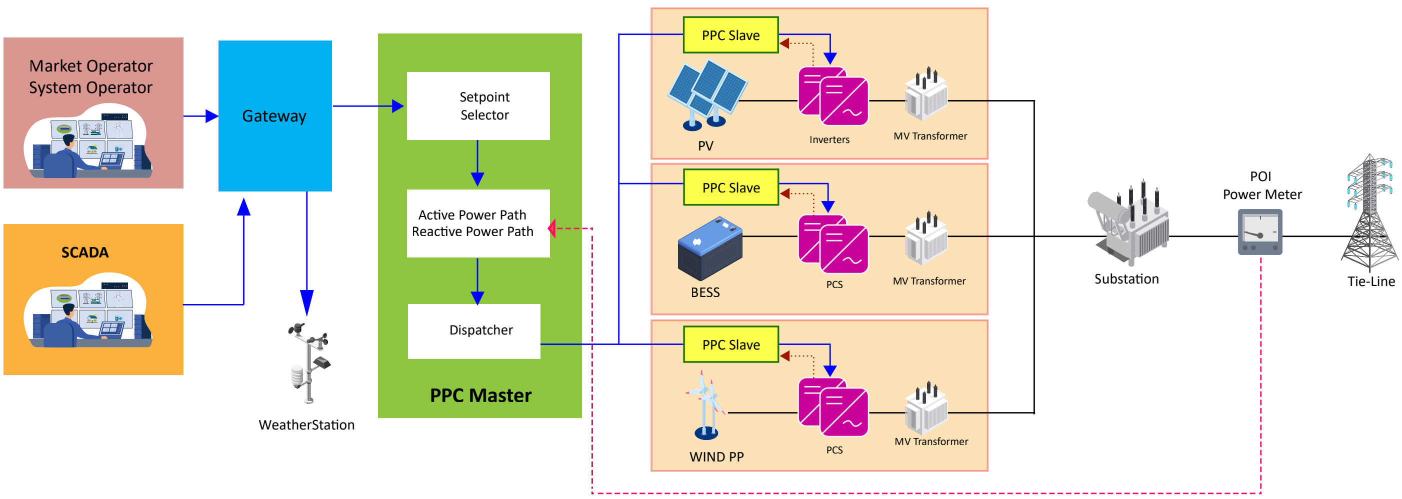

Figure 8. Typical SCADA & hybrid PPC Configuration (with PPC Slave)

B. Technical Highlights

2.4.4. Human-Machine Interface (HMI)

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

- Screen displays can be easily modified.
- HMI can immediately notify users by light and sound indications corresponding to events created by the operator or primary devices.
- Operators can implement every control action, excluding automatic control functions. All messages or warning signals will be unlimited and follow a time sequence. All signals of operation process will be collected and continuously alerted to operators via Alarm screen.
- At central control room, the HMI system is built in a way that unifies all supervisory and control functions of both 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, BESS controller, wind turbine controller, 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 will 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 attributes of the affected device or function on the schematic diagram if the operation has been performed.

a) Power Plant Control Functions:

* Dynamic voltage and/or power factor, reactive power regulation of the solar plant at the point of interconnection (POI) to the 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 the 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 it.
* Keep the fluctuation of output following a specified value during a specified time interval.
* Start-up and shut-down control of the entire power plant.

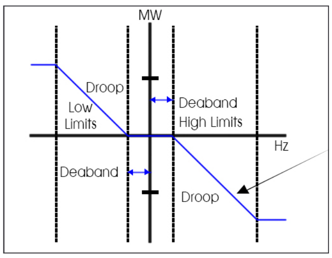

Figure 9. Frequency Droop Parameters

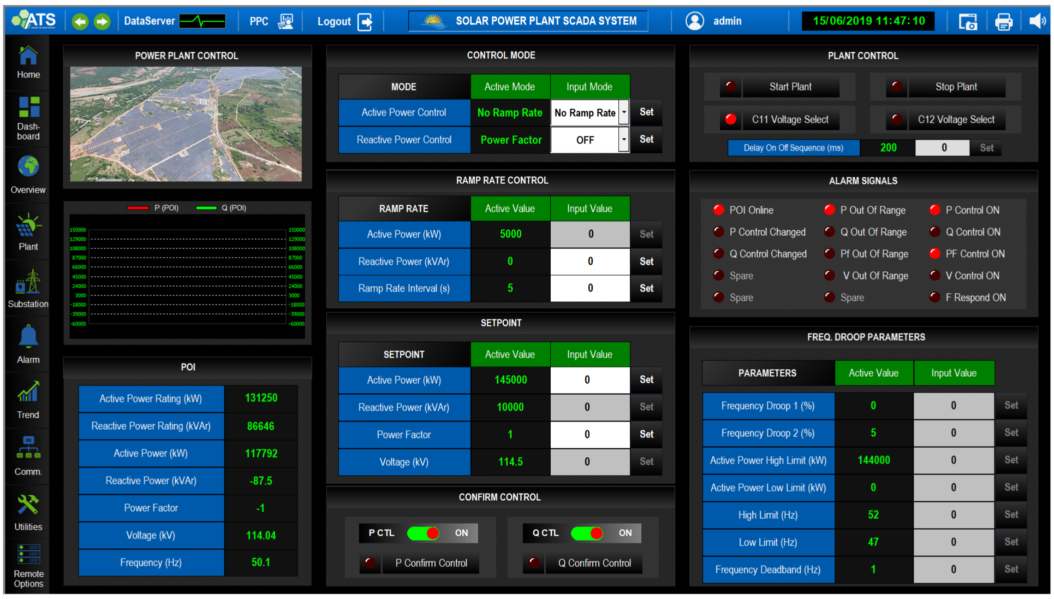

Figure 10. Power Plant Control Screen

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 10).

(2). Monitoring

a)Power Plant Monitoring

The HMI function is designed with a multi-layer architecture. The lower the layer, the more detailed information is available (Figure 11-25).

Figure 11. RMU Breaker Control

Figure 12. 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.

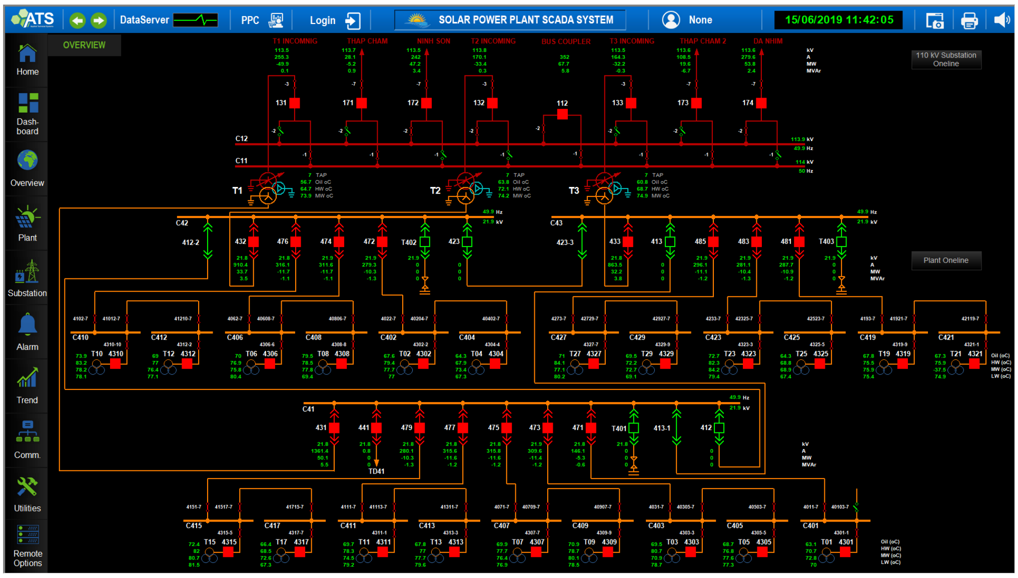

Figure 13. PV Power Plant Single Line Diagram

Display one-line diagram of solar power plant with its main devices and operation parameters.

B. Technical Highlights

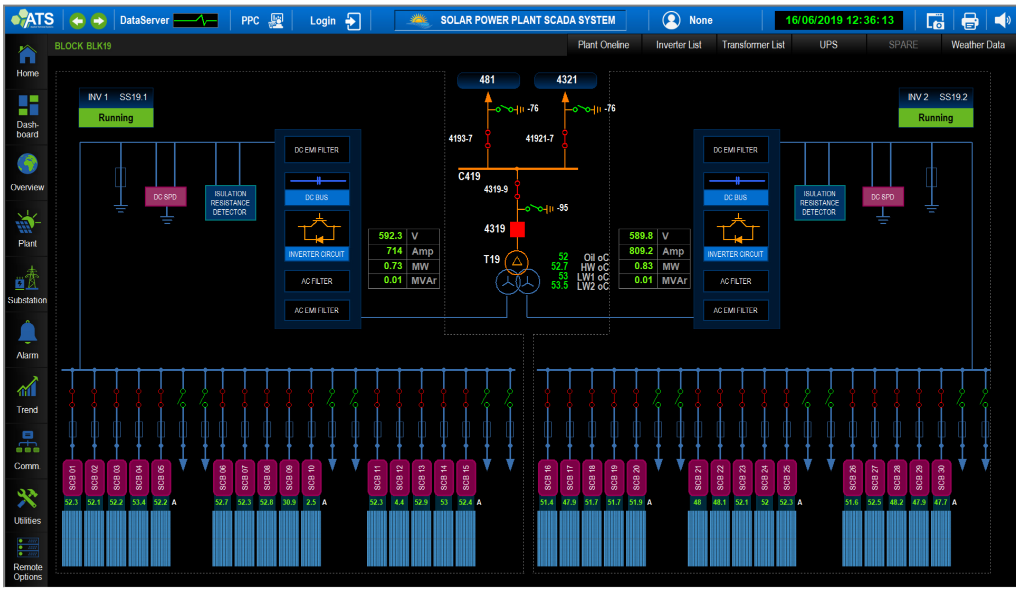

Figure 14. String Inverter Station

Display the operation parameters, status signal, alarm, and protection signal of each string inverter station

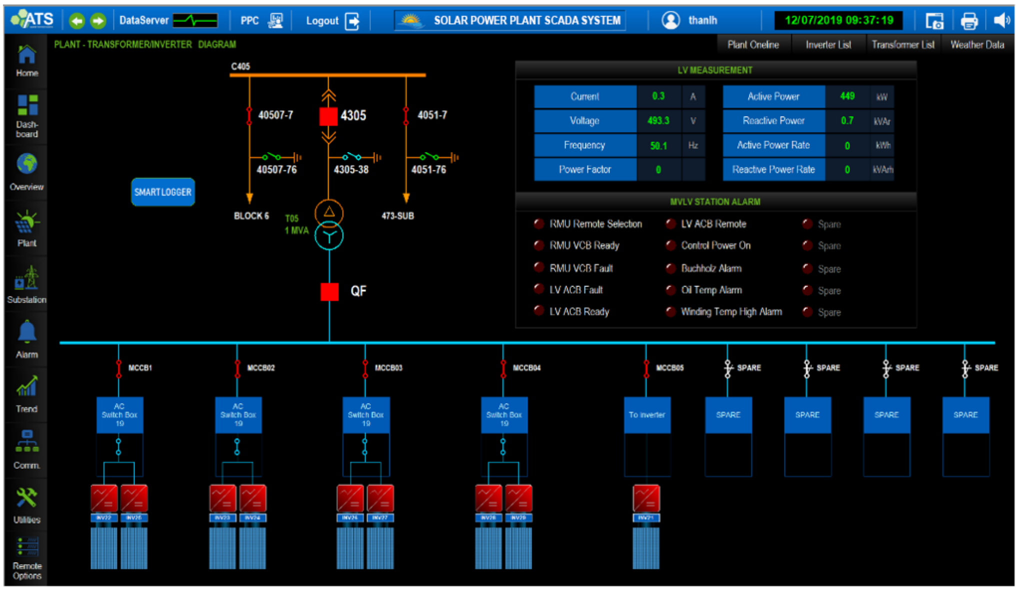

Figure 15. Central Inverter Station

Display the operation parameters, status signal, alarm, and protection signal of each central inverter station.

Figure 16. 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 17.MV Transformer Monitoring

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

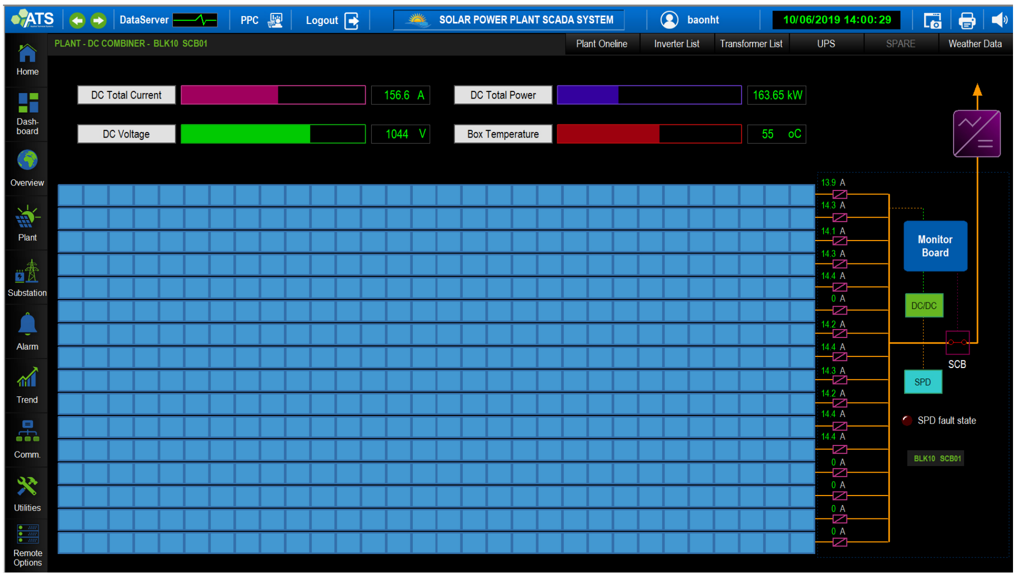

Figure 18. PV String Monitoring

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.

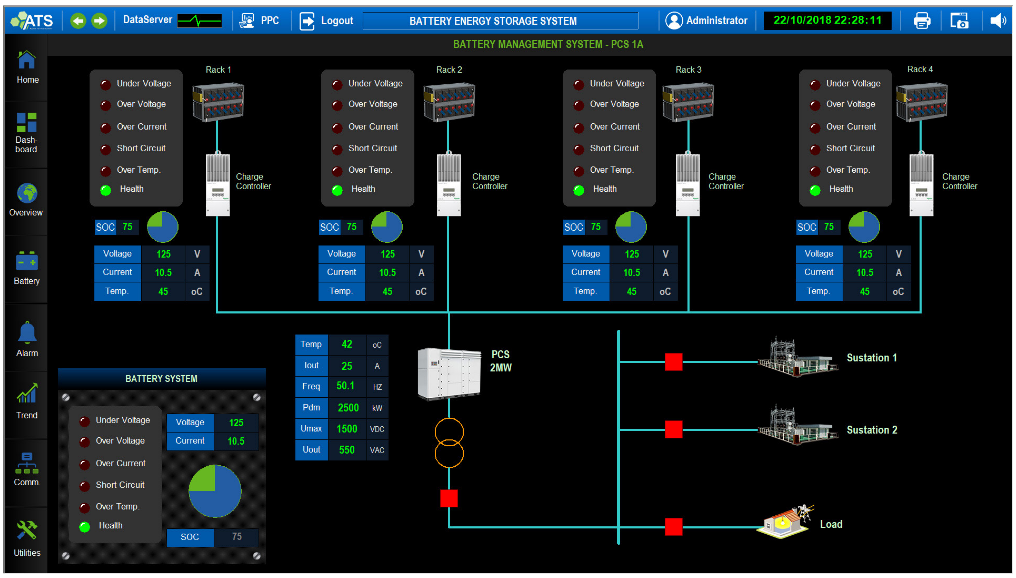

Figure 19. Battery Storage Monitoring

Display all analog parameters such as Temperature, Voltage, Current, State of charge... and alarms.

B. Technical Highlights

Figure 20. Wind Plant Overview

Display the Plant's general information, such as Location, Number of turbines, capacity, daily energy, status of all turbines, etc.

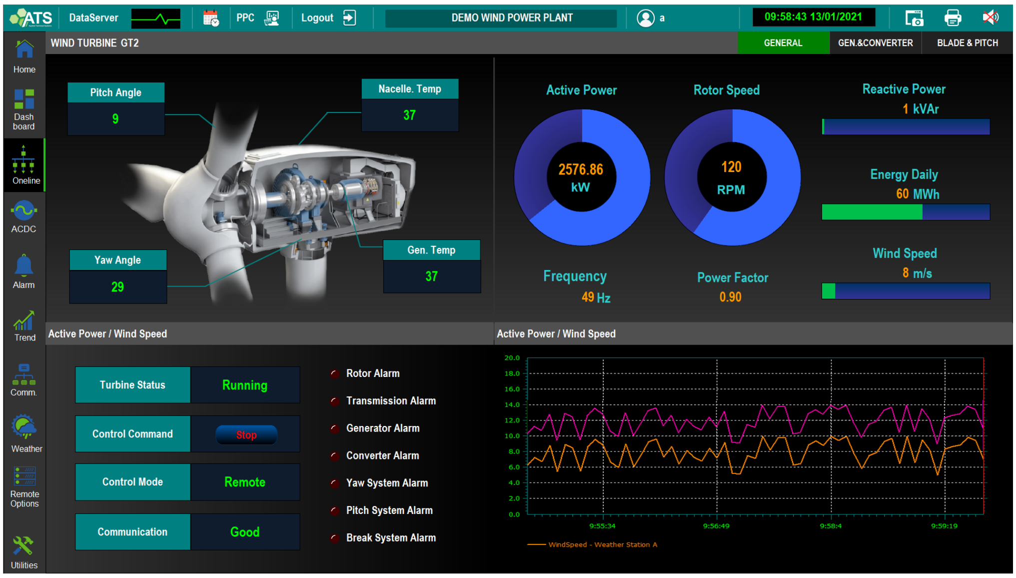

Figure 21. Wind Turbine Monitoring

Display all general information and measurements of a Turbine in operation

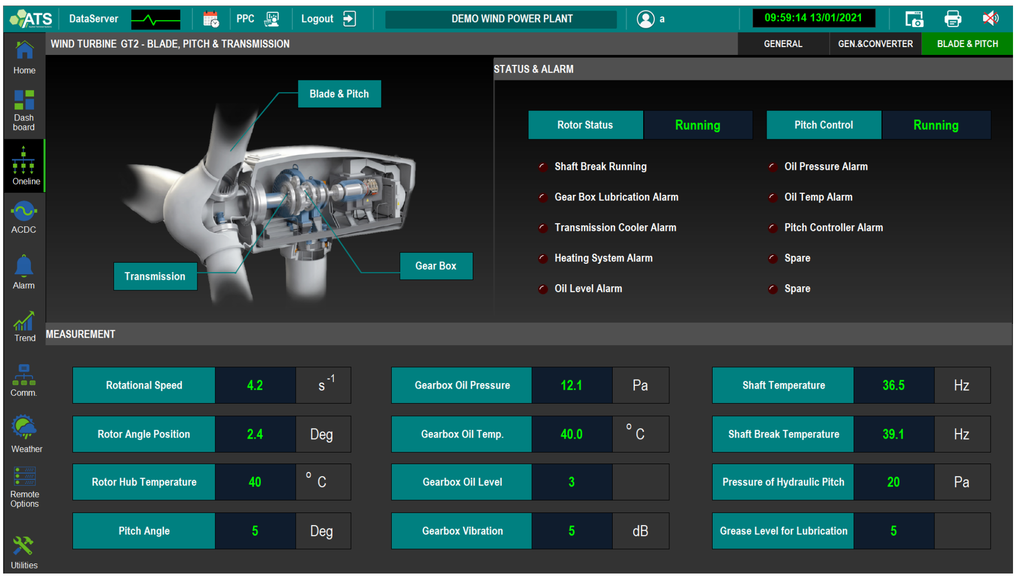

Figure 22. Wind Turbine Monitoring

Display all detail operational information and measurements of a Turbine in operation (Yaw, Pitch, nacelle, etc.).

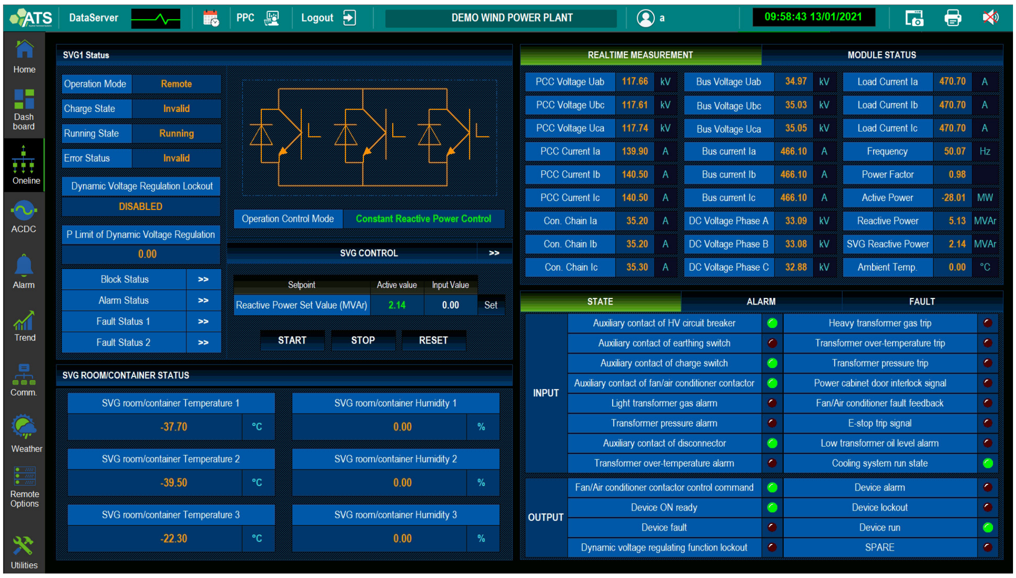

Figure 23. SVG Control & Monitoring

Display all operational information and measurements of a Static VAR Generator

Figure 24. RMU Monitoring

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

Figure 25 . Weather Conditions Monitoring

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

B. Technical Highlights

b) Power Quality Monitoring

Power quality parameters at the output of power plant are monitored for analysis and evaluation of generation efficiency and quality of the 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's 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

@ReHybrid™ 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 parameter trends (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, inverters, etc. for maintenance, hot-line work, or automatic re-closing is an important part of @ReHybrid™ design criteria. This will be accomplished by being used as one input in an 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

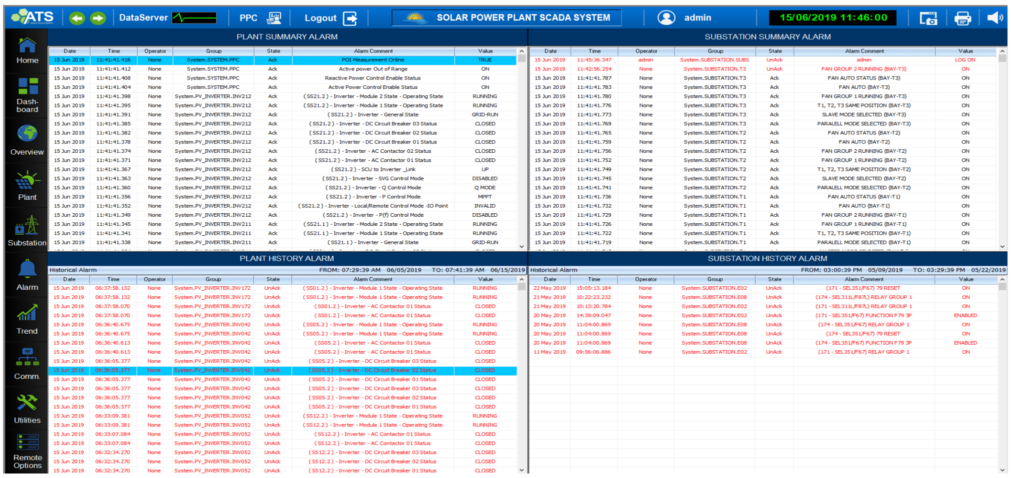

Figure 26. Alarm Presentation Window

Figure 27. Trending Window

(6). Communication Monitoring and Diagnostic

The following communication monitoring and diagnosis functions shall be provided.

- *Communications Monitoring:*
  - Interactive access to the parameters of the communication link database
  - Maintenance of the data links between elements in the same database
  - Monitoring of all operational statuses 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

@ReHybrid™ will monitor all necessary information related to plant auxiliary system or Inverter station auxiliary system such as AC and DC, UPS, etc.

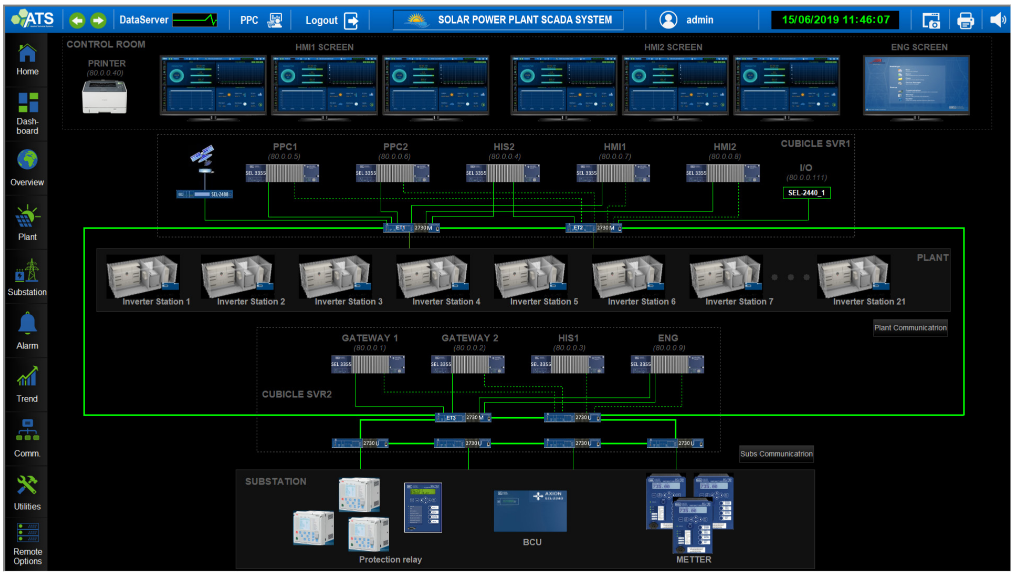

Figure 28. Communication Monitoring

Figure 29. UPS Monitoring

B. Technical Highlights

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 and historical data from a web browser.
The benefits of web-based interface include:

- Uses the latest technologies (HTML5, CSS3, SVG, etc.)
- Only requires a web browser from the client side for access (PC, laptop, tablet, smartphone, etc.)
- Ensures reliability and security
- Allows for connections from multiple users at the same time
- Availability of HIS data for display in tabular, graphic, chart and gauges format
- 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.

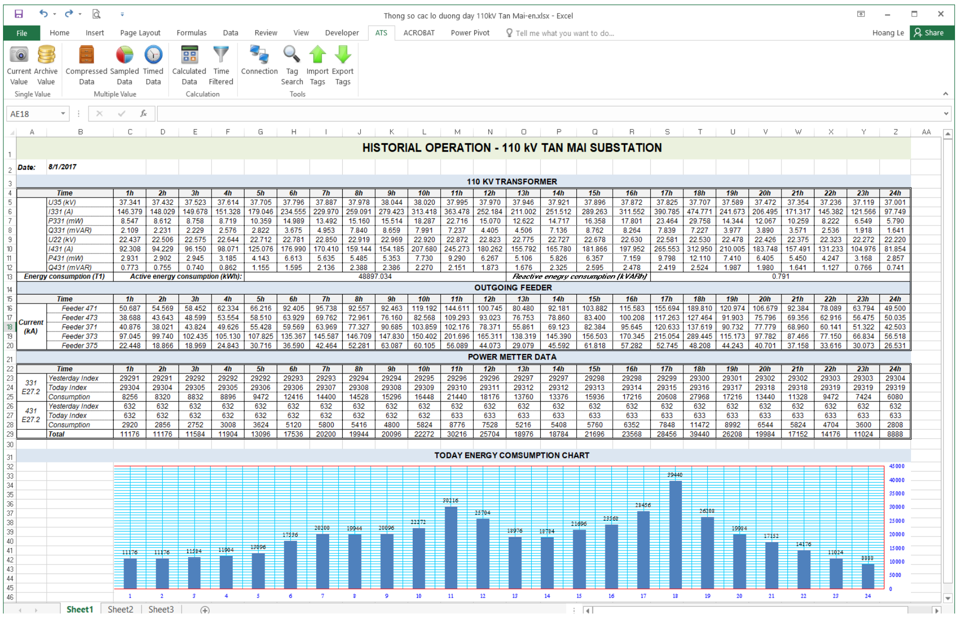

Figure 30. Operation Report

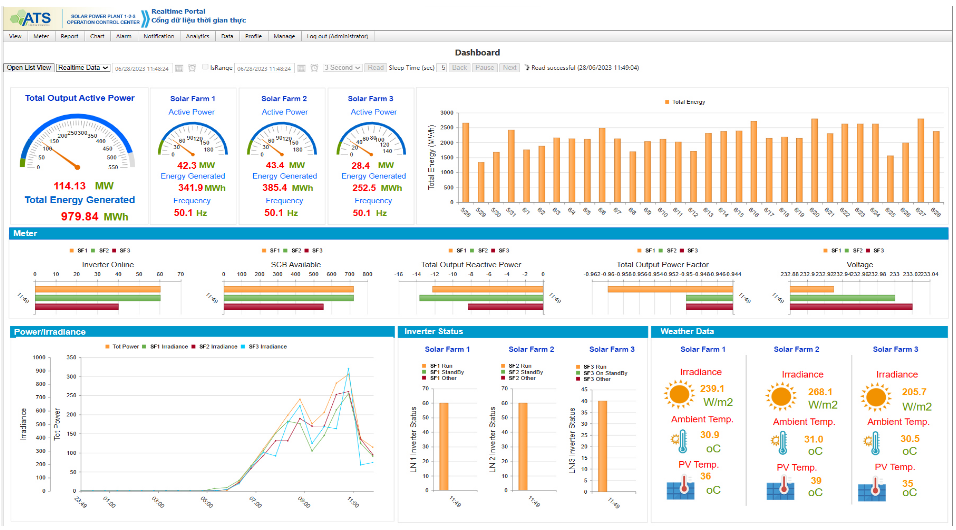

Figure 31. Web-Based Monitoring

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 determine the optimal, safe, reliable, and economical operating procedure for the power plant.

- Input data for the iEMS module are operation real-time data and historical data archived in the HIS database of the 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 the 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 the pre-set margin of error, the system will initiate an alarm to operators. This result and other signals in the system support the operator to determine the exact location of faulted devices or predict the extent the degradation of devices can affect the 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 32. Analyze and monitor PV String errors

Figure 33. PV Power Generation Forecast

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