@MicroGrid™

Protection and Control System Solution
for MicroGrid

Applied Technical Systems Joint Stock Company

Table of Content

A. Product Overview

@MicroGrid is the protection and control system solution for Microgrid which is designed and provided by ATS. @MicroGrid system fully meet international standards and can be engineered and customized to meet technical requirements of specific Microgrid project.

Modern society depends critically on the stability and secure of energy supply, especially in using of clean energy sources as renewable energy and reducing CO2 emissions. The growing concerns of load demand, primary energy availability and aging infrastructure of current electrical transmission and distribution networks as well as the upgradability of transmission network through on different geographic regions (eg. Islands, rough terrain ...) are increasingly challenging security, reliability and quality of power supply.

The Microgrid concept was built as a power distribution network comprising multiple electric loads and distributed energy resources with following characteristics:

- Use the renewable energy resources (photovoltaic, wind turbines...), in combination with other energy resources such as diesel generator, small hydro, biomass, biogas... as Distributed Generations (DG) for demand responding of the local load to ease pressure on the transmission system capacity, improve the availability of power supply, reduce the cost of power purchasing, improve economic efficiency and friendly with the environment.
- Has ability to operate independently or in conjunction with the Utility grid.
- Has one or more points of common coupling (PCC's) to the Utility grid.
- Has ability to operate all distributed energy resources (DER), including load and energy storage components, in a controlled and coordinated fashion, either while connected to the Utility grid or operating independently.
- Has ability to interact with the Utility grid in real time, and thereby optimize system performance and operational savings.

At the heart of the system is the Microgrid control system that performs the connection and controlling of distributed generators (DGs) to create a balance of the power supply with different load conditions, improve the ability and stability of the power system, reduce the power down time and improve the grid resiliency.

Microgrid control system is an integrated system comprised of the following system:

- Centralized Microgrid control system with visualization and energy management system
- Coordinated protection system
- Metering, power quality monitoring and measurement system
- Communication Infrastructure
- Engineering tools for configuration and system maintenance

The system incorporates the latest technology in the field of Microgrid system to provide its users with innovative solutions to their requirements.

The Microgrid control system provides all monitoring, control, and automaton functions in a flexible system structure for ease of operation. The Microgrid control software system has been modularly designed; its individual modules are specifically designed and tailor-made for each project.

The Microgrid control system complies with all current de jure and de facto industrial standards for open system. Such compliancy allows for communication between the control system and other devices and systems from other vendors.

Proposed scope of supply includes design, production, installation, configuration, testing and commissioning the Microgrid protection and control system in accordance with technical requirements and current specialized industrial standards.

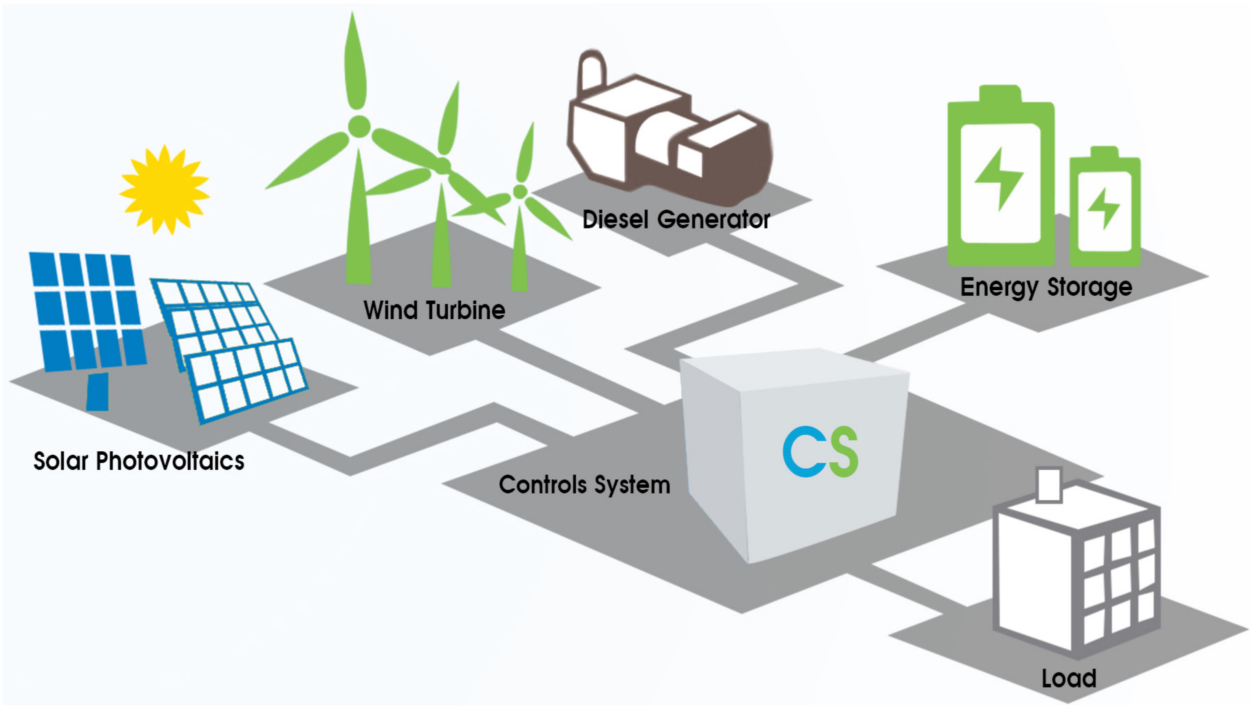


Figure 1. Example of Microgrid concept

1. KEY DESIGN ATTRIBUTES

- **Adherence to standards:** the software and hardware shall adhere to either de-jure or de-facto standards broadly used in the industry, especially ANSI/IEEE, ISO and IEC as indicated in each section. This will make it possible for the Client to subsequently use equipment coming from other sources and to avoid the dependence upon the original supplier.
- **Availability:** the system shall meet availability criteria with the availability of 99.95%, no single point of failure, and dedicated backup of critical software and hardware functions.
- **Expansion capability**: allow adding new functions without a need for significant system or program changes. Both the addition of new functions and the enhancement of the existing ones shall be achievable by means of simple procedures.
- **Open distributed design:** the overall design of the Microgrid control system shall be distributed and open, in term of off-the-shelf hardware and software, to allow the addition of additional processors and software without entailing the replacement of the existing components especially the main processors, workstations, communication processors, controllers, protection devices, measurement devices, data acquisition devices, software subsystems...
- **Scalability:** the Microgrid control system is scalable, i.e., the same basic architecture can support for the Microgrid project of varying sizes and can be upgraded to support growth in the power system (new distributed generators, load demand…) and in functionality.
- **Performance**: The Microgrid control system shall support all functions required by the Client specification with the median loading of the system resource in accordance with requirement.
- **Overall accuracy:** The overall error rate of the processed information is in compliance with requirement. The analogue values are better than 0.5% at IED, Multi-function Meters and Revenue Meters.
- **Reliability, redundancy, failover, backup:** the design ensures the Microgrid control system will continue to be operable if the main server fails. There will be no single point of failure in the Ethernet LAN or in the IEDs that can cause the system to be inoperable.

2. MAIN DEVICES

The Microgrid protection and control system will include the following main devices:

- **Data acquisition devices at floating solars** to collect all monitoring and control signals from PV combiners, charger controllers, battery management systems, PCS controllers, MV transformers.
- **Protection relays, tariff meters, power quality monitoring devices at the output of floating solar and battery energy storage system (BESS)** to protect the system, measure of power purchase, monitor as well as evaluate the performance and quality of solar power generation.
- **Protection relay and measurement device at new extension switchgear of Utility diesel generator** to protect and isolate floating solar and battery energy storage system from grid malfunction.
- **Data acquisition devices at Utility diesel generator** to collect supervisory control data for coordinating between distributed generations to create the smoothy, safe and stable power system.
- **Centralized control system** at the main control building perform all data acquisition, data processing, data storage, visualization interface and energy management functions that assist the operator to monitor, control the entire system as well as analysis and evaluate the ystem performance and statbility, thus providing the optimum operation plan.
- **Load data collection systems** at MV feeders, MV transformer for load forecast and power generation planning.

3. MAIN FEATURES

The Microgrid control system has the following features:

- Can operate to support main objective functions which is to maximize energy sell and next is to minimize number or hours of existing diesel generator operation of utility. And supports other objective functions such as reliability, power quality, peak reduction, reduce power losses in distribution line, or Volt/Var control.
- Can give weights or priority to avoid conflict between different objective functions. High priority objective function always has presidencies over lower priority objective function.
- Can communicate with the existing diesel generator controller, charge controller, PCS controller, battery management system, floating solar and weather station.
- Supports forecast on loads and generations functions, and collect the weathers forecast data from agency.
- Microgrid control system and all components in the system will be synchronized by GPS time synchronization system.
- Supports to perform fault location, isolation and service restoration.

4. SOFTWARE PERFORMANCE

The Microgrid control software system is designed and developed in compliance to the following attributes:

- The software of the Microgrid control system is based on the Windows operation system platform. All Servers and Workstations in the system will be installed the latest version of Windows operation system.
- Open and portable, in conformity with the formal (de-jour) and de-facto standards prevailing in the industry
- Expansion capability
- Consistency throughout the system
- Easy-to-use and easy-to-learn
- Efficient management of large amounts of data
- Capability to exchange data with other systems
- Capability to retrieve, process and store application, database, document and graphics files in different formats
- Modularity
- Complete documentation is provided for the installed software, covering both the base line and the changes implemented during factory testing and system commissioning.

B. Technical Highlights

1. TYPICAL MICROGRID PROJECT

The typical project will build a typical model of Microgrid system on an Island, a place far away from geographic location. It is extremely difficult and costly to build and develop a transmission and distribution system for Island power supply from national power grid.

The Microgrid project is built up including the following main components:

- Utility diesel generators
- 5 blocks of floating solar farm
- Battery Energy Storage System (BESS)
- Distribution system
- Protection and measurement system
- And centralized Microgrid control system with load forecast, generation forecast features would be able to manage efficiency of energy usage in system.

Microgrid project will operate in two conditions as same as the other system implemented in the world, grid connected condition and islanded condition. When Microgrid operates in grid connected condition, the floating solar and BESS connected to the grid which the existing diesel generator runs as the master generation to maintain and stabilize the frequency as well as the system voltage.

If outage occurred until all existing diesel generator stop, the Microgrid shall be able to operate in islanded condition. The PCS would be able to do black start and run as the master generation to control voltage and frequency. In addition, in any condition or mode of generation, PCS shall be able to run as the master generation to maintain the power system stability when needed or requested from utility for grid connected condition.

And in night mode, when the solar power is no longer useful, the backup energy stored in the battery systems will be used in combination with the diesel generators to power supply of the entire system

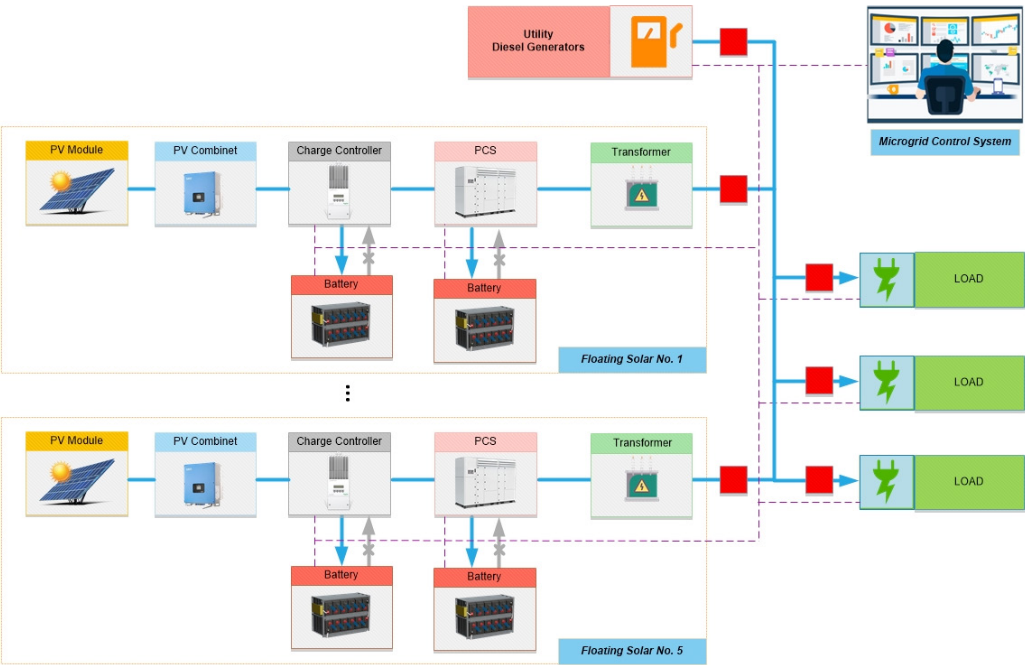


Figure 2. Grid connected condition

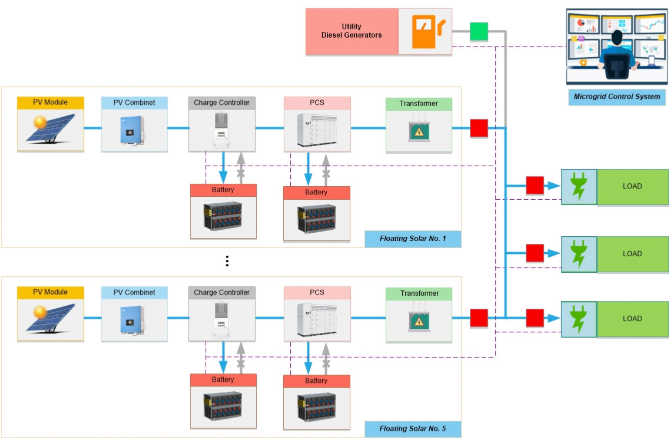


Figure 3. Islanded condition

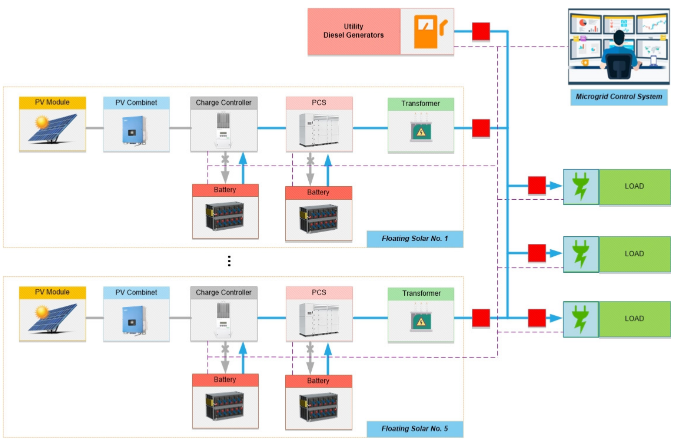


Figure 4. Night mode condition

2. HARDWARE SOLUTION

2.1. Microgrid protection system

2.1.1. Protection system at the output of floating solar and BESS

(1) Protection system

- Directional overcurrent protection relay is integrated in Bay Control and Monitoring Unit (BCMU) with Arc Flash Detection for 22kV Switchgear Cubicle and each Feeder of RMU.

(2) Control and monitoring system

The 22kV Switchgear Cubicle is equipped with Directional overcurrent for protection, monitoring, controlling and acquisition all signals of the 22kV cubicles. They are connected to the Microgrid control system according to IEC 61850 protocol. In addition, the system will be equipped power quality monitoring devices for analyzing and evaluating the quality of floating solar generation and BESS operation.

2.1.2. Protection system at existing diesel generator

(1) Protection system

Protection relay at additional 22kV switchgear of diesel generator include :

- Directional overcurrent protection relay is integrated in Bay Control and Monitoring Unit (BCMU) with Arc Flash Detection for Additional 22kV Switchgear

(2) Control and monitoring system

The 22kV Switchgear Cubicle is equipped with Directional overcurrent for protection, monitoring, controlling and acquisition all signals of the 22kV cubicle. They are connected to the Microgrid Controller System according to IEC 61850 protocol.

2.1.3. Anti-islanding detection

An islanding mode is a condition in a distributions generation (DG) which the energy resource continues to supply to the local load even though the utility grid (Diesel Generators in this case) has been disconnected from the local load. As a consequence, islanding can present serious safety hazard since a presumed disconnected power line can still unexpectedly be fed by nearby DG sources. Furthermore, prolonged islanding can also prevent reconnection to the power grid and may cause damage due to voltage and frequency excursions.

Anti-islanding methods generally can be classified into four major groups, which include passive methods, active methods, hybrid methods and communication base methods. We proposal passive methods and communication base methods as below:

(1) Passive method

Passive islanding detection methods relies on the measurement of system parameters (such as the variation in the voltage, frequency, harmonic distortion or the power) that causes the inverter to control/modify the output power in order to meet specific conditions during islanding mode of operation. The parameters vary greatly at the point of the Point of Common Coupling (PCC) when the system is islanded. The difference between a normal grid-connected condition and an islanding condition is based on the threshold setting of the system parameters. We use Frequency Protection and Voltage Protection in relay for Passive islanding detection.

The power flow in a solar grid-connected system is presented in **Figure 4** bellow, which the node PCC is the point of common coupling between the utility grid and power conditioning unit.

During islanding mode of operation, the control system should be able to maintain the active power demand for the local load equivalent to the power generated by solar power plant at the moment when the utility circuit breaker is opened. In case the power generated by solar power plant, P_{PV} is less than the load power, P_{load}, the voltage at PCC, V_{PCC} has to be increased to achieve equivalent input and output power, vise and versa. Similarly, if the reactive power of local load does not match the reactive power generated from solar power plant, the frequency, ω at the PCC has to be controlled to make both reactive power equivalents. The solar inverter continuously seeks for a frequency at which the current-voltage phase angle of the local load is equal to the solar power system. Therefore, such voltage and frequency changes can be detected for islanding mode by over/under voltage and over/under frequency embedded in solar inverters or integrated in relay.

When DG detect Islanding Mode, the DG system will takes appropriate actions for remove serious safety hazards to field engineers and maintenance personnel, keep equipment not to be damaged due to high magnetizing torques and currents…

(2) Communication base method

Communication base methods are based on communication between utilities and DG. Islanding is detected when the status of utility circuit breaker and the information was send to DGs.

Protection relay installed in additional switchgear at Diesel Generator not only uses for protection functions but also acquires the status of circuit breaker at Diesel Generator feeders. The opening signal of circuit breakers will be transmitted to protection relay in main control building via Mirrored Bits Protocol and DG system for detect islanding mode.

When DG detect islanding mode, the DG system will takes appropriate actions for remove serious safety hazards to field engineers and maintenance personnel, keep equipment not to be damaged due to high magnetizing torques and currents…

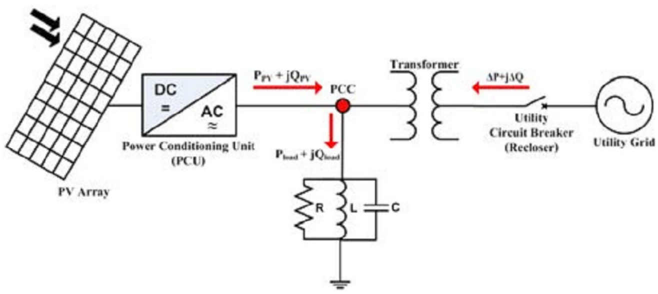


Figure 5. The power flow in a solar grid-connected system under a normal operating condition

B. Technical Highlights

2.2. Microgrid control system

The hardware of the Microgrid control system is critical for the stability and availability of the entire system; the design ensures that any single-point failure shall not affect the whole system.

The Microgrid control system is able to satisfy the following criteria:

- High reliability
- High availability
- Compliance with power industrial standards

The hardware of control system will include the following:

- **Centralized control system:**
  - Industrial grade Microgrid control servers operate in redundant mode in order to be a highly reliable controller; perform management system to communicate with IEDs (data acquisition devices, PV combiners, charge controllers, battery management controllers, PCS controllers, protection devices, measurement devices…) and perform data processing, data storage, visualization and energy management functions for supervisory and control of the entire Microgrid system. The fail of Microgrid control servers can be recovery about 10 second.
  - Two operating and engineering workstations provide user interface between the operator and the Microgrid control system; engineering tools for configuration and maintenance of the system.
  - Fiber optic network to connect all equipment in the system.
  - GPS clock for time synchronization in the system.
  - A3/A4 network printer, UPS to provides backup power.
  - Firewall devices is deployed for security, data encryption and separating internal communications from external networks.
- **Data acquisition system:**
  - **Floating solar and BESS:** At each block will be equipped one data acquisition device to collect data from PV combiners, charger controller, battery management system, PCS controller and weather station by standard protocols such as Modbus RTU or Modbus TCP or DNP… In addition, this data acquisition device also provides digital input, analogue input to collect data from transformer by hard wiring connection.
  - **Point of common coupling:** all operating analogue parameters, device status, protection signals, power quality data will be collected from protection relay, tariff meter and power quality monitoring device with standard protocol including IEC 61850, Modbus, DNP3….
  - **Utility diesel generator:** Two data acquisition devices operate in redundant mechanism will be equipped to collect monitoring and control data from diesel generator for operation and control of Microgrid system. And firewall device is deployed for security communication channel and data encryption to the Microgrid control system.
  - **Load points:** To collect data for load forecasting, calculating functions and plan the optimal, efficient operation of the Microgrid system, each load point such as MV feeder, load transformer… will be equipped a set of meter and 3G/GPRS modem to perform measurement function and transmission data to the Microgrid control system.

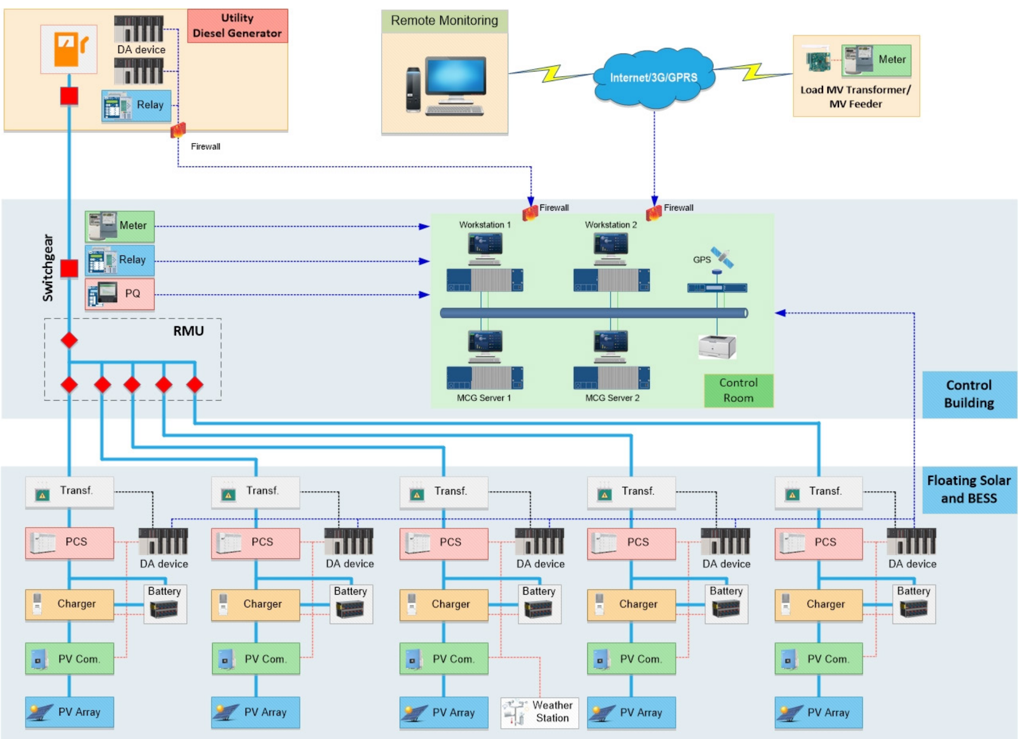


Figure 6. Microgrid protection and control hardware system

3. SOFTWARE SOLUTION

3.1. Software architect

The Microgrid control system is functioning with the data acquisition, processing, storage, visualization and energy management functions to be performed. The control system will communicate and collect all data of the Microgrid system from diesel generator, floating solar and BESS (PV combiners, charger controller, battery management system, PCS controller and MV transformer), protection devices, measurement devices, etc.

The primary data acquisition tasks shall be performed via the Data Acquisition module with appropriate protocol (IEC 61850, Modbus RTU/TCP, DNP3, FTP, Telnet, SNMP...) and interfaces via the Ethernet LAN or dedicated serial communication system. At here, the data will be pre-processed, checked for reliability, signal quality and limits to ensure the accuracy of the data and remove unreliable data.

After that, acquired operation real-time data will be transferred to Real-time Database. At here, operation real-time data will be processed and converted to specific format for all function applications of the system. The data stored in Historian Database includes processed real-time data, alarm and event signal, and communication data from other database. It also stores the results of energy management functions such as load forecast, PV power generation forecast...

Data from databases will be used for user interface monitoring display, Microgrid control, reporting evaluating, analyzing, load forecast, PV power generation forecast, operation planning (short-term, long-term). Simultaneously, the system data is ready to communicate and public with SCADA/EMS system or remote monitoring system at head office via secure and encryption communication channels.

The system is based on redundant client/server architecture and is designed to meet functional, performance, availability, and reliability and expandability requirements. With Microgrid control system, users have the complete tools and information to monitor the system and to make decisions based on the information provided.

Detailed software architect of the Microgrid control system is shown in **Figure 7**.

Main software modules of Microgrid control system include:

- Data Acquisition (DA)
- Real-time Database (RTDB) Processing
- Historical Information System (HIS) and applications
- Microgrid controller
- Human – Machine Interface (HMI)
- Fault record collection and after fault analysis (FR)
- Energy management system (EMS):
  - * Load forecast
  - * Solar generation forecast
  - * Unit commitment (Long-term plan)
  - * Economic dispatch (Short-term plan)
- System Engineering

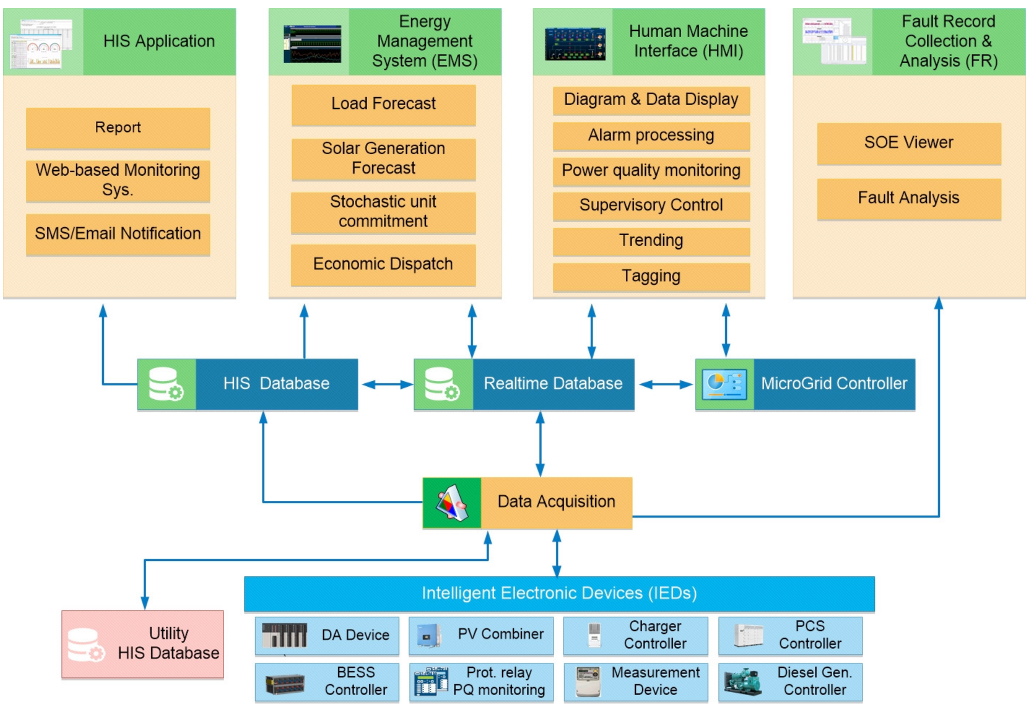


Figure 7. Microgrid control software architecture

B. Technical Highlights

3.2. Software Functions

3.2.1. Data Acquisition (DA)

The Data Acquisition module will perform initializing, managing real-time information channels and communicating data with monitoring and control devices and other systems. This is an integral part of any data acquisition, data processing and control system.

The Data Acquisition module is a complete interface for data collection. It can be used by System Integrators and Utilities to collect data from IEDs (data acquisition devices, PV combiners, charge controllers, battery management controllers, PCS controllers, protection devices, measurement devices…) with appropriate protocols such as IEC 61850, Modbus, DNP3, IEC 60870-5, SNMP, OPC… and then supply this data to other control systems or remote monitoring system supporting IEC 60870-5, OPC… communication protocols.

The Data Acquisition module also acquires fault records, power quality records via Ethernet TCP/IP or dedicated serial interfaces with IEC 61850 File service/FTP/Telnet… protocols for analyzing, identifying the cause of incidents, reducing the system recovery time and evaluating the system's power quality.

The Data Acquisition module output will provide all the collected data from standardized connection channels to the Real-time Database module. Information data sent from the Real-time Database to the connected terminals connected via Data Acquisition module can be control commands, data collection request according to the standards it supports.

In addition, to collect load parameters for energy management functions (Load Forecast, Stochastic Commitment, Economic Dispatch), the DA also equipped application interfaces to communicate with existing Utility operation database such as API, SDK, ODBC client, JDBC client, Web services, OPC HA, OPC UA… or from manual input in CSV/XLS file format. These collected data will be directly stored in HIS database.

Key features

- Supports many types of channels (DNP3, IEC61850, Modbus, IEC101, IEC103, IEC104, OPC, etc.)
- Capable of managing many channels at the same time
- Each channel can be configured to have a main connection and multiple backup connections (up to 4 connections)
- OPC Data Access Server interface supports many off-the-shelf OPC compatible applications
- Simple common interface eases data exchange between channels and adding new channel becomes easy
- Comprehensive logging for monitoring, analyzing and maintenance become convenient and intuitive.
- Compliant with NERC-CIP standard recommendation and best practices
- Certificates of compliance issued by DNV-GL (KEMA) for IEC61850, IEC60870-5-101 and IEC60870-5-104 protocols.

Applications

- Data collection and processing
- Protocol translation
- Monitoring and diagnostics

System compatible protocols

- EC 61850 Client
- ATS IEC61850 Server: a software-based IEC61850 server with support for many features of the IEC61850 standard
- Modbus Master/Slave
- IEC60870-5-101 Master/Slave
- IEC 60870-5-103 Master
- IEC60870-5-104 Master/Slave
- DNP3.0
- OPC Client/Server
- Internal Channel: supports script to evaluate C# expressions

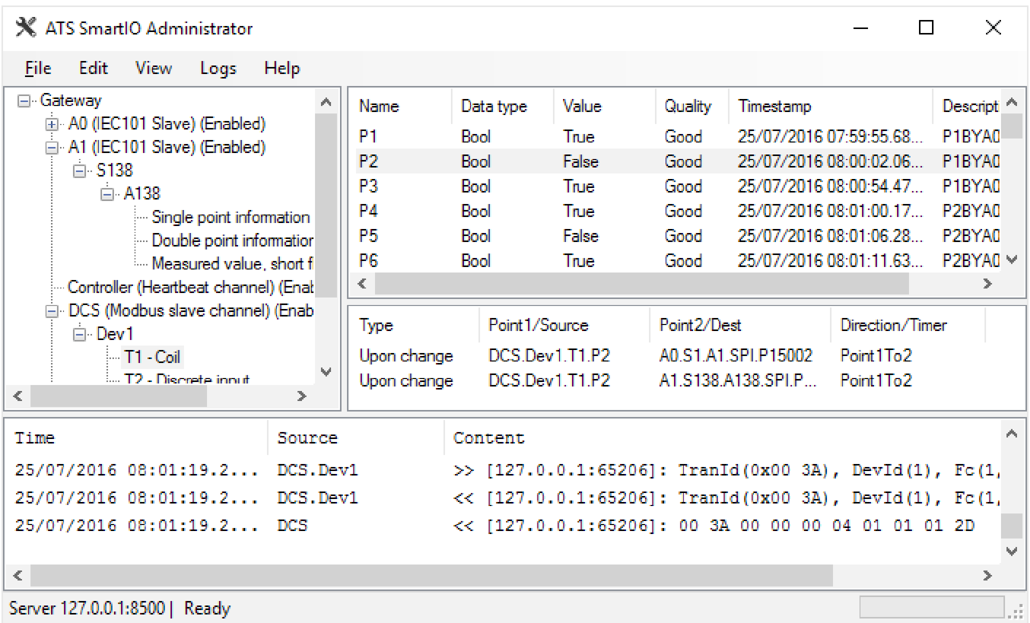


Figure 8. Data Acquisition interface

3.2.2. Real-time Database (RTDB) Processing

The Real-time Database module is a central component in the system. RTDB is a data bridge between the Data Acquisition module and other application modules (Energy Management System, Microgrid controller, HMI, HIS, etc.), which manages and processes all real-time data of the system.

Real-Time Database Management System acquires data from Microgrid system or process, usually from automated control systems such as controller, IEDs… or other sources. Data are routed through the system, where processing tools transform them into useful information. Interactive displays, that you create, make that information available wherever it's needed. And Real-Time Database Management System can store a nearly limitless amount of data, all at their original resolution, virtually forever.

The database management-support software is to provide the environment and the services needed to define, store, retrieve, edit and access the full array of data collected, processed and stored by the Microgrid control applications. Such data consist of “static”, or fixed data, “dynamic”, or real-time data, and historical data.

The static data is including but not limited to, floating solar and BESS (PV combiners, chargers, PCSs, battery system, MV transformers), diesel generator, load transformers, MV feeders, breakers, IEDs, LAN etc. Also included in the static data are the various parameters used by the application programs.

The real-time data consist of data collected and processed by the Microgrid control system functions, as well as computation results from applications. With the Real-Time Database Management System, personnel throughout the end-users gain unprecedented access to real-time information, helping them to make better business decisions.
After accordant data processing and converting, the Real-time Database will provide all data for each application module of the system. In contrast, the processed data from application modules will be returned to the Real-time Database module to communicate with the connected endpoints for control and monitoring purposes.

Database generation

The real-time data collected from IEDs, communication processors, meters, etc. will be passed directly from the appropriate protocols to real-time database management system or from the server of real-time database management system.

Real-time database management

The real-time database management system shall provide for:

- Hiding data characteristics such as their physical location and addressing modes, thus facilitating the design and implementation of new application programs
- Defining data in an easy manner – it shall be possible to specify easily and efficiently the type of file, the access mode, the interdependencies among the files, etc.
- Accessing data via queries – there shall exist a structured language for database queries providing the ability to retrieve information without the need to use a specific programming language
- Ensuring data security –safety measures, e.g., passwords and access rights to the files, directories or database areas, shall be implemented to ensure that the access to the database is allowed only to authorized personnel
- Ensuring data integrity – provisions shall be implemented to ensure that the data are correct and that there are no duplications that may lead to information inconsistencies. In case where two or more users share the information, the changes performed by one user shall be communicated to the other users
- Promoting data independence – the ability shall be provided to change the database structure without the need to change the system, support and application software.
- Assuring performance and efficiency – the database processing efficiency shall not be affected by its size
- Recovery in case of failures or system crashes
- Fast, efficient and secure information backups

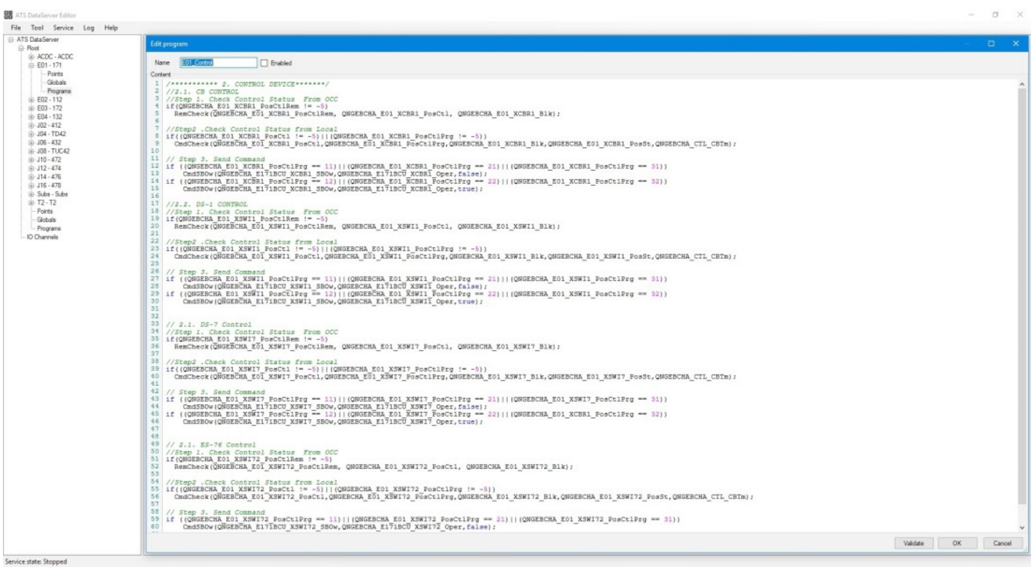


Figure 9. Real-time database interface

B. Technical Highlights

3.2.3. Microgrid controller

ATS Microgrid Controller (AMC) provides control functions to improve reliability of system and optimize the renewable resources intent to maximize the benefit of system. The AMC coordinate the devices in the control area such as diesel generator, BESS, PV Floating, controllable load and other RE within the scope of project.

The main control functions of AMC include:

- Active/reactive power control - Voltage/frequency control. It also allows power sharing between the different sources by adding or dropping generation resources during that maintenance process.
- PV Solar Inverters and Batteries control: AMC provides Automation/SCADA functions can remotely monitor and control whole solar farm, able to control the inverter of solar farm, make the solar farm is one of the dispatch-able source by using BESS.
- DG commands control: AMC provides Automation/SCADA functions can send set point commands (kW, kVAr or PF), start/stop commands, manual/automatic mode to the diesel generation controller.
- BESS dispatch to optimize and smooth PV output: AMC provide control functions of BESS to achieve ramp rate control, frequency droop response, power factor correction for smoothing PV output, able control both active and reactive power output from BESS to maintain system frequency and voltage.
- Peak shaving: AMC provides economic dispatch functions support peak shaving aim to reduce overall energy costs, and to maintain system frequency and voltage.
- Reduce GHG emission: AMC calculate GHG emission of a generation mix and take this into account in economic dispatch process, calculate a value for GHG reduction based on avoidance of diesel and on grid generation.
- Black start: Restoration of the MG and MV grid following a blackout.

(1) Operation condition

AMC is design to work with three mode of Microgrid:

- Islanded Condition
- Grid Connected Condition
- Black Start

a) Islanded condition

It is a mode that Microgrid disconnected from the main grid, BESS is assigned to be primary sources that regulate the frequency, and to supply reactive power to maintain voltage.

AMC is capable of detecting such abnormal conditions and islanding from such disturbance, for example when loss of existing diesel generator, frequency and voltage are large and rapid change during a large disturbance.

AMC is capable of disconnecting from the main grid and maintaining its stability after the islanding transition.

b) Grid connected condition

It is a mode that Microgrid synchronizes and reconnect to the main grid, main grid is assigned to be primary sources that regulate the frequency, and BESS support main grid to maintain the frequency.

AMC is able to reconnect to the main grid without interruption in Microgrid area, when reconnecting to grid from islanded mode.

c) Black start condition

It is a mode after all generators complete shutdown. Based on the system topology, capacities and sizes of resources and loads, and the controllability of the devices, the black start procedure can be pre-determined and implemented in the AMC and other devices (e.g. diesel power plant controller, inverter).

AMC is able to black start the Microgrid using any or all of the flowing generation resources include diesel generator and BESS.

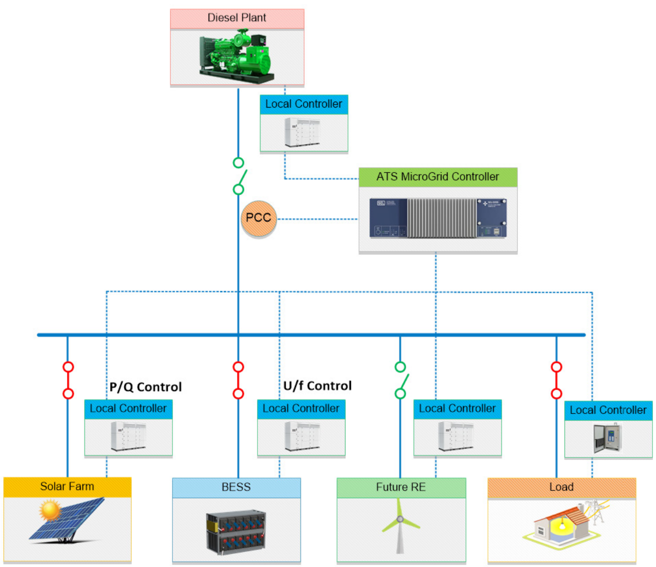


Figure 10. Microgrid system in islanded condition

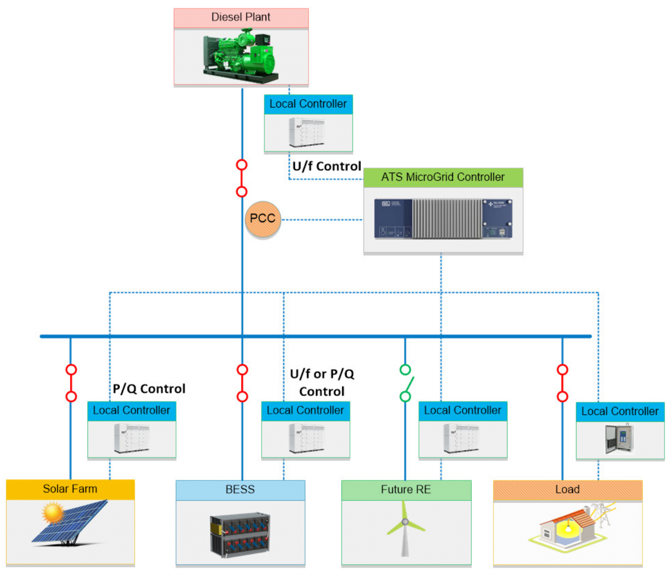


Figure 11. Grid connected condition

(2) Frequency and voltage control

The primary sources (e.g. BESS, Diesel generations) will be to set U/f control mode to maintain stability of the system voltage and frequency. Droop control is adopted in the U/f control mode. When the load changes, the changes will be automatically distributed among the primary sources according to the droop factor, but the voltage and frequency of the system also vary after load variation, and therefore, this control mode is actually a proportional control.

Reverse droop control is to control the active and reactive outputs by measuring grid voltage amplitude and frequency to trace the predefined droop characteristic. The reactive output and active output of the inverter are regulated by regulating the output voltage amplitude and output frequency, respectively.

(3) Active and reactive power control

In P/Q control, the inverters can produce active power and reactive power, and the determination of reference power is the prerequisite for power control.

P/Q control is based on the grid voltage oriented P/Q decoupled control strategy, in which the outer loop adopts power control and the inner loop adopts current control. The PI controller is usually used for outer-loop power control.

(4) Floating solar and BESS control

The controller will be based on information about the status of PV arrays, battery systems and control capacity of each unit, that giving corresponding control commands by either turning it on or off or modifying the amount of active/reactive power in its producing or absorbing.

The 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, DNP3, IEC 61850, IEC 60870-5-104, etc...

Power plant control functions:

- Active Power Control
- Ramp rate control
- Reactive Power Control
- Power Factor Control
- Grid support control:
  - Frequency droop control
  - Voltage droop control
- Power plant start-up/shutdown

(5) Diesel generator control

The controller will be based on information about the status of diesel generators and control capacity of each unit, that giving corresponding control commands by either start/stop command or modifying the amount of active/reactive power in its producing (via set point command).

In the event of a black station, the controller is able to detect a black bus and bring up replacement generation if configured to do so. Through the SCADA/HMI, the generator will automatically start and stop depending on the spinning reserve in the power system and the minimum run-time of the generator.

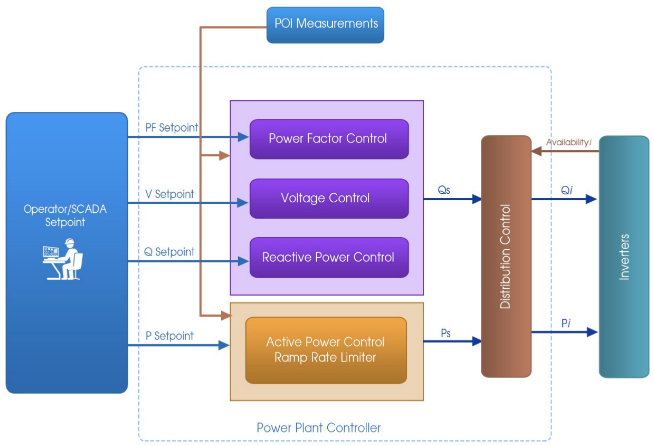


Figure 12. Power plant controller function block diagram

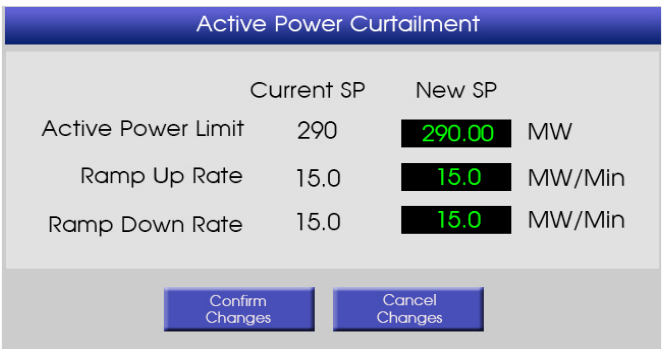


Figure 13. Active power control of floating solar and BESS

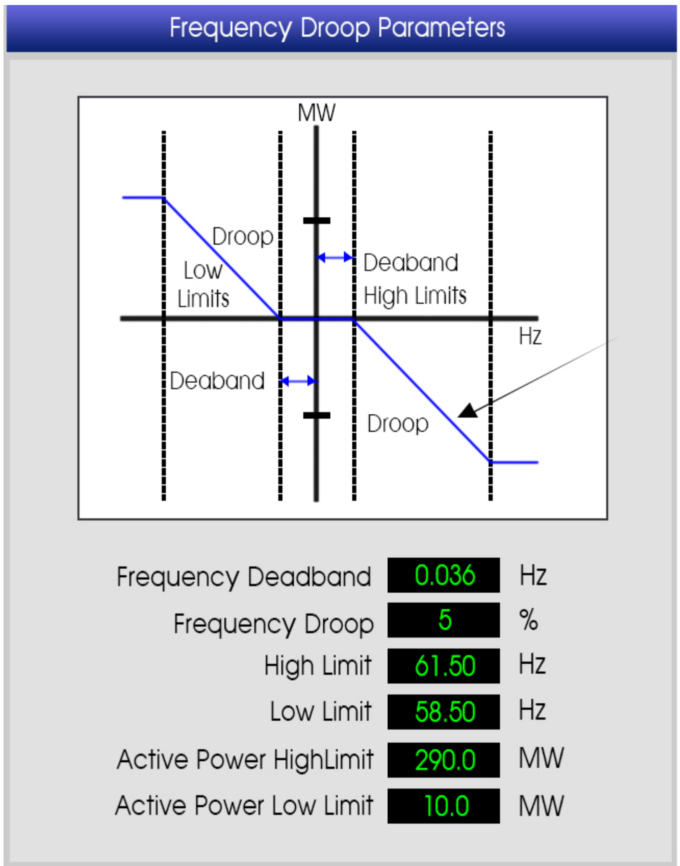


Figure 14. Frequency droop control of floating solar and BESS

B. Technical Highlights

3.2.4. Human – Machine Interface (HMI)

User Interface is defined as the link between the users, on the one hand, and the Microgrid control system that monitors and controls programs and applications in general. The User Interface shall provide the ability to monitor and control the power system, and to access any information item contained in the database, in a simple and friendly way.

(1) Operator inputs and console interaction

The following capabilities shall be assigned to each console via displays specifically designed for this purpose:

- Data entry
- Supervisory control
- Application programs selection and execution

Capability exists to perform the following functions through monitor/ keyboard:

- Activate and deactivate any device under control
- Observe any parameter that is monitored by the system
- Set tags
- Silence, acknowledge or delete any alarm
- Inhibit or enable the alarm of any monitored device
- Issue audible signals in case of alarms or important events
- Take out of service and restore back in service any monitored device, controlled device or Microgrid system component
- Display the status of all the peripheral devices, controller, IEDs and communication lines.
- Display the most recent alarms by pressing one key. The operator could delete individual alarms. When the alarm list is full, the system will delete automatically the oldest alarms to let pass the most recent ones
- Display all the system points that are tagged. Each listed point shall include all the warning tags for this point. Each warning tag shall be defined and shall include a message/text describing it.
- Generate a hard copy of any system display and print any report and/or list of events

(2) Basic display examples

General graphical displays will be provided including:

- Detailed equipment status and network configuration information
- Visual indication of device setting, selection, operation and interlocking
- Service and measurement values, including analogue measurements and their limit setting
- Alarm annunciation
- Visual record of system alarms, including fault information and events
- A means of displaying the status of devices that are not monitored automatically but care under the operator's control such as application of tags or labels
- Display the power quality monitoring of the Microgrid system
- Display detailed equipment and network configuration information according to each use cases
- Operating Report Summary
- Auxiliaries system and GPS status

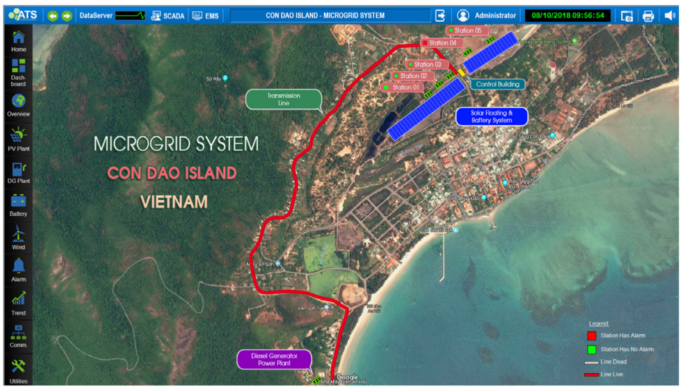


Figure 15. Displaying Microgrid project on map

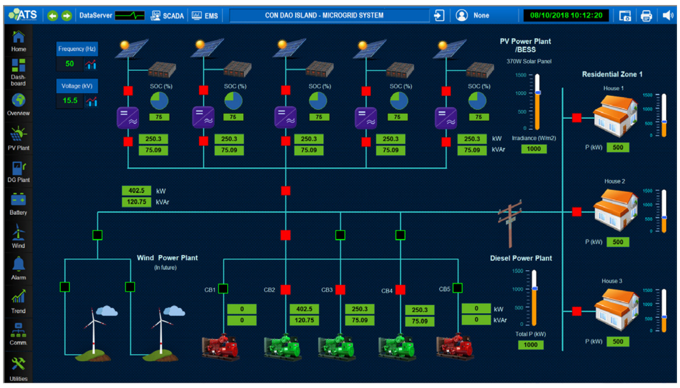


Figure 17. Microgrid overview display

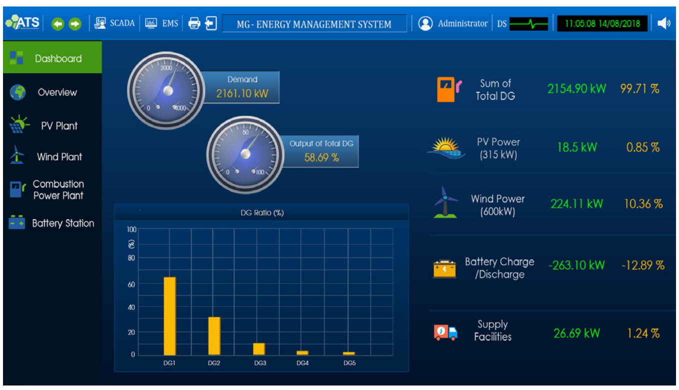


Figure 16. Microgrid system dashboard

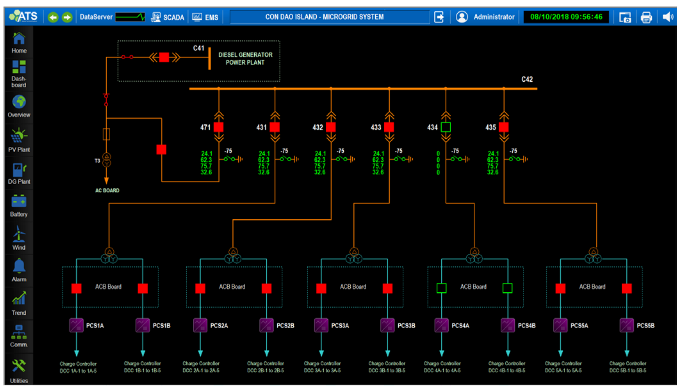


Figure 18. Microgrid system single line diagram

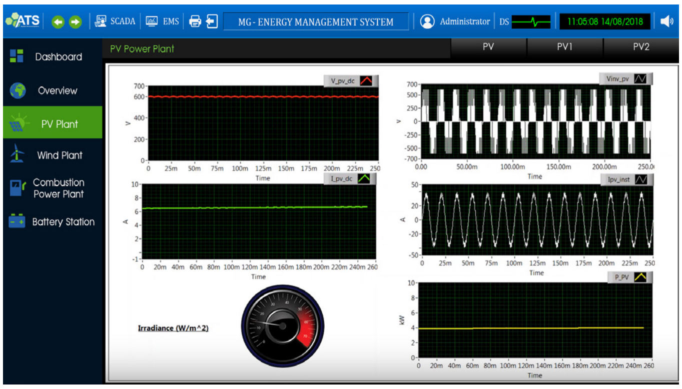


Figure 19. PV Plant overview

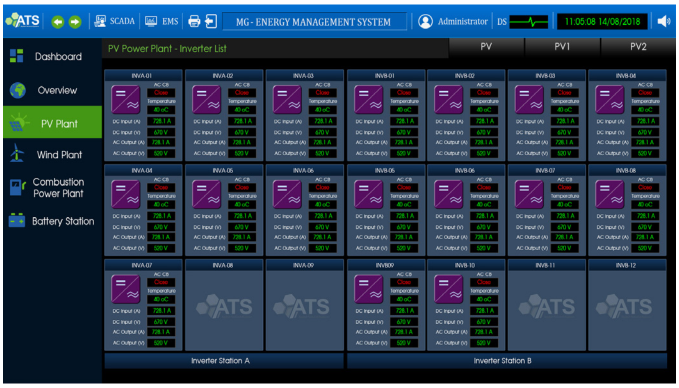


Figure 20. PCSs monitoring display

Figure 21. Specific Inverter unit

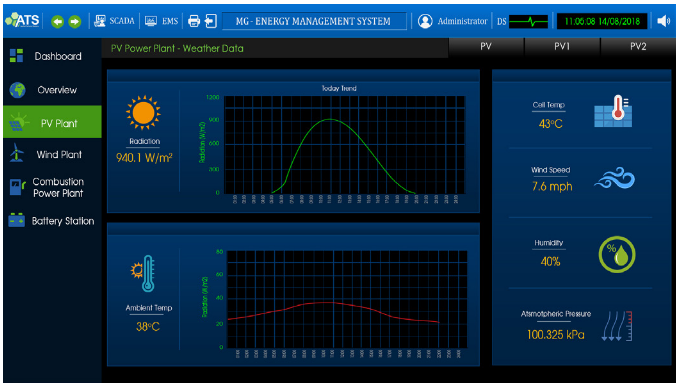


Figure 22. Weather data display

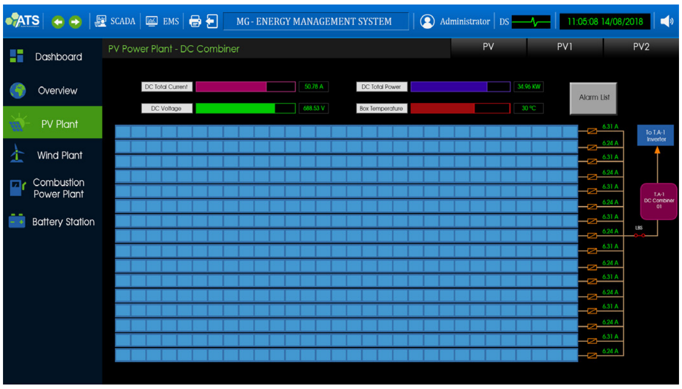


Figure 23. PV Combiners monitoring

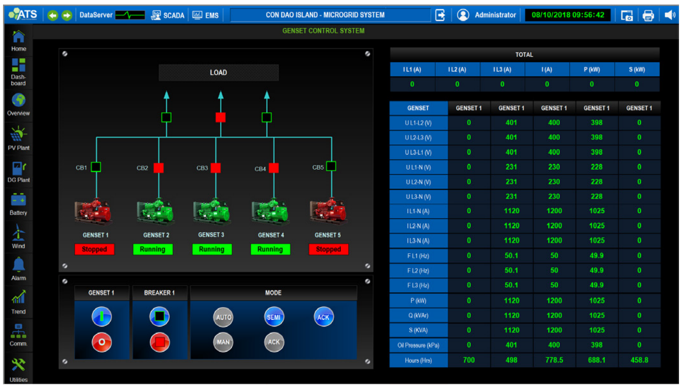


Figure 24. Diesel generator overview

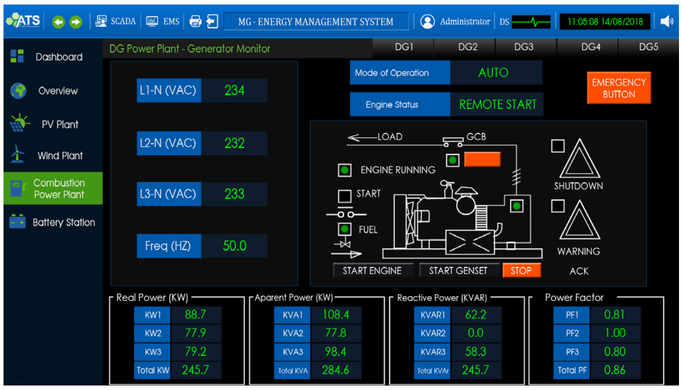


Figure 25. Specific diesel generator monitoring

Figure 26. Battery management system

B. Technical Highlights

(3) Supervisory control

The supervisory control commands shall be enterable from the Operator's request, via tabular and graphic displays, and sent to the controllers/data acquisition devices/relays 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.

a) Supported control types:

- Set point control.
- Device and function control
- Open/Close control.
- Forced operation interlocks condition verification.

b) Device control sequence

The Device Control Sequence capability shall permit scheduling multiple control commands for being automatically execution in a predefined sequence and shall be used for:

- Closing and opening breakers and disconnect switches to isolate and recovery the fault point.
- Automatic start/stop of diesel generator, floating solar and BESS in difference operation condition
- Suspending the execution of a command until the Operator sends the "continue" command
- Conditionally checking before execution

(4) Alarm processing

An event is defined as any change in the Microgrid system. 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.

a) Events with Alarms

The events with alarms are:

- Any unexpected status change of an entry
- Any control point change request or indication that does not result in a change of the associated input (status) within a determined period of time.
- Any analog input that violates one of the alarm limits.
- A device does not feedback correctly to a predefined number of requests.
- The status of equipment has changed without having been previously scheduled and/or requested by the Operator.
- Protection relay operation event

b) Alarm classes and conditions

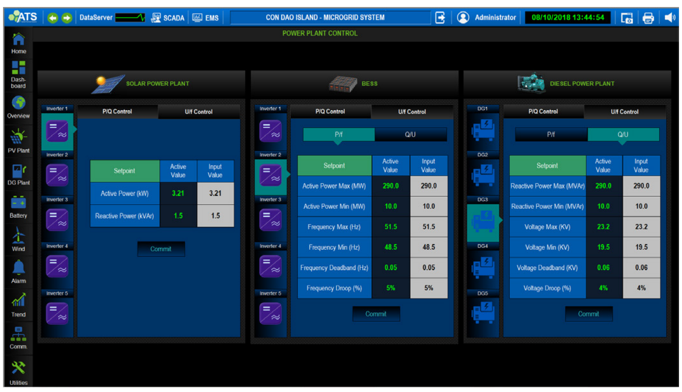


Figure 27. User control interface of distributed generation

The Microgrid control system shall differentiate between critical and non-critical alarms. The Operator shall have the ability to assign critical alarms or non-critical alarms to any input or device.

c) Alarm presentation

The following information shall be included for each alarm:

- Date and Time
- Alarm Group
- Element Identifier (alarm description)
- A brief description of the alarm condition (value, limit, type)

(5) Trending

The system can generate real-time and historical trends for the measurements: Currents (A), Apparent Power (kVA), Active Power (kW), Reactive Power (kVAr), Power Factor (PF), Frequency (Hz), Weather data (irradiance, temperature...) and other parameters.

(6) Tagging

Tagging of controllable devices such as charger, battery system, PCS, transformer, diesel generator and switchgears (circuit breaker, disconnector switch, MV feeder) for maintenance, hot line work... will be accomplished by using as one condition input of interlocking validations process for device/function control from the Microgrid control system. The Tagging function also allows the user to enter the following information:

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

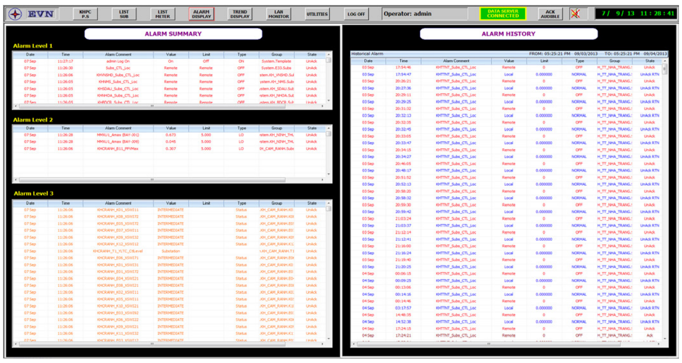


Figure 28. Alarm presentation Window

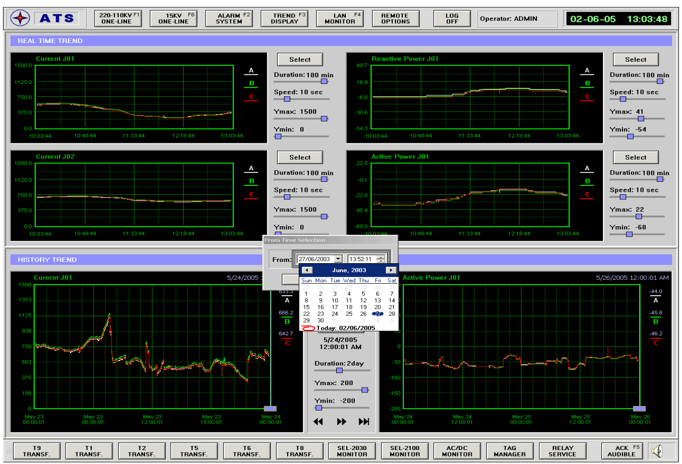


Figure 29. Substation operation trending

3.2.5. Historical Information System (HIS)

The Smart Historical Information System (SmartHIS) is the historical repository of all the information related to the Microgrid system which is time-series generated under normal operating conditions and/or during disturbances. The SmartHIS implementation will be predicated on the client-server architecture to collect, process, store, manage and retrieve data.

With SmartHIS the operators can store and maintain real-time data from any system point. The data will be stored in its exact resolution for a long period of time.

Multiple access security levels will be provided with firewalls, users ID and passwords. It must come with proxy server and IP masking capability to prevent unauthorized IP access to the server. Security for data access and point configuration is defined for read only; write only, both or none.

(1) Benefit

- 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: In scenarios where downtime is unacceptable, 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: High resiliency translates into fewer resources needed to manage outages. Fast and easy scaling using commodity hardware reduces the operational and hardware costs of scaling up or down.
- Improved business decisions: customers can 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

(2) HIS applications

a)Report

Reports can be built using Data Link tool (an add-in for Microsoft Excel). This add-in can allow data to be retrieved directly from within the spreadsheet program. User can create complex reports and graphs using current or historical data from the HIS.

b) Web-based monitoring subsystem

The Microgrid control system supports to display data at utility office for remote monitoring. It is able to display in web service or mobile application with integration open source web server.

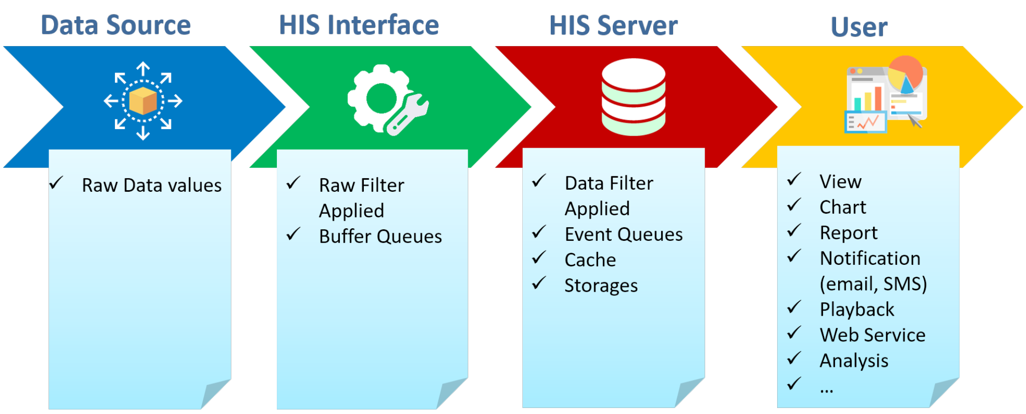


Figure 30. SmartHIS system overview

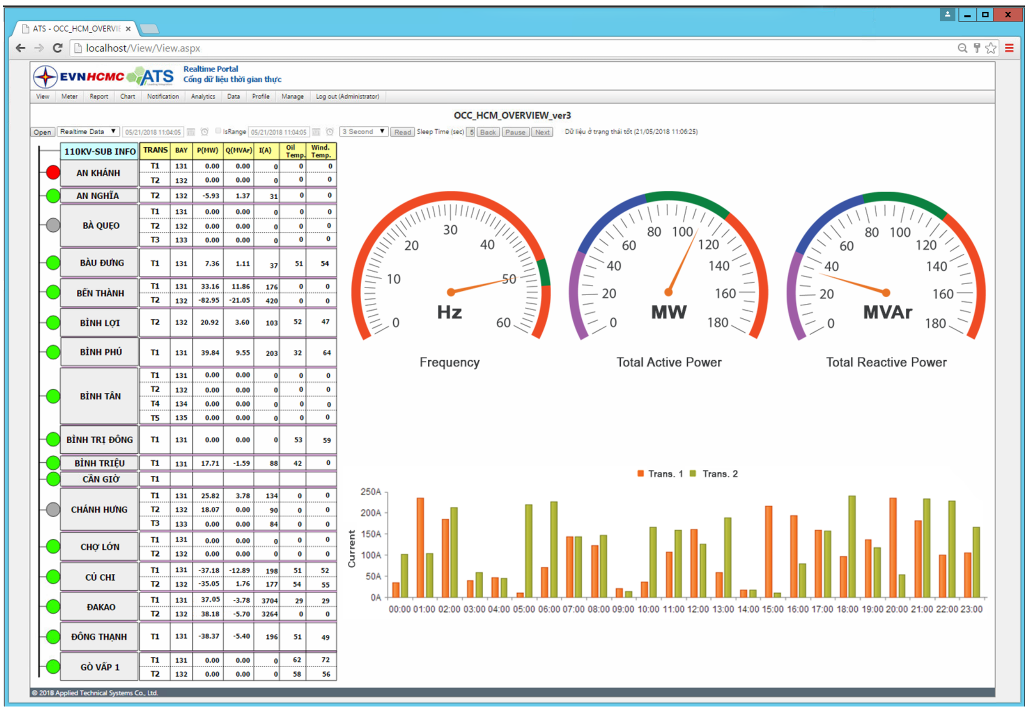


Figure 31. Real-time and Historical Data presented on Web

B. Technical Highlights

3.2.6. Energy management system (EMS)

Microgrid-EMS system maximizes the user of RE by forecasting its fluctuations and optimizing the multiple resources, while ensuring the power stability.

EMS in power systems looks at processes ranging from minute to day/week/month:

- Long-term schedule: is performed from one day to one week/month with 30-minutes time resolution.
- Short-term schedule: is performed from few minutes to few hours with one minute time resolution

The main control functions of EMS include (Figure 30):

- Load Forecast
- RE Forecast.
- Unit Commitment function
- Economic Dispatch functions.

(1) Load forecast

Electricity demand forecasting is a central and integral process for planning periodical operations and facility expansion in the electricity sector.

We provide AI-powered SaaS Solutions. Our solution makes use of Machine Learning/AI and Deep Learning Model to provide Electricity demand forecasting for a multitude of applications.

We offer hour-ahead, day-ahead, week-ahead for Electricity demand in multiple level of locations. Application can run on cloud or standalone. We deliver power forecasts for several levels:

- Single location
- Areas
- Countries

We build platform on the cloud:

- Scale unlimited
- Working cross platforms
- Easily to export to API to integrate with other system

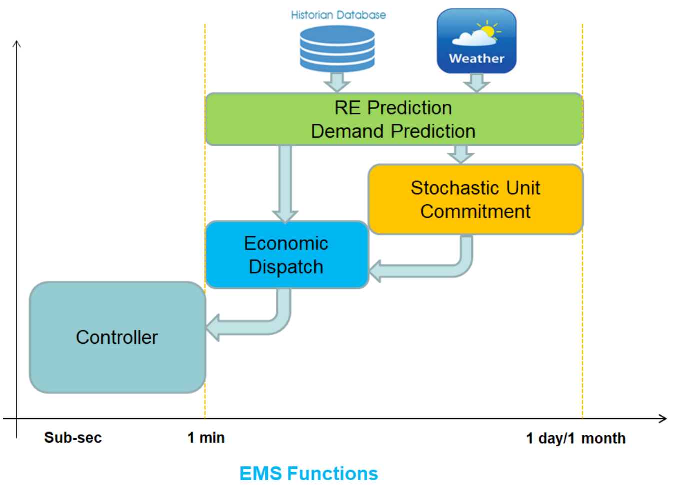


Figure 32. Microgrid energy management functions

- Can run multiple predictions simultaneously on demands
- Easy to custom model from a certain base model
- Easily to integrate many models to one platform

Our Solution offers features as:

- Hour-ahead forecasting
- Day-ahead forecasting Week-ahead forecasting
- Custom modeling and development
- Highest Accuracy
- Uncertainty bands
- Support multiple format types as xml, csv, sql or support multiple data sources included but not limit to mysql, cloud sql, bigquery, and more.

Highlight functions of load forecast:

- Create AI model with parameter (Figure 35)
- Custom model function (Figure 36)
- Report tool:
    - * Weather toolkit (Figure 37)
    - * Model comparison tool (Figure 38)
    - * Predict tool (Figure 39)
    - * Job monitor (Figure 40, 41)
    - * Add managed model (with NEP protocol) (Figure 42)

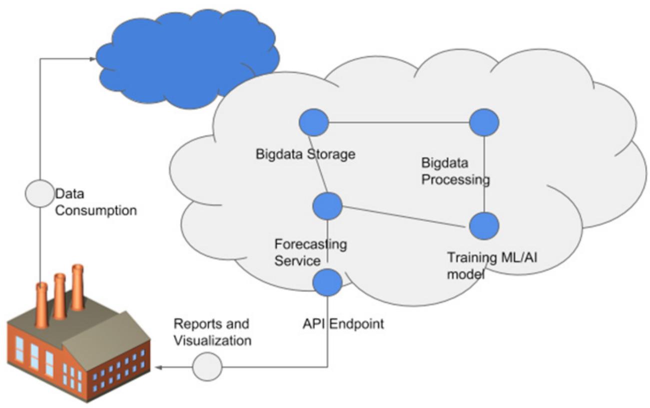


Figure 33. Overall system architecture of Load Forecast function

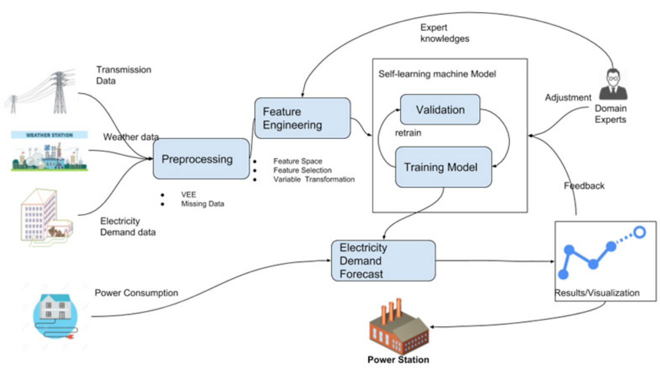


Figure 34. Electricity demand forecasting engine

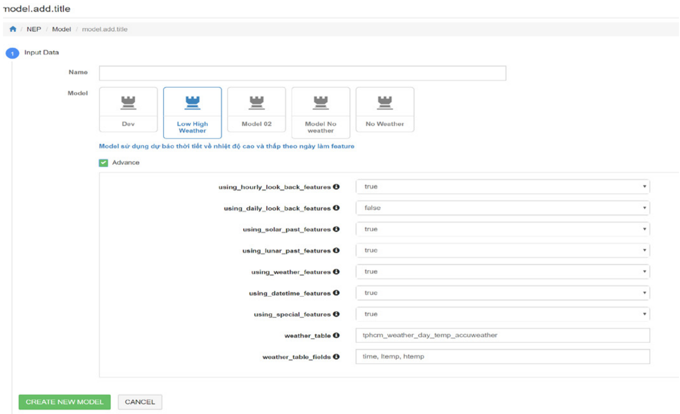


Figure 35. Electricity demand forecasting model selection

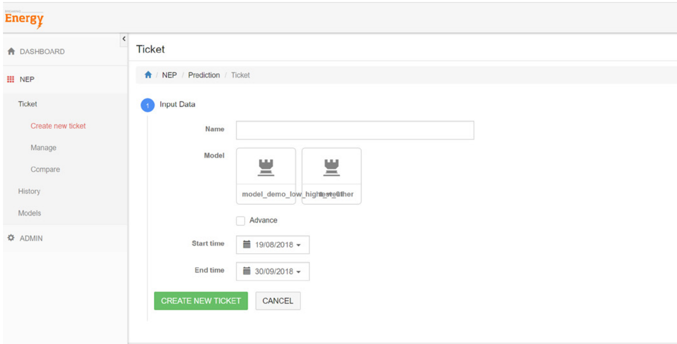


Figure 39. Prediction tool

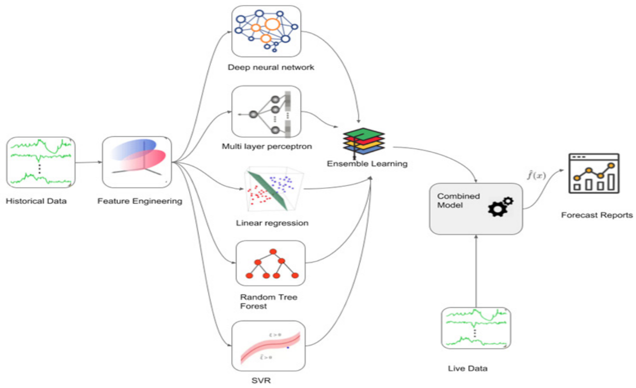


Figure 36. State-of-art ML algorithms integrated as default plugins. Supports unlimited plugins through NEP protocol

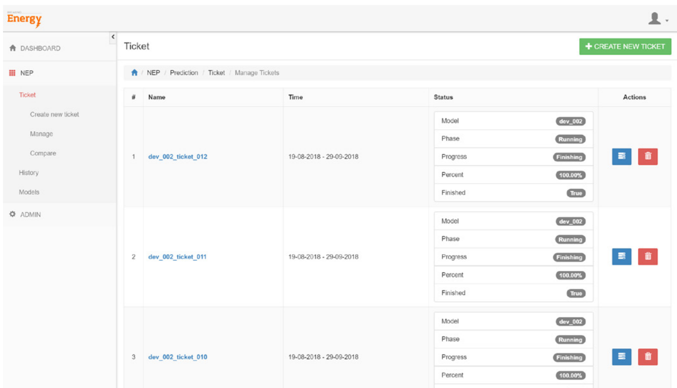


Figure 40. Running and monitor many predictions at the same times

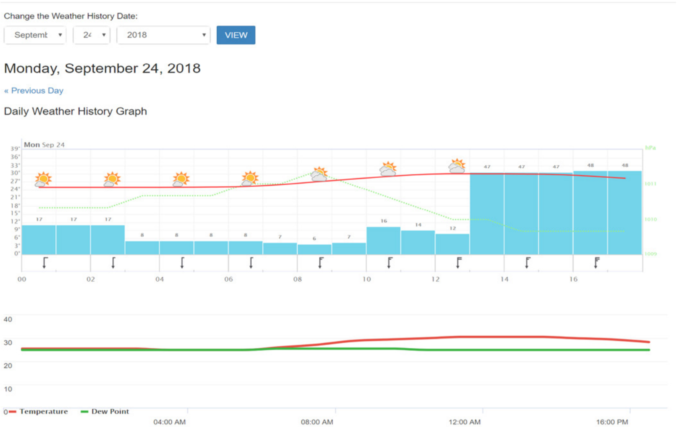


Figure 37. Weather dashboard

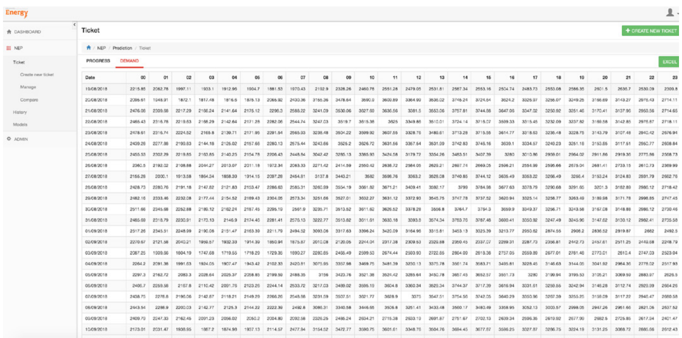


Figure 41. Editable result

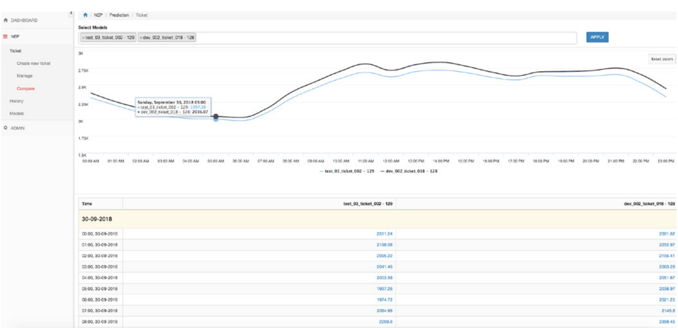


Figure 38. Model result compare tool

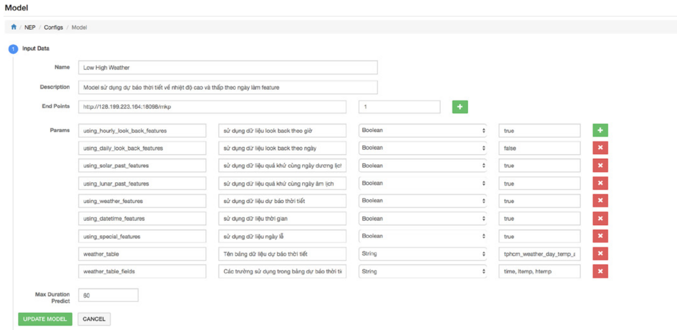


Figure 42. Integrate more model with NEP protocol

B. Technical Highlights

(2) Solar generation forecast

Accurate solar generation forecast is one of the key tools to mitigate challenges created by intermittent nature of energy generation from Renewable Energy systems.

We offer hour-ahead, day-ahead, week-ahead for individual PV power plants or distributed solar power systems.

We deliver power forecasts for several levels:

- Single solar parks
- Areas
- Countries

We provide AI-powered SaaS Solutions. Our Solution offers features as:

- Hour-ahead forecasting
- day-ahead forecasting
- Week-ahead forecasting
- Custom modeling and development
- Highest Accuracy
- Uncertainty bands
- Support multiple format types as xml, csv, sql or support multiple data sources included but not limit to mysql, cloud sql, bigquery, and more.
- SCADA Interfaces

Our System includes two key components:

- Offline Training:
    * Use multiple ML/AI models for PV power dynamics modeling and Pattern Discovery method.
    * Methods used include artificial neural networks, regression models, autoregressive models, support vector machines, and Markov chains, as well as composite methods, such as using genetic algorithms to optimize a neural network.
- Online Forecasting:
    * Use temperature, solar irradiance and history measured PV power with ML/AI model to forecast PV power at time (t + k)

(3) Stochastic Unit Commitment

The Stochastic Unit Commitment is performed from one day to one month ahead providing: the start-up and shut-down schedule for each generation, and allocate the total power demand to the available generation units in such a way that the overall power system costs is minimized. Due to the stochastic nature of the renewable resources such as solar and wind, the mismatch in forecast and realized power may result in extra operating costs for committing costly reserve units or penalty cost for curtailing demand. To address these problems, the stochastic model of renewable energy should be incorporated into the Unit Commitment.

The main model features can be summarized as follows:

- Monthly/Weekly/Daily schedule
- Uncertainty in renewable resource data
- Battery operation cost model
- Minimum and maximum power for each unit
- Power plant ramping limits
- Minimum up/down times
- Load Shedding
- Start-up and no-load costs
- Constraints on the targets for CO2 emissions

The goal of the Stochastic Unit Commitment problem to minimize the expected operation cost of a Microgrid over a time horizon.

Results of the calculation are:

- Committed status of each diesel generation in each period
- Power output of each diesel generation, in each period, scenario
- Power charge/discharge of each battery, in each period, scenario
- SOC status of each battery in each period, scenario
- Power purchases from main grid in each period, scenario
- Power shed in each period, scenario
- Total cost of the Microgrid in each period, scenario
- Total cost of the Microgrid over time horizon
- Total expected cost of the Microgrid over time horizon

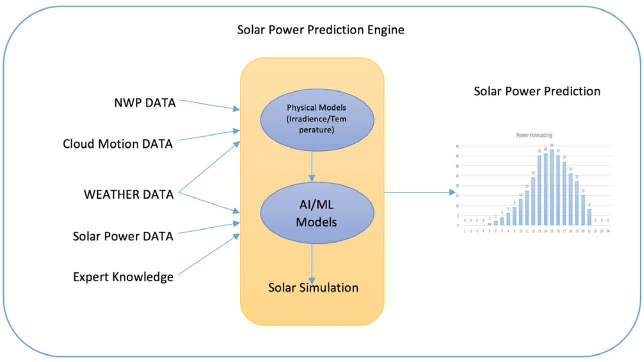


Figure 43. Solar generation forecast engine

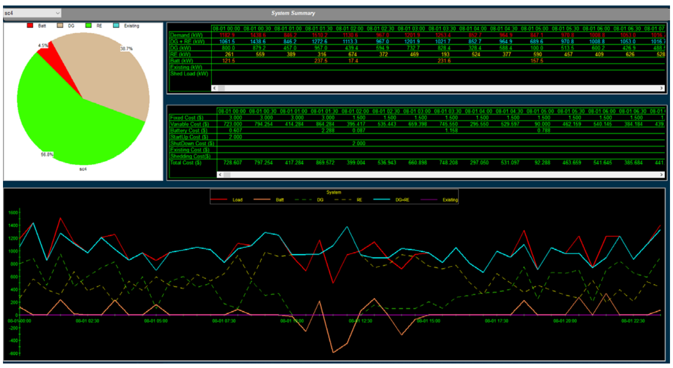


Figure 44. Stochastic Unit Commitment results

(4) Economic dispatch

Economic Dispatch used the load and renewable from forecasting module, and the committed status of diesel generation from Unit Commitment module, is performed from few minutes to few hours in advance to economically allocate the demand to the on-line units while considering all unit and system constraints.

Every minute, Economic Dispatch is performed with initial is the real-time values of the system (power out of diesel generations, power charge/discharge of batteries, SOC status of batteries), demand supply imbalance is judged: DG output, storage battery charging/discharging, load control are implemented.

The main model features can be summarized as follows:

- 1 minute time resolution
- Battery operation cost model
- Minimum and maximum power for each unit
- Power plant ramping limits
- Load Shedding
- Constraints on the targets for CO2 emissions

The goal of the Economic Dispatch problem to minimize the operation cost of a Microgrid over a time horizon.

Results of the calculation are:

- Power output of each diesel generation, in each period
- Power charge/discharge of each battery, in each period
- SOC status of each battery in each period
- Power purchases from main grid in each period
- Power shed in each period
- Total cost of the Microgrid in each period
- Total cost of the Microgrid over time horizon
- Total expected cost of the Microgrid over time horizon

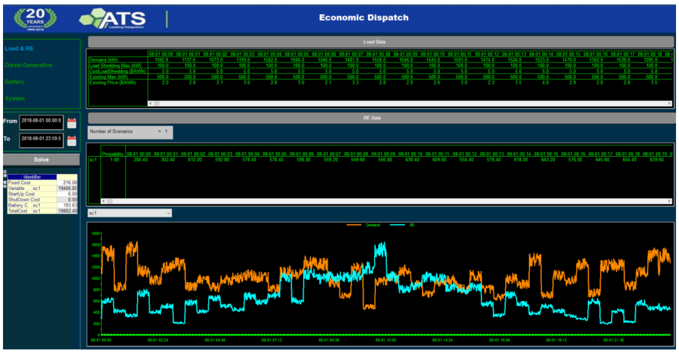


Figure 45. Economic dispatch Dashboard

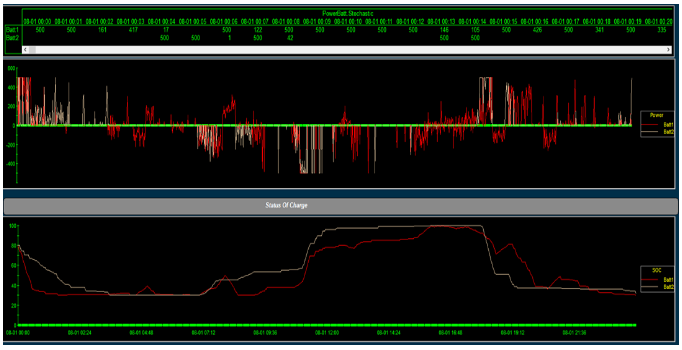


Figure 47. Battey results

Figure 46. Diesel generation results

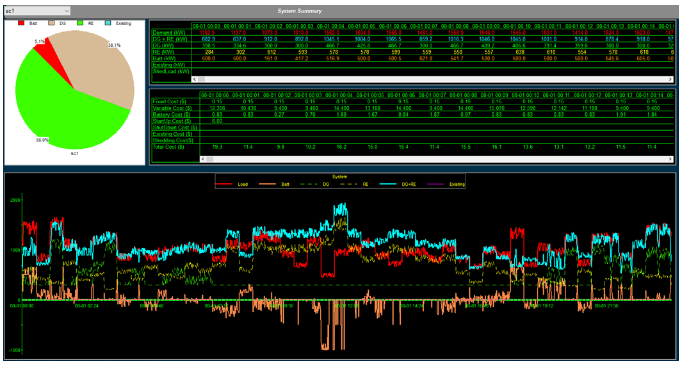


Figure 48. Economic dispatch results

B. Technical Highlights

3.2.7. Fault record collection and After-fault analysis (FR)

Features of fault information management and analysis:

- Automatically collect, archive and display Sequence of Events (SOEs) of protection relays and BCUs
- Accurately time-stamp SOE, FR, and DDR data, which can then be easily time-synchronized by the user
- Fully meet with requirements to facilitate the analysis of disturbances on power system or both generation and transmission & distribution assets
- Provides High-Accuracy Time-Stamping
- Provides Oscillography and Event Reporting
- Automatically collect, archive and visualize for fault records and disturbance records of protection relays & fault recorders.
- A compact, economical system that includes the needed equipment to fully meet all of customer requirements; these systems are designed to operate in harsh substation environments
- Provide system-wide detail records and analysis tools, such as: searching and filtering for data analysis
- Manage more than 2000 IEDs in hierarchy
- Compliant with International standards: IEC, NERC, IEEE
- Compatible with Fault record and Disturbance record protocols including: IEC61850-8-1 File Services, FTP, Telnet, proprietary protocol, etc.
- Support latest version of COMTRADE file format
- Support IEDs from various manufacturers: SEL, Alstom, GE, Siemens, IngeTeam, Nari, Toshiba,etc.

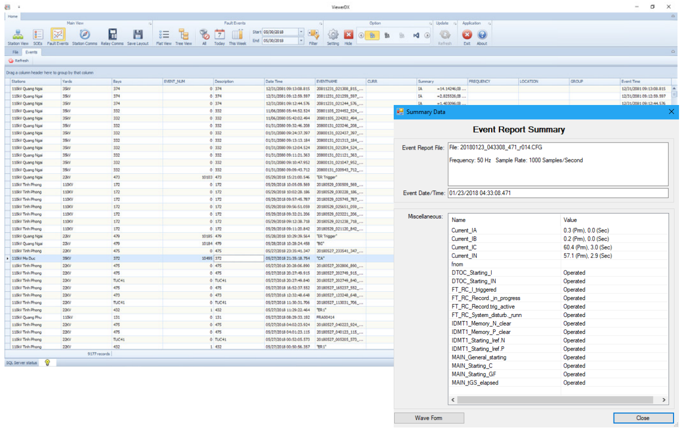


Figure 51. Fault Events Screen

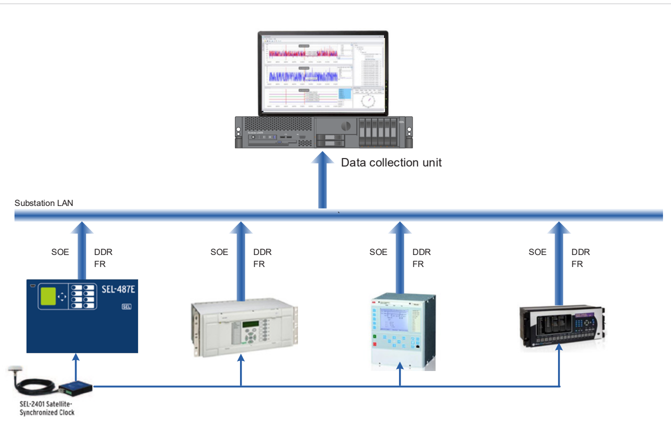


Figure 49. Architecture of fault record collection and After-fault analysis

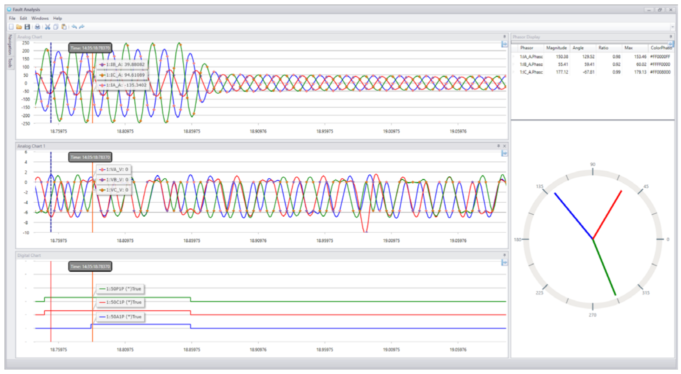


Figure 52. Fault Analysis

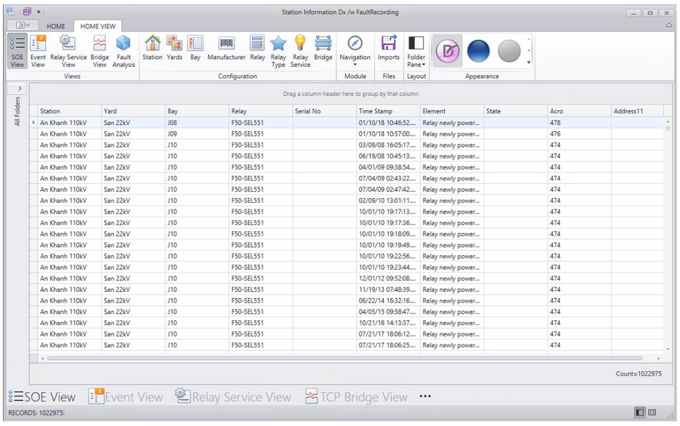
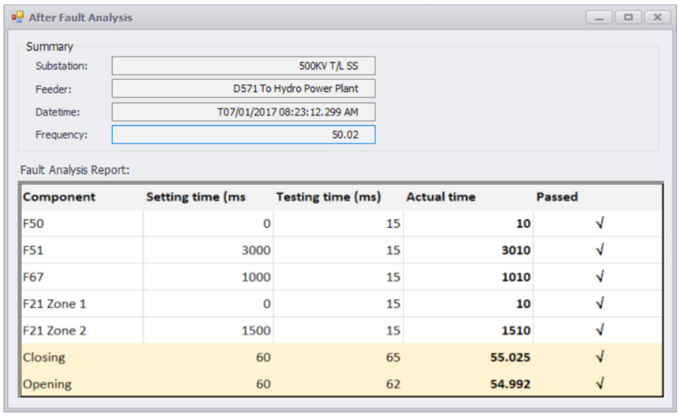


Figure 50. Configuration GUI


After Fault Analysis

Summary

Substation: 500KV T/L SS

Feeder: D571 To Hydro Power Plant

Datetime: T07/01/2017 08:23:12.299 AM

Frequency: 50.02

Fault Analysis Report:

Component	Setting time (ms	Testing time (ms)	Actual time	Passed
F50	0	15	10	√
F51	3000	15	3010	√
F67	1000	15	1010	√
F21 Zone 1	0	15	10	√
F21 Zone 2	1500	15	1510	√
Closing	60	65	55.025	√
Opening	60	62	54.992	√

Figure 53. After-Fault summary report

4. COMMUNICATION AND CYBER SECURITY

4.1. Communication

The communication system allows to establishing the connection between Microgrid control system, floating solar, BESS and Utility diesel generator via managed Ethernet switches, firewalls and optical fiber cable with required lengths.

The basic goal of any Microgrid control system is to communicate data from the field component to the operator/dispatcher/manager at the control building in a timely and accurate fashion. The communications media does not add any functionality to the basic goal, but rather should be completely transparent to the operator. The less the communication architecture is noticed, the better. Careful analysis of the communication requirements and availability of communications infrastructure indicate that the most economical and functional architecture will Optical cable system.

The communication network of the Microgrid control system will be based on three separate parts:

- Links between the Microgrid control system and IEDs (Data acquisition devices, controller, protection relay, measurement devices…) at floating solar system and BESS. These links will be configured with multi-mode optical fiber ring network structure.
- Links between the Microgrid control system and IEDs (Data acquisition devices, controller, protection relay, measurement devices…) at the Utility diesel generators. The system will be equipped with dual Single-mode fiber optic channels from the control building to the Utility diesel generators; ensuring failure of one channel does not affect the operation of the system.
- Links between the Microgrid control system and measurement device at load points; between the Microgrid control system and remote monitoring system. These links are based on secure VPN connection through Internet/3G/GPRS network.

To build the communication network, the optical cables and the optical mainframe transmission will be installed in each data collection point (floating solar and BESS, diesel generator) and in the Microgrid control system. All Ethernet switches are equipped fiber optic ports.

The communication network architecture of the system is shown in the following figure:

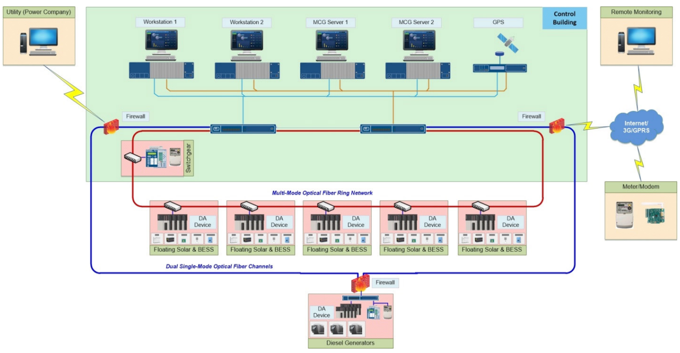


Figure 54. Microgrid control system communication network

4.2. Cyber Security

4.2.1. Cyber security at system level

Interactions between the Microgrid control system, corporate networks and the outside world are usually handled at the system level, which means that ensuring a high level of security at the boundary is vital to the security of the system itself. All communication from the outside world to the Microgrid control system must, for instance, be protected by using a firewall and/or VPN-enabled communication.

4.2.2. Cyber security features at local are level

Verified antivirus software is supported to protect the system computers from attacks and viruses. The cyber security can be for instance further improved by limiting the use of removable media in the system computers. Additionally, we have built security mechanisms such as advanced account management and detailed security audit trails into local area network level supporting many security features. This allows our customers to easily address NERC CIP requirements and maintain compliance according to the standards and beyond.

4.2.3. Secured remote access-Smart Secured VPN Gateway solution

ATS provides Smart Secured VPN Gateway solution for Secured remote access, this solution allows secure access to corporate resources for upgrade and maintenance works. By created Remote Access VPN channel, remote end can establish an encrypted tunnel across the Internet. Solution allows organizations to reduce the cost and securely extend the reach of their networks to anyone, anyplace, anytime and on any device. The key features of solution as follow:

- Provide secure communication with access rights tailored to individuals
- Enhance productivity by extending corporate network and applications
- Reduce communications costs
- Reduce the time for upgrade and maintenance work

Figure 55. Smart Secured VPN Gateway Device

Head Office

Suite #604 - VNA8 Building,
8 Tran Hung Dao Str., Hanoi, Vietnam
T. +84-24-3825 1072
F. +84-24-3825 8037
W. www.ats.com.vn
E. ecommerce@ats.com.vn

Factory

Lot No. A2CN6,
Tu Liem Industrial Zone,
Hanoi, Vietnam
T. +84-24-3780 5053
F. +84-24-3780 5060

HCMC Office

13-15 Nguyen The Loc Street
Ho Chi Minh City, Vietnam
T. +84-28-3948 3548
F. +84-28-3948 3549