Chapter 11
Energy Management of the Grid-Connected PV Array

Florentina Magda Enescu, Nicu Bizon and Ioan Cristian Hoarca

Abstract Solar energy has an important place in the global energy context, this leading to an intense concern in the unconventional energies field. Even if the earth receives only a small fraction of the solar radiation emitted by the Sun (because the radiation suffers the phenomena of absorption and diffusion in the atmosphere) the solar energy has become one of the most important renewable sources. Solar energy can be captured and converted into electrical energy by using the photovoltaic technologies and/or thermal energy, through the use of various types of solar panels heat shields. In this context, the field of producing electricity with photovoltaic panels is approached in this chapter. The photovoltaic panels are devices that convert the solar energy into electrical energy. Depending on weather conditions, the generated renewable energy oscillates, being required an energy storage system to store the excess energy or to discharge energy during the lack of energy. The best solution applied for short-term storage of energy is the battery. On the other hand, the photovoltaic systems only use a portion of the solar radiation and of certain wavelengths, in order to produce electrical energy. The rest of the energy received at the surface is converted into heat, leading to a rise in temperature of the cells components and reduction in yield. In conclusion, increasing productivity and energy efficiency of these facilities involves both the efficiency of their operation in the electric field and the study of the thermal phenomena that take place. In order to ensure a high degree of felicity of the electrical energy management at the level of a microgrid type user, it is necessary to know the energy flows, the structure of the distribution network, and identification of the technical solutions depending on the field. In this chapter, the

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main functional parameters of the system considered will be analyzed, the quality parameters at the level of the electricity system of the user will be estimated, and the operating parameters of the system considered will be also analyzed. The objective of the chapter is to propose a technical solution to improve the efficiency of a photovoltaic power plant within an area of seventy hectares through control, surveillance, metering and monitoring of the system from distance based on Supervisory Control and Data Acquisition (SCADA) system. The photovoltaic power plant used to carry out the experiments is located in Romania. The location of the photovoltaic park is in a plain area where solar radiation is higher (over 1450 kWh/m^2 year, in particular in the summer). With the help of the SCADA system, the energy management of the photovoltaic park can be achieved for: a short period (one day) or for a longer period (a week). The SCADA system offers information about: total energy delivered (kWh), day energy delivered (kWh), active inverter power (kW), percent of availability for photovoltaic power plant, weather info (ambient temperature, plane radiation etc.), hourly graphs about plant production, alarms, current strings, energy meter (exported active-reactive power, imported active-reactive power), data about the weather station, inverter graphs, state of power transformers, breaker state, earthing state, month radiation, month exported active energy, currents variation (I_a, I_b, I_c), leakage current variation (I_g), and voltage variation (V_a, V_b, V_c). The data stored by the system will allow the user to receive current information, but also these data can be compared with the data stored in the same period of the past years, in order to establish the productive efficiency of the photovoltaic power plant.

Keywords Alarms · Control · Energy management · Energy meter · Metering · Monitoring · Photovoltaic power plant · SCADA · Surveillance

11.1   Introduction

The sun is the most important source of energy for all natural processes on Earth. It is a source of energy vital for the survival of all species of plants and animals and supplies power for many critical processes such as photosynthesis.

The production of energy using solar radiation can be made using direct or indirect methods. The indirect form of solar energy is biological material from the past which has been converted into fossil fuels (oil or coal), and the wind energy, hydro and bioenergy. The photovoltaic installations generate a form of direct solar energy.

11.2   SCADA Microgrid Architecture for Photovoltaic Power Plant Studied

Key parts of a photovoltaic system for the generation of electricity are:

– The photovoltaic cells and modules for capturing solar energy;
– An inverter to convert the direct current (DC) in alternating current (AC);

– A set of batteries and charging controller for autonomous systems;
– The other components of the system.

All the components of the system, with the exception of the photovoltaic modules, are called components of the Balance-of-System (BOS).

Measurements have been carried out in a photovoltaic park situated in the southern part of Romania.

Modules are connected in series (called string) to obtain necessary voltage. Enumerated strings are connected in parallel to obtain required current of the system (Fig. 11.1).

The PV modules can generate power between 25 Wp up to 350 Wp depending on the size of PV panel. The small power modules are usually used in standalone applications, where usually required power is not so big. Modules can be dimensioned for quick installation in any location (Fig. 11.2). The module manufacturers usually provide an output power of 70% from the nominal power and after 25 years of use [1–3].

11.2.1 SCADA System-Presentation

Supervisory Control and Data Acquisition (SCADA) are the management and supervisory components system [4–7].

This system is composed of:

– The center of computing equipment which is considered as a Master User Terminal (MUT);
– Units located in the field (remote terminal) for acquisition and adjustment (RTU);
– Software for monitoring, control, remote control and adjustment of the equipment.
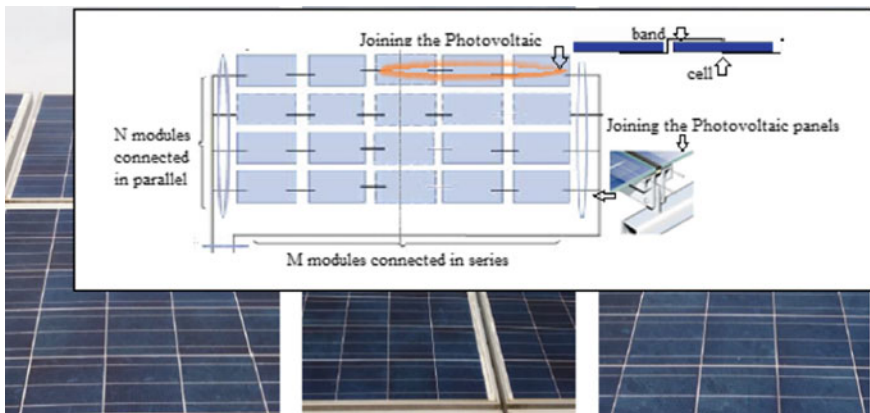

Fig. 11.1 Modules checks in the park of the PV analyzed

Fig. 11.2 Cables arranged on the structure

Fig. 11.3 IBM compatible
PC computer

The calculation is intended to allow the process and the execution of the application program which will allow monitoring and implementation of the energy balance sheets.

In this respect, an IBM compatible PC computer (Fig. 11.3) is used, which must to have the following minimal features:

– Intel Core 2 Duo Processor: 2.13 GHz;
– Hard disk—1 × 160 GB SATA drives;
– RAM—1 GB;
– 2 free slots on the standard PCI bus;
– DVD—R/W;
– 10/100 Fast Ethernet network interface;

– Audio—on board;
– Power management;
– Graphical User Interface—least 256 MB RAM;
– TFT color Monitor—22″;
– Mouse, Keyboard;
– A Windows Operating System;
– Uninterruptible Power Supply 220 V/50 Hz;
– Putter: 1000 VA.

11.2.1.1 The Switch Cabinet with Programmable Automation Automatically

The cabinet of automation is structured on the programmable resources of the automatics Simatic S Series 7 200 [4].

The process automatically interfaces with Siemens programmable is composed of:

1. Uch block CPU 224 XP AC/DC/Relay (component 6ES7 224-2BD23-0XB0):

    – The maximum expansion modules: 7;
    – Number of communication interfaces RS 485: 2;
    – Numeric inputs: 14 galvanic isolations by optocoupler;
    – Numeric outputs: 10 with relay;
    – The maximum number of I/O Extension numeric controlled: 256 256 entries and exits numerics;
    – The maximum number of analog I/O:16-16 analog inputs and outputs;
    – The maximum number of central unit on RS 485 Serial Bus: 32;
    – Power: 220 V/50 Hz through the filter.

2. The Profibus communication protocol (Code 6ES7 277-022-0 said AA0)

    – Industry Standard serial port RS 485;
    – The Profibus communication protocols: DP (slave); MPI (slave);
    – The Communication Speed: 12 Mbit/s with automatic detection of the transmission speed;
    – The address of the programmable station: 0–99; (Fig. 11.4).

3. Block Extension analog EM231 you 4 × 12 Bit (Code 6ES7 231-0HC20-0XA0):

    – Number of analogue channels: 8;
    – Type entry: Current unipolar/unified selectable voltage.

4. A display device type Touch Panel TP 177A:

    – The touch control panel;
    – 16 shades of gray, the protocol dialog: PPI, MPI, Profibus.

Fig. 11.4 Communication from PV ST1
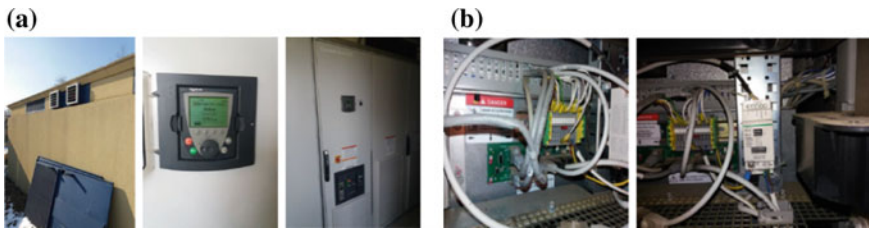
Fig. 11.5 **a** Inverter checks, **b** the inverter communication system

5. The control block/pump drive:

   – The safety switch (breaker) Code 3CC10 11-1JA1;
   – Soft starter type 3RW 30-16/380 VAC—3RW30 16-1CB14;
   – Fuses 3NA 3807-0; support fuse 3NP 40-10.

11.2.1.2 The Closet of the Electronic Regulators

In the closet are installed:

– The regulator TriStar is an all-in-one;
– Sources photovoltaic regulators;
– Accumulator battery;
– Inverter type XTH 6000-48 system: (Fig. 11.5a);

– The task of unloading (diversion);
– Connecting Block photovoltaic sources (Fig. 11.5b).

11.2.2 The SCADA System Functions

The system drop is implemented for the purpose of monitoring the main parameters of the energy sector, the establishment of arrangements for operation, the acquisition of data and storing them in the database, processing on the data bases for the drawing up of energy balances and the determination of the efficiency of the generation [3, 4, 7].

The main functions are:

- Achievement of the console operator—dispatcher man—machine interface (HMI);
- Tracking System layout of detail at each point of monitoring and other equipment integrated into the fall;
- Sending commands to the equipment performance;
- Measurement of analogue and numerical magnitudes continuously and storage in the data bases of measurements;
- View analog and numerical data from each measuring point on the general or his own screen automation cabinet;
- Demonstration in real time the occurrence of critical events of alarm or hazard warning lights and visual and audible alert the operator to operator interfaces;
- Configuration of the generating equipment; set the parameters for the transducers; the allocation of signals; defining the damage, filtering information and generate a report of events;
- Saving data acquired and the specific information events in relational database;
- Tracking status for the operation of the energy sources and protections in real time;
- Perform the correlation between parameters and processing on the quantities purchased;
- Display of reports and tables relating to the operation of the system and equipment for the generation technology.

11.2.2.1 The Structure of the SCADA Informatics Systems

The computer system uses the standard procedures by defining a rigorous task for the used and developed documents and detailed rules for the testing and validation stages. Application software packages are developed under development environments as appropriate for the type of application by using the facilities given by the specific functions developed in the language of high level, the modules provided by the libraries environment for development, the possibilities for the generation, and the management of databases.

It will ensure that the computer after the implementation of the Decision Support System (DSS) components system must comply with the following essential requirements of the application [3, 8]:

– Compliance with the response times, required by technological processes;
– The concomitance use (facilities for multiple users at the same time, the execution of several independent tasks for the same user);
– The efficiency of the system in the optimum use of the resources;
– Sharing and protection, prevent unauthorized access and accidental or intentional alteration of information;
– Reliability and availability of the system;
– Commonality, flexibility, and expandability;
– Modularity horizontally and vertically;
– The transparency and visibility for the purposes of the efficient use and performance;
– Flexible structure, so as to permit the integration into the system of databases used for storing the historical data [6, 7].

11.2.2.2 Decision Support System (DSS)

Decision support system, being integrated into the main system of supervision and control at the level of the human operator, is one liabilities for a single human decident (does not have effective role in the process control; see F.G. Filip in presentation about decision support systems, 2004).

Its construction consists of a series of activities which have as their purpose the obtaining of stable, usable variants of the decision support system.

Further improvement is provided by its capacity of supervised learning [4, 5, 9–14]. The decision system support is detailed by stages of development in Fig. 11.6.

11.2.2.3 The Analysis of the System

It involves the collection and processing of data. It includes:

– The inventory and the in-depth study of the decision-making statements for which it is intended to provide a computer;
– The identification of each operator who will become a user of the system;
– Registry of items of context that the restrictions placed at the top level in the development of the transmission infrastructure/decisions, the computerized existence;
– The assessment of the results of initiatives prior to the introduction of the decision support system.
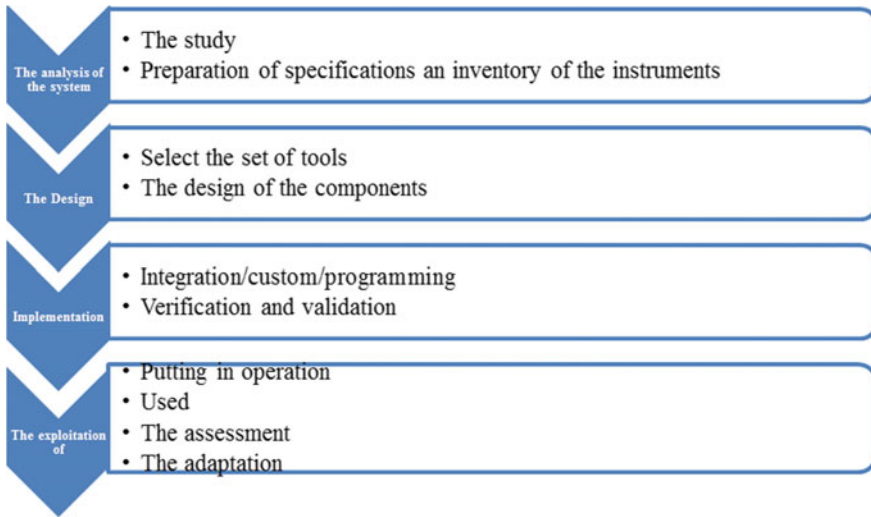
- The study
- Preparation of specifications an inventory of the instruments

The analysis of the system

- Select the set of tools
- The design of the components

The Design

- Integration/custom/programming
- Verification and validation

Implementation

- Putting in operation
- Used
- The assessment
- The adaptation

The exploitation of

Fig. 11.6 The stages of development of the decisional system support

11.2.2.4 Technical Design

At this stage, the system and its components is actually designed as a whole from the point of view of information technology, the content of the specification being already transposed into a project of execution. The modern design is based on modern and modular information tools, which provides high flexibility in designing of the system. The design process consists in activities to establish of the structure of the DSS, define the technology of each component of the system, and set ways of integration with other parts of the main information system (note that the DSS is a software module embedded in the system of supervision and control at the level of the dispatcher).

11.2.2.5 Implementation

It is the stage at which will be carried out of the DSS software module in accordance with the technical project. It is the implementation and testing of the model of the original DDS. The test involves checking the solutions generated by the DSS with an indication that the system has the ability to learn while supervised. The activities of the verification and validation are intended to determine the extent to which the implementation has led to the achievement of an efficient system. Checking the aims to the appreciation of the correctness of the transposition of the systems of the project Validation is intended to determine the extent to which they are satisfied with the detailed specifications regarding the functions carried out by the DSS.

11.2.2.6 The Exploitation and Development

Operation consists in the putting into service of the system validated and constant analysis by dispatcher performance decisions generated by the DSS. Supervised learning capability (storage of corrections introduced by the dispatcher) allows the decision support system to evolve [4, 6].

11.2.2.7 The Implementation of an Embedded System for Decision Support at the Level of the SCADA Application

Decision support system will be implemented at the level of the operator who will supervise the system energy efficiency through SCADA platform.

The practical implementation of the DSS will consists in adding additional functions of specific SCADA functions.

The operating strategy must help the human operator of the system to decide how many and which generators must be running, which controllable tasks to be connected and storage control energy. Selecting the best combination of operation for each application depends on several parameters: the load characteristics; the system configuration; requirements regarding the quality of energy.

The control strategy adopted should determine the best operating mode of the system.

It is influenced by multiple factors:

– Change in energy demand in time; the variation of power;
– The number of renewable energy generators;
– The uncertainty of power products from specific sources;
– The quality of the energy supplied (of the required quality—variation in frequency and voltage around the nominal value).

The quality of the power represents a main concern in electrical networks, especially in our days when the power converters producing harmonicas are most often encountered in all branches of industry and in the residential sector.

Improvement of the quality of the power will consist of the following:

– Compensation and voltage voids;
– Frequency Control;
– The control voltage;
– The phase unbalance compensation;
– Compensation harmonics.

Of these adjusting voltage and frequency are the most important aspects in the framework of the control system of a Micro MN (Network Micro).

In addition to these another very important aspect is to ensure continuity in the energy supply of consumers [5, 7, 15, 16].

11.3 Management Processes Through SCADA

Since 1980, the supervisory Control and data acquisition (SCADA) has been used as a computerized system for the collection and analysis of data in real time of the supply system [5, 6, 17, 18].

11.3.1 The Correlation Energy Resources on the Basis of Geographic Area

Choosing the location of a photovoltaic park is of great importance from the point of view of the effectiveness of the investment and the acceptability for the population.

Also, the cost of connection to the main power supply will be influenced by the position of the site in relation to the connection point.

On completion of the site the following general aspects:

– The characteristics of the solar radiation in the area (evaluate the solar potential);
– Graph of the temperatures in the area;
– Atmospheric moisture;
– The air density;
– Solar irradiation;
– Important weather phenomena;
– The presence of the chemical active substances;
– The presence of active mechanical particles;
– The possibility of the employment land (environmental impact).

11.3.2 Location of the Photovoltaic Panels

For the location of the solar sources knowledge of solar potential is required (the quantity of solar irradiation in that area).

The photovoltaic panels will be placed on a flat surface, free of mechanical shock. The surface occupied by a photovoltaic panel is proportional to its power.

Thus, photovoltaic panel of 80 W will occupy an area of $0.75456 \, m^2$ less than the area of $1,773 \, m^2$ needed for a 150 W photovoltaic panel.

For these reasons, the calculation of the available surface used to place the panels in relation to the energy production desired by the solar source needs to be analyzed during the farm design phase.

The photovoltaic panels must be placed in such a way as to be oriented toward the sun. As a rule, when it is necessary to power in the winter months when solar radiation is low, the tilt angle of the panel should be located toward the vertical position (approximately equal to the latitude plus 15°) to maximize exposure to sunlight.

The photovoltaic systems (PV) contain cells which convert the sun's energy into electricity. The light intensity determines the amount of electrical power generated by PV module.

11.3.3 Corrective Maintenance

For the photovoltaic park analyzed based on the results stored by SCADA, maintenance adjustments can be made as shown in the Table 11.1.

In Table 11.1 equipments used for corrective maintenance is described: inverter, SCADA, Diesel generator, air oven.

The following data are presented for equipment: failure of the equipments, repair explanation, failure data, response data, fixed data for repair, total time reparation, spares uses. Based on these technical dates, corrective maintenance is made [6, 8, 18–25].

Based on these data, the proposals for the pursuit of preventive maintenance are made in Table 11.2.

In Table 11.2 (preventive maintenance) the dates are fixed to verify the equipments, task description are set for every equipment, results and observation are also made.

11.3.3.1 Preventive Maintenance Works

1. Meteorological Stations—Cleaning of pyranometers and etalon PV sensor/weekly;
2. String and Combiner Boxes/monthly:

    – Visual inspections of string and combiner boxes,
    – External enclosure (No broken or scratched envelope),
    – Electrical boxes wear the proof integrity,
    – Checking doors properly opening and closing,
    – No rust on metallic parts,
    – Checking switchgears fuse bases, fuses, circuit-breakers and surge arrestors integrity and operating condition and calibration,
    – No dust, moisture, corrosion, etc.,
    – Checking correct switch opening and closing,
    – Checking correct execution and state of terminal screws,
    – Checking correct box labeling,
    – Verify electrical testing (open circuit voltage, ground continuity, switches, disconnects),
    – Checking tightening torques,
    – Visual inspections for every inside of combiner boxes and check the functionality of electronic modules (string monitoring);

Table 11.1 PV plant corrective maintenance—2017

PV plant corrective maintenance log

No.	Equipment	Failure	Repair explanation	Failure data (data hour)	Response data (data hour)	Fixed data (data hour)	Repair total time	Spares uses	Obs.
1	Inverter	AC Switch Response. Service Mode	Check the cables, power suply, AC switch	06.12.2017 11:21:00	06.12.2017 23:22:00	06.12.2017 12:58:00	1.62 h		The reinforcing mechanism was blocked
2	SCADA	Problems with the EDPR server	Verification of communication equipment. Reset server	13.12.2017 08:30:00	13.12.2017 09:00:00	13.12.2017 22:00:00	1 h		
3	Diesel generator	Failure to start the Diesel Generator	Checking automatic switching between AASS transformer and Auxiliary Diesel Generator	14.12.2017 10:30:00	14.12.2017 14:00:00 PM	14.12.2017 14:30:00 PM	0.5 h	Diesel fuel pump	
4	Air oven	Switch burn	Replace the switch from the air oven	15.12.2017 09:00:00	15.12.2017 21:05:00	15.12.2017 21:35:00	0.5 h		
5	SCADA	Problems with the EDPR server	Verification of communication equipment. Reset server	27.12.2017 11:30:00	27.12.2017 11:35:00	27.12.2017 12:15:00	0.67 h		

Table 11.2 PV plant preventive maintenance—2017

Ingeteam			PV plant preventive maintenance log		
No.	Date	Equipment	Task description	Status	Observations
1	04.12.2017	Transformation centers	Transformer isolation measurements. Operation checking of transformer protections. Checking tightness of connection at transformer	OK	TRAFO, MV Cubicles to PVST8, PVST9 and PVST10
2	05.12.2017	Transformation centers	Transformer isolation measurements. Operation checking of transformer protections. Checking tightness of connection at transformer	OK	TRAFO, MV Cubicles to PVST1, PVST3 and PVST5
3	06.12.2017	Transformation centers	Transformer isolation measurements. Operation checking of transformer protections. Checking tightness of connection at transformer	OK	TRAFO, MV Cubicles to PVST6 and PVST7
4	07.12.2017	Transformation centers	Transformer isolation measurements. Operation checking of transformer protections. Checking tightness of connection at transformer	OK	TRAFO, MV Cubicles to PVST2 and PVST4
5	07.12.2017	Inverters, meteorogical stations	Checking for general condition of the inverters. Checking the fans working. Cleaning pyranometers and calibrated cells	OK	

(continued)

Table 11.2 (continued)

Ingeteam			PV plant preventive maintenance log		
No.	Date	Equipment	Task description	Status	Observations
6	12.12.2017	PV modules	Check the modules in fields number 1, 2 and 3	OK	I don't found any broken modules
7	12.12.2017	Security systems	Check all the cams and the perimetral alarm	OK	The cams work ok, without the cam D5: has image but when in move up, down, left or right don't work, don't made any move
8	14.12.2017	PV modules	Check the modules in fields number 4 and 5;	OK	I don't found any broken modules
9	15.12.2017	PV modules	Check the modules in fields number 6 and 7	OK	I don't found any broken modules
10	15.12.2017	Inverters, meteorogical stations	Checking for general condition of the inverters. Checking the fans working. Cleaning pyranometers and calibrated cells	OK	
11	19.12.2017	Buildings (connection point, SCADA, control room, inverters)	Visual inspection of the electrical/lightning installation of the building. Checking there is no signs of animals (rodents). Inspection of door lock	OK	The electrical installation from the inverters building are ok
12	19.12.2017	Buildings (connection point, control room, inverters)	Checking there is no abnormal humidity conditions or signs of water accumulation	OK	
13	19.12.2017	Inverters, String and Combiner Boxes	Checking for general condition of the inverters. Checking the fans working. Visual inspection of string and combiner boxes. The connection boxes verified to inverters PVST1 and PVST2	OK	

Table 11.2 (continued)

Ingeteam			PV plant preventive maintenance log		
No.	Date	Equipment	Task description	Status	Observations
20	29.12.2017	Inverters, meteorogical stations	Checking for general condition of the inverters. Checking the fans working. Cleaning pyranometers and calibrated cells	OK	

3. Inverters General and other Conditions/daily and monthly:

 – Checking for general condition of the inverters (physical appearance),
 – Checking the heating working,
 – Checking proper condition of inverts building/enclosure,
 – Visual inspections of general condition and cleanliness,
 – Checking for adequate temperature,
 – Checking for adequate ventilation,
 – Visual inspection of the electrical/lightning installation of the building,
 – Checking there is no signs of animals (rodents) and installation of traps for rodents,
 – Checking general cleanliness and filters;

4. DC & AC Cabling—biannually:

 – Checking physical integrity of cabling. General appearance of grounding cables/connectors,
 – Checking physical integrity/tightness of cable connections, Checking state of the splices,
 – AC and DC cabling properly traced inside trays or buried corrugated conducts,
 – All cabling fastened to structural elements to ensure its stability and no sharp edges which may damage the cabling;

5. Civil Infrastructure—monthly, biannually and annually:

 – Terrain condition: Fence and Road;

6. Security Systems—Visual inspection/monthly [2, 24, 25];
7. Diesel Generator—Visual inspection/monthly;
8. Cleaning Building PUNCT CONNECTING PBL and PVST/daily and monthly.

11.3.4 Estimation of Energy Production for the Photovoltaic Park

For the year 2017, the amount of energy produced by the photovoltaic park is presented in Table 11.3. These estimates of the annual production energy for each month are made in accordance with the capacity of the photovoltaic park and estimated solar radiation for each month of the year.

Table 11.3 shows the energy values to be realized each month, but also the cumulative values from the beginning of the year to the current month [8, 26, 27].

11.4 Data Collection and Processing System

11.4.1 Analyzed Solar Park Configuration

The analyzed solar park, as site location, has the following configuration (Fig. 11.7).

The characteristics of the photovoltaic park analyzed:

– Solar potential—7.5 MWh;
– 30646 Modules/14 Inverters—7.5 MW;
– SUNTECH STP 245—20Wd/Schneider XC540.
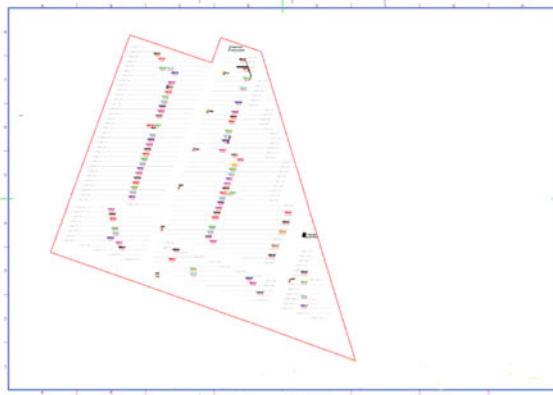
Fig. 11.7 The solar park—general plan connecting panels

Table 11.3 2017 proposal budget PV energy park

Production budget	Monthly											
	January	February	March	April	May	June	July	August	September	October	November	December
	386,81	520,76	882,30	943,31	1102,99	1086,91	1204,52	1141,43	1017,09	776,11	463,85	407,93
	Cumulative											
	386,81	907,57	1789,88	2733,18	3836,17	4923,08	6127,59	7269,02	8286,11	9062,22	9526,07	9934,00

11.4.2   The SCADA System Functions

Functions available to the operator in the control room of the Fire Emblem Heroes (FEH) [5]:

(1) Control Functions—allowing operation through a friendly man-machine graphical interface:

- View functions of the system setup, carried out by:
  - The Base Station/workstation operator;
  - Additional Equipment in the control room;
  - The Network Connections.

The organization of the view through the graphical interface man—machine is based on a hierarchical structure, containing information with different degrees of abstraction and detailing, which will allow the operator to request a comprehensive or detailed analysis of the processes:

- Level 1: screens with overview of installations and equipment in field (at the level of technological installations)—Fig. 11.8;
- Level 2: screens with overview of the main functions of the facilities and equipment;
- Level 3: displays images detail regarding the operation of installations, with surveillance information (Figs. 11.9 and 11.10), and allow corrective actions (Table 11.4) and provide diagnoses (Figs. 11.11, 11.12 and 11.13).

In Fig. 11.9 is presented the man machine interface, which provides information about energy production (total energy delivered, day energy delivered), ambient temperature, active inverter power, plane irradiation, and total availability [24, 28].

In Fig. 11.10 the power, currents for a certain string (array box 1.1.2); and the diagram of current versus voltage on the same graph are presented.
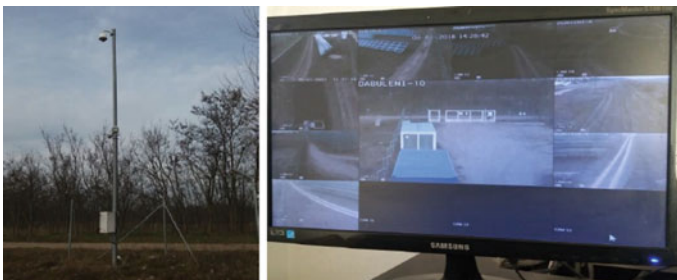
Fig. 11.8   CCTV checks
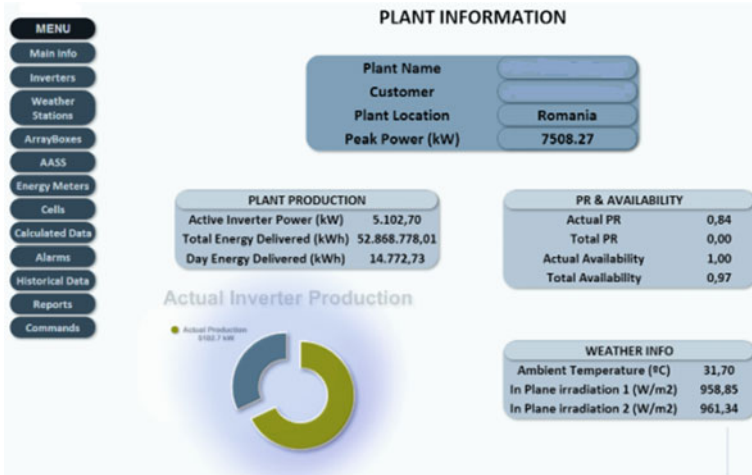
Fig. 11.9 The surveillance information

Fig. 11.10 Example of the string selection and obtaining information

Table 11.4 Work order table—March 2017

Date stop	Hour stop	Date start	Hour start	Total down-time	Code alarm	Alarm	Part descrip-tion	Comments	State	Intersor
08.03.2017	10:20	08.03.2017	10:26	0:06	Main Cell/PBL/SIM UNDERf REQ1 STATUS			CEZ dis-tribution	o.k	Total
16.03.2017	11:02	16.03.2017	11:03	0:06	Main Cell/PBl/27P Phase STATUS			CEZ dis-tribution	o.k	Total
16.03.2017	14:00	16.03.2017	14:11	00:11	Wain Cell/PBl/27P Phase STATUS			CEZ dis-tribution	O.k	Total
17.03.2017	10:44	17.03.2017	10:55	00:11	Wain Cell/PBl/27P Phase STATUS			CEZ dis-tribution	o.k	Total
17.03.2017	14:11	17.03.2017	14:17	00:06	Wain Cell/RBL/Z7P Phase STATUS			CEZ dis-tribution	o.k	Total
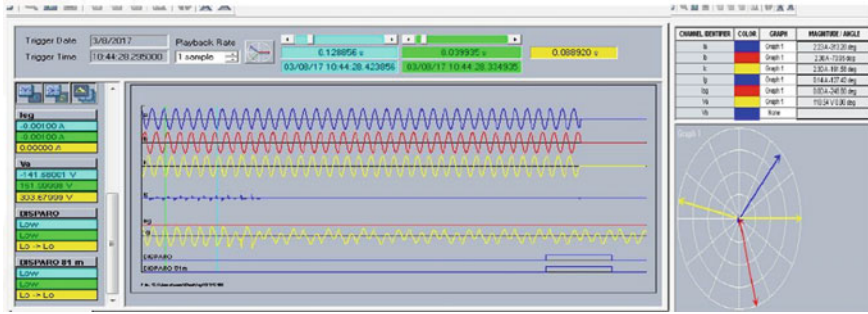
Fig. 11.11 Diagram and oscillogram from 08.03.2017/10:44
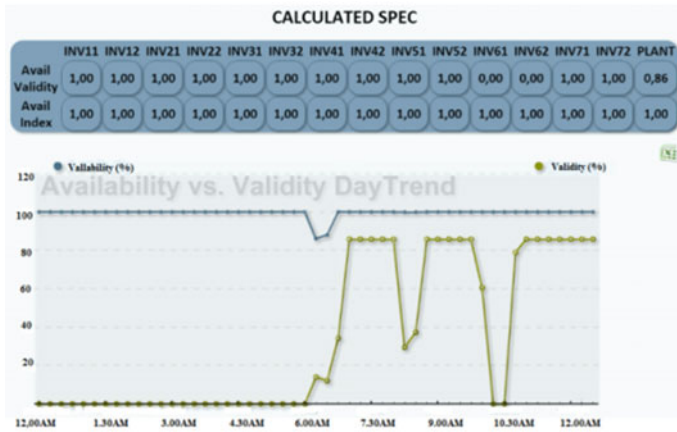
Fig. 11.12 The variation of yield daily

Table 11.4 presents information obtained when the alarm is triggered. The information is related to: date of the incident, time for stop alarm, periods of stagnation, causes of the alarm, and comments and conditions [20, 29–32].

Diagram and oscillation of currents on the three phases (I_a, I_b, I_c), leakage current (I_g) and voltage variation (V_a, V_b, V_c) are presented in Fig. 11.11. Also the yield daily variation and current variation for the sting number one are presented in Figs. 11.12 and 11.13 [6, 27].

- Alarm Functions: informs the operator in good time of any abnormal operation or fault in the technological processes.

The organization screens for viewing the alarms will be made taking into account the features:

- The screen with the overview of all alarms from process;
- The screen with the latest Alarms Window;
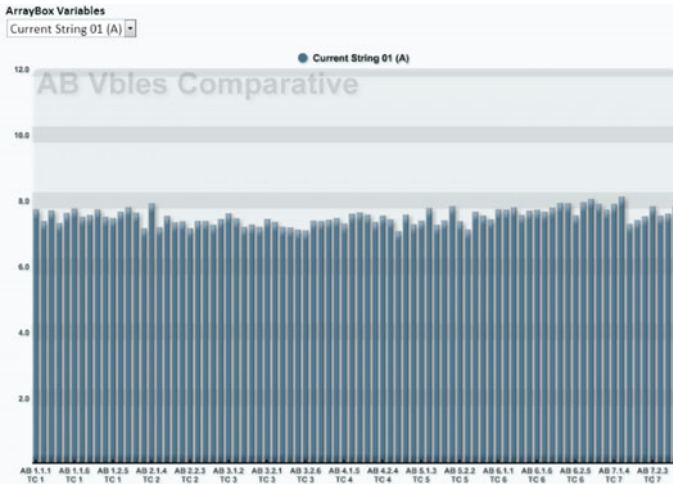
Fig. 11.13 Current of string
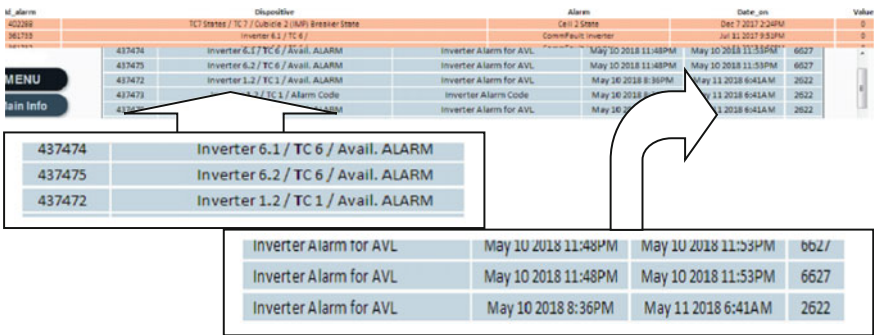
Fig. 11.14 Alarms

– The window with the other lists of alarms, sorted by various criteria (pre-program) Fig. 11.14.

An example of alarm functions is presented in Fig. 11.14. It describes the cod of the alarm (example: 437474), the breaker state (TC6/avail.alarm), time and hours (May 10 2018, 11:48 PM).

Monitoring Functions of the variables in the technological processes: display on the screen of the graphs of evolution in time of the magnitudes of the importance of the measured from the process allowing highlighting deviations from the normal values (differentiated colors) Fig. 11.15 [5, 6, 24, 26, 28, 30, 33–36].
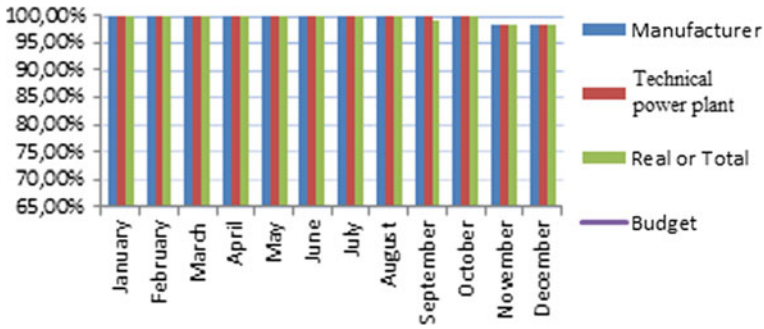
Fig. 11.15 Availabilities

(2) Advanced Functions:

- Historical data storage features (database—date, year, hour) is presented in Table 11.5, showing the cumulative values for the requested period;
- Successfully archiving of the regular data with the ability to view at any time, the form of graphical trend;
- Successfully archiving of the events accompanied by the date of the occurrence, with the possibility to view in the form of lists with the chronological Table 11.6;
- Functions for the preparation of the various reports (historical records for a specified period of time of the main variables from process; reports on the maintenance of technological developments; reports on the events, incidents, etc.) Table 11.7 [25, 27, 31, 36].

11.5 Computer Simulations

Data storage and simulation was performed using the SCADA system, used to track and process on-line data [28, 30, 33, 35, 37].

All problems that occur are automatically signaled by the system to be repaired in a timely manner so that the capture of solar energy is achieved near maximum capacity.

For example, we chose three months of the year—January, February and March—months with a small solar radiation, precisely to show the performance of the photovoltaic park, at a time of year when the solar radiation is low.

Tables 11.5, 11.6 and 11.7 shows differences that occur within the same time frame but in two different years 2017 and 2018. Graphical expression of these dates is made in Tables 11.5, 11.6 and 11.7 [24, 27, 31, 32, 36].

Table 11.5 Historical data storage features

| Date | Meteo | | | | | | |
	Isol. A1 (Wh/m^2)	Isol. A2 (Wh/m^2)	Isol. HZ (Wh/m^2)	Avg. Calib. cell isol. (Wh/m^2)	Avg. Mod. temp. (°C)	Air temp. (°C)	Filtered avg. isol. (Wh/m^2)
May 1, 2018 1:00 AM	0	0	0	0,05	13,94	19,83	0
May 1, 2018 1:15 AM	0	0	0	0,07	14,7	20,28	0
May 1, 2018 3:45 PM	199,54	196,1	178,59	1451,10	53,48	34,64	197,82
May 1 2018 4:00 PM	193,09	190,83	174,1	1397,23	52,65	35,11	191,96
May 1, 2018 4:15 PM	168,68	167,4	153,03	1242,64	50,59	34,89	168,04
Total	7294,66	7257,09	6958,28	54287,08	29,93	25,51	7234,5

(continued)

Table 11.5 (continued)

Date	DC Total DC prod. (kWh)	AC Total AC prod. (kWh)	AC MV Exp. meter act energy (kWh)	Exp. meter react energy (kWh)	PR (%)	ETA AC (%)	Avail. (%)	Switchgear Status
May 1, 2018 1:00 AM	0	0	0	0	0	0	0	0
May 1, 2018 1:15 AM	0	0	0	0	0	0	0	0
May 1, 2018 3:45 PM	1056,43	921	1200,00	0	0,81	1,14	1	0
May 1, 2018 4:00 PM	1035,66	1309,30	1227,27	0	0,85	1,19	1	0
May 1, 2018 4:15 PM	930,27	640,6	954,55	0	0,76	1,03	1	0
Total	39212,04	37953,90	44154,55	990,91	0,81	1,13	1	0

Table 11.6 Summary list of the dates of occurrence in chronological order—report for PV plant, February 2018

Day	Hours with working condition for inverter to produce (radiation > 10 W/mp)	Total string hours	Total radiation (Wh/mp)	Exported active energy end Landis (MWh)	PR (%) calculated in SCADA	Real availability (%)	Expr. availability (%)	Real IT availability (%)	Availability in SCADA (%)	Events and disturbance in energy production
27.02.18	9,50	13233,50	5035,99	16,34	56,00	100,00	100,00	100,00	97,00	The panels are covered by snow
28.02.18	10,50	14626,50	4780,52	7,78	28,00	100,00	100,00	100,00	94,00	The panels are covered by snow
Total	265,25	369493,25	64713,65	331,56	84,21	98,55	100,00	98,55	96,79	
Panels	30646,00									
Strings	1393,00									

Table 11.7 Summary of data for the year 2017

Production (MWh)	Monthly											
Source	January	February	March	April	May	June	July	August	September	October	November	December
SCADA	384,31	667,49	963,83	1094,28	1114,32	1202,27	1211,54	1174,46	973,31	676,93	309,00	437,49
Meter	385,49	669,67	967,25	1098,55	1118,93	1207,43	1216,85	1179,71	977,24	916,36	341,30	505,45
Cumulative												
SCADA	384,31	1051,80	2015,63	3109,91	4224,23	5426,50	6638,04	7812,50	8785,81	9462,74	9771,74	10209,2
Meter	385,49	1055,16	2022,41	3120,96	4239,89	5447,32	6664,17	7843,88	8821,12	9737,48	10078,78	10584,23
Performance Ratio	Monthly											
Source	January	February	March	April	May	June	July	August	September	October	November	December
SCADA	74,84	91,40	87,87	86,90	84,65	81,30	80,39	79,90	83,63	84,23	92,57	90,23
Cumulative												
SCADA	74,84	83,12	84,70	85,25	85,13	84,49	83,91	83,41	83,43	83,51	84,33	84,83
Radiation	Monthly											
Source	January	February	March	April	May	June	July	August	September	October	November	December
SCADA	77585,00	92286,00	150633,00	171454,00	178868,00	199665,00	204351,00	199136,00	163509,00	128759,00	51786,00	77767,00
Cumulative												

(continued)

Table 11.7 (continued)

Production (MWh)	Monthly											
Source	January	February	March	April	May	June	July	August	September	October	November	December
SCADA	77585,00	169871,00	320504,00	491958,00	670826,00	870491,00	1074842,00	1273978,00	1437487,00	1566246,00	1618032,00	1695799,00
Theoretical Performance Ratio	Monthly											
Source	January	February	March	April	May	June	July	August	September	October	November	December
SCADA	66,05	96,44	85,31	85,10	83,06	80,29	79,05	78,64	79,37	70,10	79,56	75,01
Meter	66,25	96,75	85,62	85,43	83,41	80,63	79,40	78,99	79,69	94,89	87,87	86,66
Cumulative												
SCADA	66,05	81,24	82,60	83,22	83,19	82,71	82,19	81,74	81,48	80,34	80,27	79,83
Meter	66,25	81,50	82,87	83,51	83,49	83,01	82,50	82,06	81,80	83,11	83,54	83,80

Operation and Maintenance Report

– PV 30646 modules/14 inverters—7.5 MW

A. Operational data—March 2017

Production (MWh)	Monthly		
Source	January	February	March
SCADA	384,31	667,49	963,83
Meter	385,49	669,67	967,25

3

Production Budget	Monthly		
Source	January	February	March
	386,81	520,76	882,30

3

	Production (MWh)	
Source	March	Cumulative
SCADA	963,83	2.015,63
Meter	967,25	2.022,41
Diff. (Meter- SCADA)	3,42	6,78
Dev. SCADA Meter (%)	0,35%	0,34%

3, 42/967, 25/100

Production Status Real vs Budget		
	4 March	**5** Cumulative
	882,30	1.789,88
Diff. Meter	84,95	232,53
Dev. Meter (%)	9,63%	12,99%

967,25-882,30 2.022,41-1.789,88

84, 95/882, 30/100

Availability (%)		
	6 March	**7** Cumulative
Contractor	97,10%	99,01%
EDPR or Technical	97,10%	98,52%
Total or Real	97,10%	98,52%

	Normal Load Factor		Equivalents Hours	
Source	March	Cumulative	March	Cumulative
SCADA	17,27	12.47	128,51	268,75
Meter	17,33	12.51	128,97	269,65

((963, 83/1)*1000*100) / (744*7500)   963, 83/7, 5

((967, 25/1)*1000*100) / (744*7500)   967, 25/7, 5

2

	Performance Ratio	
Source	March	Cumulative
SCADA	87,87	84,70

1

	Radiation (Wh/sm)	
Source	March	Cumulative
SCADA	150.633,00	320.504,00

Theorical Performance Ratio**	SCADA	85,31
	Meter	85,62

(**without temperature corrections, etc.)

(963, 83*100) / ((150.633, 00 /1000)*7, 5)   (967, 25*100) / ((150.633, 00 /1000)*7, 5)

$$PR_T = \frac{\text{Energy produced during a certain period } T \, (\text{kWh})}{\frac{\text{Average incident solar radiation during } T}{1000 \, \text{W/m}^2} \times \text{Peak plant wattage} \times T\,(h)}$$

B. Operational data—March 2018

3	**Production (MWh)**	
Source	**March**	**Cumulative**
SCADA	743,37	1.624,15
Meter	743,37	1.627,33
Diff.	0,00	3,18
Dev. SCADA Meter (%)	0,00%	0,20%

Production Status Real vs Budget	
4March	**5Cumulative**
882,30	1.789,88
-138,93	**-162,55**
-15,75%	**-9,08%**

Diff. Meter (beside rows); *Dev. Meter (%)*

	Availability (%)	
	6March	**7Cumulative**
Contractor	97,10%	99,01%
EDPR or Technical	97,10%	98,52%
Total or Real	97,10%	98,52%

Source	**Normal Load Factor**		**Equivalents Hours**	
	March	**Cumulative**	**March**	**Cumulative**
SCADA	13,32	9,95	99,12	216,55
Meter	13,32	9,97	99,12	216,98

2	**Performance Ratio**	
Source	**March**	**Cumulative**
SCADA	84,84	85,13

Theorical Performance Ratio**	SCADA	78,63
	Meter	78,63

1	**Radiation (Wh/sm)**	
Source	**March**	**Cumulative**
SCADA	126.056,00	266.219,00

(**without temperature corrections, etc.)

Graphical expression of these dates is made in Table 11.8. Comparatively, we can observe the differences that occur during the same period of time from year to year [24, 25, 27, 30, 31, 33, 36].

The legend:

1Radiation (Wh/mp)   **5**Meter vs Budget
2Performance Ratio   **6**Availabilities
3SCADA vs Meter   **7**Cum. Availabilities
4 Meter vs Budget

Table 11.8 Operational data

2017	2018
1Radiation (Wh/mp)	

| **2**Performance Ratio | |

Production

3SCADA vs Meter

4 Meter vs Budget

Cumulative

5Meter vs Budget

Table 11.8 (continued)

Availability
6 Availabilities

7 Cumulate availabilities
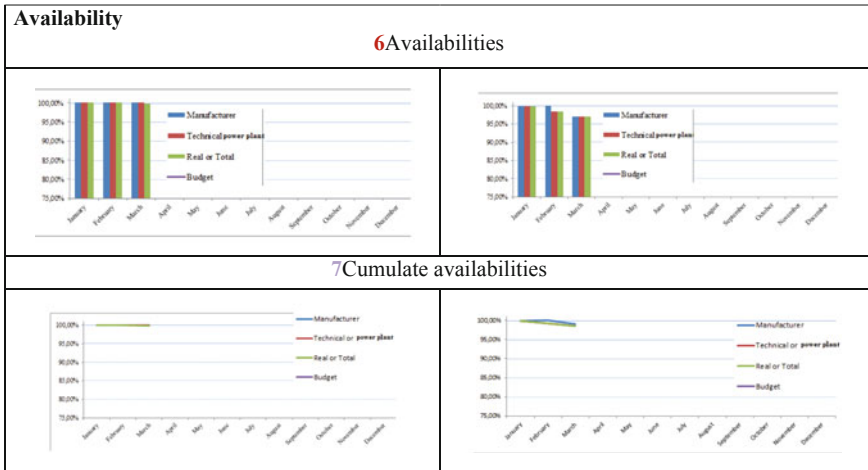
11.6 Conclusion

In this chapter, the main functional parametres of a photovoltaic power plant are presented using Supervisory Control and Data Acquisition (SCADA) and these parameters are used to obtained information about energy management of PV system.

The dates presented are obtained from a photovoltaic power plant within an area of seventy hecters, located in the south part of Romania, where the solar radiation is over 1450 kWh/m^2 year.

With the help of SCADA system, the control, the surveillance, the metering and monitoring of the photovoltaic power plant can be made from distance. Also the energy management can be achieved starting white one day and finishing with one year.

Total energy delivered (kWh), daily energy delivered (kWh), active inverter power (kW), percent of availability for photovoltaic power plant, weather info (ambient temperature, plane radiation etc.), hourly graphs about plant production, alarms, current strings, energy meter (exported active-reactive power, imported active-reactive power), data about weather station, inverters graphs, state of power transformers, breaker state, earthling state, month radiation, and month exported active energy can be achieved using SCADA.

Also, the dates obtained from a certain months of the year are compared with the dates obtained from the same months but for different years in order to establish the efficiency of the photovoltaic power plant.

Based on the resulting dates stored by SCADA, the corrective maintenance can be done.

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