Instituto Politécnico de Viseu

Escola Superior de Tecnologia e Gestão de Viseu

Hugo Zeferino Pereira Ribeiro

Monitoring Platform For Photovoltaic Plants

February 2015

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Monitoring Platform For Photovoltaic Plants

Thesis
Energy and Industrial Automation Masters Degree

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Fundings
Martifer Solar

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"*The will to win, the desire to succeed, the urge to reach your full potential... these are the keys that will unlock the door to personal excellence.*"

Confucius

RESUMO

A apresentação desta dissertação conclui o curso de Mestrado em Energia e Automação Industrial - Engenharia Eletrotécnica, da Escola Superior de Tecnologia e Gestão de Viseu. É o resultado de um trabalho de desenvolvimento, de estudo e pesquisa realizado no âmbito do desenvolvimento de sistemas SCADA (*Supervision Control And Data Acquisition*) e a sua utilização/implementação em parques fotovoltaicos. O desenvolvimento do trabalho realizou-se na Área de Automação e Controlo do Departamento Técnico da Martifer Solar.

Os sistemas de geração de energia elétrica solar fotovoltaica necessitam de ferramentas de análise e tratamento de dados. A generalidade das entidades desenvolvedoras de sistemas SCADA estão habituadas a criar aplicações de cariz industrial. Um sistema desta natureza implica, além do conhecimento de desenvolvimento de aplicações industriais, um conhecimento específico da produção de energia elétrica proveniente da energia solar. Desta forma, é possível averiguar eficazmente quais as variáveis de campo e temporizações associadas à sua monitorização e registo. É ainda possível aferir, por exemplo, o tratamento estatístico a dar às variáveis, o seu correto processamento, gestão e severidade de alarmes, entre outros.

Como referido, esta dissertação foi desenvolvida em parceria com a empresa Martifer Solar. Uma das suas áreas de negócio consiste em desenvolver soluções EPC (*Engineering, Procurement and Construction*) no ramo da energia solar. Sob um contrato EPC, o contratante projeta a instalação, adquire os materiais necessários e constrói o projeto, diretamente ou através da subcontratação de parte do trabalho ou do seu todo. Um dos subsistemas incluídos no EPC é o sistema de monitorização que permite operar de forma eficiente os equipamentos associados à instalação fotovoltaica.

A necessidade deste tipo de sistemas e a sua especificidade implica que, frequentemente, se tenha de recorrer a empresas externas para o desenvolvimento de software de monitorização o que, por sua vez, aumenta o custo total do projeto. Acresce ainda o facto de tal implicar a transmissão de *know-how* a empresas que posteriormente poderão vender software baseado neste *know-how* a outras empresas concorrentes no ramo de desenvolvimento de soluções de sistemas de monitorização. A adicionar aos riscos anteriormente expostos, existe ainda o facto de que, sempre que é necessária uma alteração aos sistemas previamente instalados, os custos cobrados pelas empresas que desenvolveram a solução são exorbitantes.
Por todas as razões apresentadas, tornou-se evidente a importância do desenvolvimento de um sistema de monitorização na Martifer Solar.

Resumo

Com o intuito de desenvolver um sistema de monitorização o mais otimizado e eficiente possível, é necessário definir, à priori, a arquitectura da rede de campo a instalar nos parques fotovoltaicos. Tal análise engloba, por exemplo, definir em que situações será necessária a utilização de autómatos programáveis, *dataloggers*, *gateways* ou conversores da camada física de protocolos para comunicação com os equipamentos a monitorizar. Consequentemente, através deste estudo, também é feita uma primeira definição da organização que o sistema de monitorização apresentará. Tal organização deverá reflectir da forma mais fiel possível o *layout* do parque fotovoltaico a monitorizar. Ainda mais importante, a análise cuidada do projeto permite definir qual o meio físico a utilizar e seguidamente permite identificar quais os protocolos de comunicação a considerar. No desenvolvimento do sistema de monitorização, a análise dos equipamentos e do meio físico, permitem uma quantificação prévia das variáveis referentes a cada um dos equipamentos que se pretendem monitorizar.
Esta primeira análise é fulcral para definir os pré-requisitos que o software de desenvolvimento utlizará, para a criação do sistema de monitorização.

A escolha da ferramenta de desenvolvimento para a execução dum projeto deste tipo é fulcral. Estabeleceu-se um conjunto de características de forma a avaliar diferentes softwares e *frameworks* de desenvolvimento. A escolha desse software recaiu naquele que cumpria a maior quantidade de requisitos pré-estabelecidos.
O software SCADA, além de programável graficamente, deverá ter a possibilidade de ser programado através de excertos de código em linguagem de programação comumente utilizadas no mercado, tais como a linguagem VBA, C++, JAVA, etc.
Tendo em conta a localização das instalações fotovoltaicas, isto é, localizados em zonas remotas e sem operadores locais a tempo inteiro, é importante que o software SCADA possua características que permitam um acesso remoto ao sistema de monitorização para sua análise e, em caso de existirem alarmes, melhor depurar a razão dos mesmos.
A existência de uma política de utilizadores com diferentes privilégios deverá estar presente para que cada um dos perfis de utilizadores tenham capacidades de interação diferentes.
A capacidade de armazenamento de informação é outro dos requisitos de extrema importância quando o objetivo passa pela concentração de dados através do software SCADA. A ligação a motores de bases de dados é um requisito imprescindível, tanto pela forma como a informação poderá ser organizada nestes motores, como pelo facto de existirem requisitos de compatibilidade com um sistema já existente na Martifer Solar que concentra os dados de todas as plantas fotovoltaicas numa só ferramenta denomidada de Martifer Solar OMS (Operation Management System).
Como requisito prioritário temos o custo de uma aplicação deste tipo. No que se refere à aplicação, podemos distinguir entre o custo do software de desenvolvimento e o custo do desenvolvimento (horas/homem). O custo do software de desenvolvimento é um factor que pode muito facilmente inviabilizar um projeto. Assim, o custo de aquisição deverá ser o mais

baixo possível, de acordo com as suas potencialidades. Por outro lado temos o custo de desenvolvimento para atingir o objetivo de criar uma aplicação SCADA no mais curto espaço de tempo e tendo sempre em mente a reutilização do desenvolvimento inicial da aplicação em novos projetos com o mínimo de alterações.
Após escolhido o software de desenvolvimento, foi iniciado o processo de criação da ferramenta de acordo com as características necessárias à correta operação do sistema fotovoltaico.

Foram desenvolvidos vários ecrãs que permitem ao utilizador visualizar de forma intuitiva os dados provenientes do parque fotovoltaico, nomeadamente os ecrãs:

- Inicial - possui informação generalizada referente ao parque fotovoltaico. Entre essa informação encontra-se, por exemplo, a localização geográfica do parque, dados de produção do dia em questão e alarmes mais recentes;

- Equipamento - nesta interface é possível visualizar, em tempo real, o valor das variáveis por equipamento monitorizado;

- Performance - neste são expostos os indicadores de desempenho inerentes ao parque fotovoltaico;

- Alarmes - permite visualisar, em tempo real, sinais de alarme, avisos ou estados dos equipamentos monitorizados;

- Histórico alarmes - permite a consulta de alarmes, avisos ou estados dos equipamentos monitorizados em histórico;

- Histórico de dados - permite a consulta em tabela dos dados provenientes dos equipamentos monitorizados. Estes dados estão armazenados numa base de dados. É possível fazer a consulta dos dados numa base temporal de minutos, horas, dias, meses ou anos. De forma a apresentar os dados mencionados, o software de monitorização foi programado de modo a executar os cálculos estatísticos necessários e adequados para cada uma das variáveis;

- Gráficos - permite visualizar graficamente os dados armazenados em histórico;

- Produção - permite visualizar dados de produção de energia desde o tipo de equipamento mais “próximo” do gerador fotovoltaico até ao contador de energia colocado no ponto de injeção;

- *Dashboard* - neste ecrã visualizam-se as variáveis mais representativas de cada um dos equipamentos.

De forma a tornar a plataforma de monitorização uma ferramenta mais poderosa, para além dos ecrãs mencionados, foram desenvolvidas uma panóplia de funcionalidades, tais como:

- Envio de dados de histórico por correio eletrónico em formato *.csv*;
- Envio de notificações de alarme por correio eletrónico. O operador define os alarmes a receber;
- Cálculos estatísticos para tratamento da informação proveniente dos equipamentos monitorizados;
- Processamento inteligente de informação dos equipamentos;
- Funções de gestão e manutenção da base de dados;
- *Backups* periódicos e automáticos à base de dados;
- Gestão de ficheiros em disco;
- Monitorização do servidor onde a plataforma está instalada (processos, serviços, espaço em disco, aplicações de arranque, entre outros);
- Envio de dados para um servidor FTP;
- Envio de notificações por correio eletrónico de erros inerentes ao código dos programas que gerem a plataforma.

A plataforma de monitorização, para além da interface gráfico e as funcionalidades mencionadas, possui também uma base de dados onde toda a informação proveniente dos equipamentos é armazenada. Utilizou-se para este projeto uma base de dados SQL. Para a criação da base de dados do sistema, uma série de pontos foram tidos em conta:

- Gestão de utilizadores;
- Indexação apropriada de colunas de forma a melhorar o desempenho da base de dados;
- Otimização de *queries* de forma a tornar as consultas e operações mais rápidas;
- Gestão de espaço em disco;
- Gestão do crescimento dos ficheiros que compõem a base de dados.

De acordo com as características necessárias a este sistema e considerando as soluções comerciais conhecidas, foi possível desenvolver uma das melhores e mais completas aplicações para a monitorização de parques fotovoltaicos existentes no mercado, completamente orientada para este sector.

Esta aplicação permite apresentar dados ao operador com frequências de amostragem na ordem do segundo e armazenamento de histórico de dados com capacidade para mais de 20 anos a trabalhar ininterruptamente.
Os objetivos propostos foram concluídos com sucesso.

PALAVRAS-CHAVE

Parque Fotovolatico
Sistema de Supervisão, Controlo e Aquisicão de Dados
Redes de Comunicações
Aquisição de Dados
Base de Dados

ABSTRACT

This document terminates the Energy and Industrial Automation Master Degree - Electrotechnical Engineering, in Escola Superior de Tecnologia e Gestão de Viseu. The outcome of this thesis is the result of work development regarding SCADA systems programming and its use/implementation in photovoltaic plants. The development process was carried at Martifer Solar's Technical Department - Automation and Control Systems Area.

General SCADA developers usually create industrial nature applications. Premises generally taken from granted to build industrial applications do not usually fit photovoltaic monitoring systems. To develop a monitoring system of this nature, specific knowledge about electricity production from photovoltaic resources is required. This knowledge allows system developers to be aware of the monitored field variables and its acquisition times. Besides, it gives the user a higher sense of which variables to store as well as their statistic conditioning. Correct alarm management and configuration is also an outcome of this specific required knowledge.

As mentioned, this thesis was developed under a partnership with Martifer Solar, a global player in EPC (Engineering, Procurement and Construction) for photovoltaic solutions. Under an EPC contract, the contractor designs the project, procures materials and builds the project, either directly or by subcontracting other companies to do it. A monitoring system is an EPC subsystem. The need and specificity of these systems often lead to the hiring of an external company to develop the monitoring software. Resort to external companies to develop software, implies the transmission of know-how. The know-how transmission puts the EPC contractor in a fragile situation because the contracted company may sell, in the future, this know-how to other EPC competitors. Therefore, it is clearly visible that the internal development of a Martifer Solar monitoring system is very important.

KEYWORDS

Photovolatic Plant
Supervision Control and Data Acquisition System
Communication Networks
Data Acquisition
Database

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ACRONYMS

AC Alternate Current.

CDO Collaboration Data Objects.

CIM Computer-Integrated Manufacturing.

CSV Commma Separated Values.

CTE Common Table Expression.

DBMS Database Management System.

DC Direct Current.

EMI Electromagnetic Interferences.

EMS Energy Managment System.

EPC Engineering, Procurement and Construction.

FIFO First In, First Out.

GB Gigabyte.

GPRS General Packet Radio Service.

GUI Graphic User Interface.

HMI Human-machine interface.

IP Internet Protocol.

IT Information Technology.

KPI Key Performance Indicators.

LAN Local Area Network.

MTU Main Terminal Unit.

MV Medium Voltage.

ODBC Open Database Connectivity.

OF Optical Fibre.

OLE Object Linking and Embedding.

OMS Operation Managment System.

OPC OLE for Process Control.

OSI Open Systems Interconnection.

PCB Printed Circuit Board.

PLC Programmable Logic Controller.

PR Performance Ratio.

PV Photovoltaic.

RTU Remote Terminal Unit.

SCADA Supervision Control And Data Acquisition.

SQL Structured Query Language.

STC Standard Test Conditions.

TCP/IP Transmission Control Protocol/Internet Protocol.

UPS Uninterruptible Power Supply.

VBA Visual Basic For Applications.

WMI Windows Management Instrumentation.

XML Extensible Markup Language.

1. Introduction

1.1 Introduction

In this chapter, the motivation that led to this thesis elaboration is presented.
Additionally, the objectives of this thesis are also depicted.
At last, the summary of each chapter is presented.

1.2 Motivation

A Supervisory Control and Data Acquisition (SCADA) system is capable to collect data from one or more distant equipment and make it available to one or more users. Equipment monitoring and control intends to maximise the produced energy, reduce the down time and consequently prevent equipment failure due to wearying. On this way, equipment malfunction and failure can be earlier detected.

The motivation to accomplish this work comes from the challenge that it represents. The development and implementation of a monitoring system requires skills from many areas, such as: automation, programming, industrial instrumentation, database management and communication networks. The development of a SCADA for Photovolatic (PV) plants presents the following challenges:

- Create a monitoring platform from scratch, without any foreknowledge or required assumptions;
- Select the development software to build the application (Graphic User Interface (GUI)

and background features);

- Study the photovoltaic monitoring methodology;
- Deepen knowledge about programming;
- Implement Key Performance Indicator (KPI) calculation and analysis abilities;
- Study a variety of communication protocols to be used;
- Configure and manage Structured Query Language (SQL) databases;
- Develop complex and optimised SQL queries;
- Create correct and optimised data conditioning;
- Understand industrial communication networks.

It is certainly difficult to address areas that are so vast and distinct but, at the same time, necessary to this work completion. It presents a challenge to write this thesis without miss information, without lack of objectivity or without making its content heavy or confusing.

The research and development work revealed to be very profitable. Not all of it was directly used but, despite of that, sooner or later it became useful in troubleshooting situations or on new feature implementation ideas.
In addition to all presented reasons, this work revealed to be even more interesting and motivating as it allowed to merge itself with the author's professional activity.

The work involving this thesis resulted in a commercial solution for Martifer Solar portfolio. Hence, due to intellectual property rights, the full know-how to develop the monitoring platform will not be stated in this document. Code excerpts or system screen illustrations will be depicted.

1.3 Objectives

Particularly requirements for supervision systems to monitor PV plants usually lead companies to subcontract its development. This situation flows into know-how transmission. Moreover, monitoring systems bought to external companies often lack correct data conditioning or reliable equipment information. Due to the complexity of a supervision system, sometimes these anomalies are detected after the SCADA installation and its corrections result into extra-cost due to extra-works.

It is clear the importance of a own SCADA software, developed internally at Martifer Solar. With the purpose of developing an optimized and efficient supervision system it is necessary to

be aware of the equipment to be monitored as well as the PV plant infrastructures where this equipment will be installed.
A PV plant architecture is arranged in a simple and logic manner, aiming to present an organisation which can be seen often in real photovoltaic plants. More information related to the mentioned facilities can be depicted in Subsection 2.3.2.
A general PV plant monitoring system architecture is depicted in Figure 1-1.

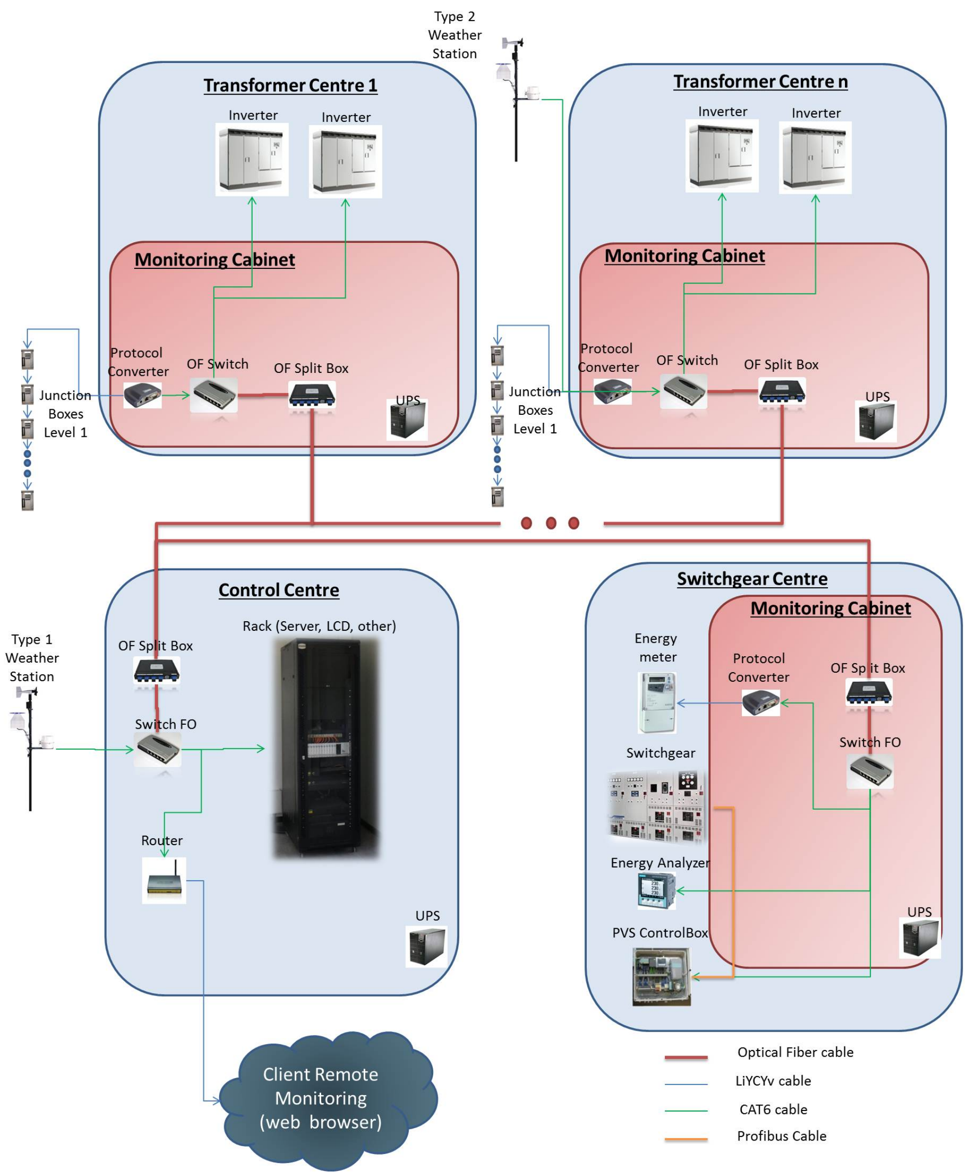


Figure 1-1: Photovoltaic plant monitoring system architecture.

The monitoring platform intends to monitor equipment like Junction Box, Inverter, Transformer, Solar Tracker, Medium Voltage Switchgear, Energy Meter or Energy Analyser. More information regarding the mentioned devices is given in Subsection 2.3. There are several facilities in a PV plant, such as the Transformer Centre, Switchgear Centre and Control Centre. These facilities can host one or more of the mentioned equipment. Monitoring system cabinets are usually located in these facilities and have equipment like protocol converters, Optical Fibre (OF) switches or Uninterruptible Power Supply (UPS).

In summary, it becomes necessary to develop a platform able to monitor and log important data. The platform shall enable fault detections not only to maintain the PV plant performance but also to prevent damage to its components.

1.4 Overview of the Thesis

This introductory chapter presents the motivation that led to this dissertation as well as the objectives to be achieved.

Chapter 2 presents the general aspects of monitoring systems for PV plants. It is given a introduction to the SCADA system history and main components. The main focus of this chapter is to state the reality regarding monitored and monitoring hardware present in PV plants.

Chapter 3 depicts the main requisites and characteristics for the developed supervision system. An overview regarding the tools and third party software used is given. This chapter also focus one of the main component of a monitoring software: the database.

Chapter 4 presents the developed monitoring platform. The features from the operational and administrator GUI are presented. Additionally, the monitoring platform background features are described.

Finally, Chapter 5 presents the overall conclusions, encountered difficulties and optimisation proposals for the mentioned aspects that requires improvement.

2. SCADA Systems And PV Plants

2.1 Introduction

This chapter begins with a sketch of the SCADA history. After, a brief definition of a SCADA system is given.

Additionally, the photovoltaic equipment that shall be monitored are detailed in this chapter. A description and purpose of these devices is exposed. An attentive focus is given to an essential equipment: the weather station. The communication network is approached at the end of the chapter.

2.2 Overview

2.2.1 SCADA Brief History

It is always handy to become aware of a small amount of a subject's history. Therefore, it is possible to place all the information in a known context and understand that field of study in terms of development over time.

The Industrial Revolution led to the evolution of the control systems. Concepts like massive production or production lines gave birth to automation and consequently to automated processes.

The emerge of electricity, at late 19th century, boosted a new evolution of the control systems. The evolution led to the substitution of mechanical systems by electrical ones. This innovation allowed more complex and effective systems creation [1].

From the 40s to the 60s, two new events led to another evolution of the control systems: the invention of the transistor and the Printed Circuit Board (PCB). Discrete logic, more efficient, faster and miniaturised systems were some of these two inventions consequences [1].

In the 60s, the invention of the computer allowed the centralisation of all the information of a control system. The programmability of the computer enabled the creation of more generic and powerful applications [1]. Furthermore, the microcontrollers appearance enabled the creation of decentralisation systems. Despite of these innovations, one problem remained: the communication between devices were still based on analog serial communication. This topology did not allowed high transmission rates or high amount of information transmission. It was based on point-to-point connections which implied large cable quantity usage and, therefore, difficulting the networks project and their maintenance [1].

The evolution of industrial networks came to solve this problem. The development of field networks enabled the peer-to-peer connections substitutions for bus based ones. This allowed the interconnection of different devices. Moreover, this innovation led to the performance improvement.
The absence of regulated standards led to a proliferation of solutions regarding field networks, some of them proprietary. Therefore, it became difficult to interconnect devices from different manufacturers. Standards as IEC 61158 and IEC 61784, described in Appendix A, gave the first steps to solve this problem. Most relevant market solutions are included on these documents [1].

At late 90s, the introduction of communication networks in industrial environment bursted. So far, communication networks were used in non-industrial environment. As consequence, cheaper communication interfaces and better performance solutions appeared. An example of that is the Industrial Ethernet.
The industrial networks development eventually led to the appearance of Computer-Integrated Manufacturing (CIM) that enabled the interconnection between all process sectors, hence, allowing an integrated process management [1].

Despite the appearance of concepts like CIM and field networks evolution, a fully process integration was not yet totally executable. Different communication requisites hinders the use of a unique solution capable to cover all these requisites. In order to solve this, solutions for different networks integration were developed. These solutions are based on the Open Systems

Interconnection (OSI) model [1].

OSI was conceived for computer interconnection. It enabled the creation of right concepts for data communication understanding, design and new communication protocols standardisation [2].

In industrial environment, these monitoring and control problems were fought by using SCADA systems. Nowadays, these systems are widely used in industry for SCADA of industrial processes. Standardisation committees (e.g. Object Linking and Embedding for Process Control (OPC)) members are setting the trends in matters of Information Technology (IT) generally developing these systems.
In terms of functionality, scalability, performance and openness, SCADA systems have made substantial progress. They are an alternative to in house development even for demanding and complex control systems [3].

2.2.2 SCADA Brief Definition

SCADA stands for "supervisory control and data acquisition". It is a concept that allows data collecting and control of equipment located in one or more distant facilities. A SCADA system offers the possibility to reduce costs in routine visits to monitor and operate a distant facility. The more remote is located, the more these benefits can be seen [4].
SCADA systems are used in a range of applications, such as:

- Hydroelectric generating stations;
- Oil or gas production facilities;
- Pipelines;
- Electric transmission systems;
- Irrigation systems that cover hundreds of square miles.

Applications were successfully installed on these types of processes. The complexity of SCADA systems has grown as the technology matured. The major components of a SCADA system are:

- Operator - The one who accesses the system by an HMI;
- Main Terminal Unit (MTU)/Host Computer/Server - It monitors and controls the process even with the operator absence;
- Remote Terminal Unit (RTU) - There can be several in a SCADA system. It transmits data to the MTU, and uses messages from the master supervisory system to control connected objects.

Normally, the MTU has auxiliary devices such as backup memories. All of this devices are part of the MTU.
The MTU scans each RTU. Similarly, the RTU scans each sensors or actuators. The MTU scan is done at a higher rate than the RTU scan of the field devices [4].

On the monitoring platform developed with this thesis work, the MTU role belongs to a server. This server is placed inside a rack in one of the PV plant facilities. The RTU role is portrayed by Programmable Logic Controllers (PLC), dataloggers or other devices with communication capabilities.
More information about the monitoring hardware and PV plant facilities is depicted in the next section.

2.3 Monitored Hardware

The next sections present the equipment that is usually monitored in a PV plant. These equipment are usually placed inside facilities where other devices assure the PV equipment monitoring.

2.3.1 Photovoltaic Equipment

The following hardware shall be monitored. Despite of that, is not mandatory that all equipment must exist on a PV plant. Table 2-1 depicts the standard photovoltaic equipment.

Table 2-1: Monitored hardware of a PV plant.

Equipment	Function	Provided Information
Junction Box	Provides information, at string[1] level, about string individual current and bus voltage	Module production
		Module and string problems
		Fuse problems
		Cable problems
Inverter	Converts direct current (DC) from PV modules to alternating current (AC)	Inverter production
		Equipment errors and alarms
		Cable problems
		Yield Energy
Transformer	Converts Low Voltage current into Medium Voltage	Equipment problems
		Equipment temperature
Medium Voltage Switchgear	Monitors digital protection relays for current and voltage protection. This device also monitors analog variables	Production problems
		Equipment errors and alarms
		Cable problems
		Grid information and problems
Solar Tracker	Orients a payload toward the sun and are used to minimise the angle of incidence between the sunlight and the PV panel	Production problems
		Equipment errors and alarms
		Check optimal modules position
Energy Meter	Monitors the PV plant produced energy	Equipment problems
		Energy for PR[2] calculation
		Energy for Availability calculation
Energy Analyser	Monitors the consumption of all the devices installed in the PV plant	Energy consumption
		Energy quality indicators

2.3.2 Monitoring Equipment

This subsection presents the monitored equipment by facility and the devices that may be installed to fulfil the monitoring task. These devices are usually PLC/data loggers and protocol and gateway converters. They are responsible for ensuring communication between the SCADA system and the equipment mentioned in Table 2-2.

[1] Set of PV modules connected in series.
[2] Performance Ratio.

Table 2-2: Monitoring equipment.

Facility	Hosted Equipment
Transformer Centre	Junction Boxes
	Inverters
	Transformer
	Transformer Switchgear
	Solar Tracker
	Energy analyser
Switchgear Centre	Medium Voltage Switchgear
	Energy Meter
	Energy Analyser
	Grid Control
Control Centre	Rack
	PLC/Datalogger
	Server
	HMI (Display, keyboard, mouse)
	Optical Fiber Ethernet Switch
	Router
	UPS

For Transformer monitoring, digital inputs and, when applicable, analogue variables are collected.
Optical Fiber Ethernet Switches are usually included to interconnect all facilities. Equipment which use Ethernet are connected to the Ethernet Switches per facility. When required and due to distance between facilities, the communication between them is made using optical fibre.
To guarantee an autonomy for the monitoring system equipment, an UPS is used to hold the energy for at least 15 minutes.
A brief description of Transformer and Switchgear Centre hosted equipment was given in Table 2-2. In the next paragraphs, a brief description regarding the Control Centre hosted equipment is given.

Rack
The Rack is where all the electronic devices are hosted inside the Control Centre.

PLC/datalogger
The PLC/datalloger is responsible to acquire the information from each Transformer and Switchgear Centre PLC and/or data loggers. It will provide the information for the SCADA System.

Server
The Server acquires information from the PLC/datalogger, or even gateways, and presents this information graphically to an user by means of the Display.

It hosts the SCADA software, a database and web server which allows for remote connection.

Optical Fibre Ethernet Switch
The Optical Fibre Ethernet Switch manages Ethernet/OF connections on/between every PV plant building.

Router
The Router manages how the Ethernet Network shall act. The Router is responsible to assign IP addresses to every Ethernet device. Router with LAN and GPRS redundant connection is used to assure servers remote connection anytime and anywhere.

Uninterruptible Power Supply
The UPS is used to backup whenever there is a power shortage. This UPS is usually sized for 2 hour energy backup.

2.3.3 Weather Station

Since the energy production depends directly on meteorological conditions, such as temperature or solar radiation, an autonomous Weather Station is installed. Best practices state that one Weather Station shall be supplied for each 2 MW, if the PV plant has only one tilt and one azimuth.
If the PV plant installation has more than one tilt or azimuth, one weather station shall be installed for each combination. This is a requisite for Performance Ratio calculation, since the Peak Power will be affected by the Irradiation measured on these sensors.
Usually, for one PV plant, a Weather Station Type 1 is installed and if more are required, these Weather Stations shall be of Type 2. The “Type 1” and “Type 2” denominations were created by the Automation and Control Systems Area of Martifer Solar to differentiate between both Weather Station types.

2.3.3.1 Weather Station - Type 1

Figure 2-1 depicts an example of the Weather Station - Type 1 architecture, including datalogger, sensors and power supply.

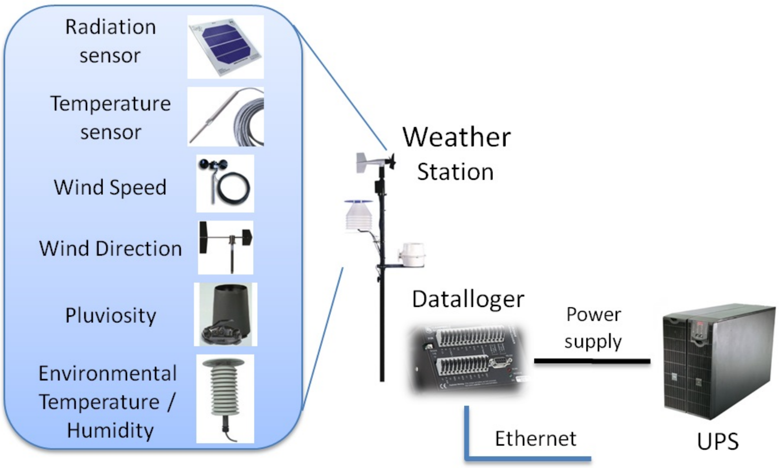


Figure 2-1: Weather Station Type 1 architecture.

The Weather Station Type 1 measures the following meteorological variables:

- The ambient temperature;
- The module temperature;
- The solar radiation on the solar modules plane by means of a reference cell;
- The solar radiation on the horizontal plane by means of a reference cell;
- The wind speed and direction;
- The Relative humidity;
- The Barometric pressure;
- The pluviosity.

A datalogger is used to deal with all these variables and make them available to the server, as it should be able to record all the information from the sensors according to IEC 61724 and for at least 15 days. The datalogger shall have energy backup (battery pack with charge regulator).
Variables shall be acquired by the system and meet certain and predefined parameters in terms of quality and installation. All acquired data shall be present on the SCADA software and stored on the SQL database. The basic characteristics that should be followed for each weather station sensor are depicted in the next paragraphs.

Irradiance

The irradiance shall be measured through a reference cell, since this sensor has a manufacturing process similar to the PV module, as well as its technology (mono, polycrystalline or amorphous).
The accuracy of irradiance sensors (acquisition and signal conditioning) shall be better than 5%.

The sensors shall have its calibration certificate including the cable length. The cable shall not be shorten or lengthen. The sensor connections shall be directly made in the Weather Station datalloger.
Additionally, no shade shall be created on the top of this sensor during the day.

Reference cells
The solar radiation shall be measured at the PV array plane as well as at the horizontal plane. The measurement shall be done by calibrated Reference Cells. The cells shall be made of the same technology of installed PV modules. The reference cells must be calibrated and maintained in accordance with IEC 60904-2 or IEC 60904-6.

Pyranometers
The Pyranometer shall have high quality ("secondary standard"). It shall be calibrated and maintained in accordance with IEC standards and normative. Pyranometer shall comply with ISO 9060 requirements.

Ambient Temperature
The sensor location shall be representative of Photovoltaic array location.
The accuracy of ambient temperature sensor (acquisition and signal conditioning) shall be better than 1K.

Module Temperature
The sensor location shall be representative of the PV array location and be placed on the back surface of modules.
The sensor shall be placed on the PV module as stated in IEC 61829 by the method A (on the centre of back surface of the module, in the centre of array field, bellow a cell).
The accuracy of module temperature sensor (acquisition and signal conditioning) shall be better than 1K.

Wind Speed and Direction
The sensor location and its height shall be representative of the PV array location.
The accuracy of wind speed sensor (acquisition and signal conditioning) shall be better than 0,5 $m.s^{-1}$ for wind speeds less than 5 $m.s^{-1}$, and better than 10% of the reading for wind speeds greater than 5 $m.s^{-1}$.

Humidity
The sensor location shall be representative of the PV array location.
The relative humidity sensor must provide 0 to 100% results.
The accuracy of the relative humidity sensor (acquisition and signal conditioning) shall be better than 5% (globally).

Rainfall
The sensor location shall be representative of the PV array location.
The accuracy of rain / precipitation sensor (acquisition and signal conditioning) shall be better than 5% (sometimes this can be difficult due to low level precipitation scenarios).

Barometric Pressure
The sensor location and its height shall be representative of the PV array location.
The accuracy of the barometric pressure sensor (acquisition and signal conditioning) shall be better than +/-1 hPa at range -50 to 60 °C (globally).

2.3.3.2 Weather Station - Type 2

In order to achieve a complete overview of environmental variables of the photovoltaic plant field, it is important to collect data on different locations. Besides the main weather station - Type 1, a Type 2 weather station containing a set of sensors that shall be installed and configured in predefined location of the plant. This location should reach its desired functionality while avoiding the creation of shadow in the solar modules.
The architecture of the required minimal weather station can be seen in Figure 2-2. All required accessories to fulfil the installation shall be supplied.

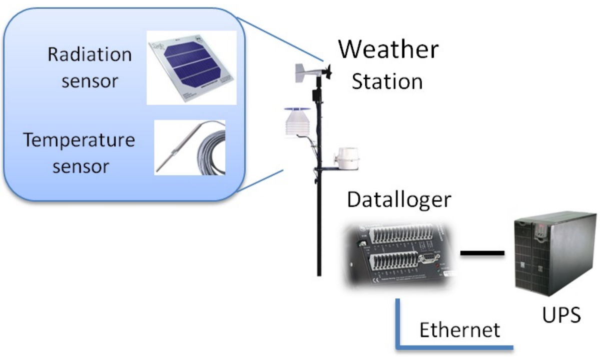


Figure 2-2: Weather Station Type 2 architecture.

An autonomous Weather Station Type 2 with the following characteristics shall include:

- The acquisition device (datalogger);
- The module temperature (accuracy better than 1K);
- The measurement of the solar radiation on the solar modules plane;
- The module temperature sensor;
- The measurement of the solar radiation on the solar modules plane by means of a reference cell;

- Ethernet Communication;
- Calibration Certificates;
- Energy backup (battery pack with charge regulator).

A data logger is required to deal with all the variables and, as mentioned before, make them available to the server. The data logger specifications are the same as mentioned for Weather Station Type 1. Additionally, the variables shall be acquired with the same predefined parameters in terms of quality, installation and sensors characteristics as for the Weather Station Type 1.

2.3.4 Communication Network

Among the several equipments included on monitoring system, a field network must be created, installed and configured. It includes the cable for powering all equipments supplied as well as all the network cabling.
As a requisite, since energy cabling induces Electromagnetic Interferences (EMI) on the communication, communication cables shall always be routed far away from energy cables (exception made to the Optical Fiber cable) by means of a metallic separator for wire trays and an admissible distance between pipes in ditches.

2.3.4.1 Optical Fibre Cable

The optical fibre cables used for the monitoring system shall have the following main characteristics:

- 50/125 µm (core size/cladding diameter) for optical fibre multimode cables;
- 9/125 µm for optical fibre monomode cables.

Network topology
The optical fibre cables shall be connected as a ring topology [5] as depicted in Figure 2-3.

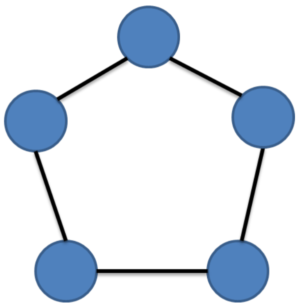


Figure 2-3: Network ring topology.

2.3.4.2 Ethernet Cable

The ethernet cables shall be shielded, twisted-pair (STP), preferably of category 6 in order to reduce the noise created due to “crosstalk” or system interference.

Network topology
The ethernet cables shall be connected as a star topology [5] as shown in Figure 2-4.

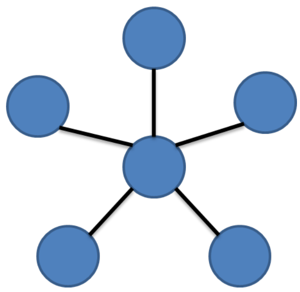


Figure 2-4: Network star topology.

2.3.4.3 RS485 Cable

Whenever necessary, RS485 network (physical network) will be made using Li2YCY[1] (TP[2]) 2x2x0,5mm^2 cable or Li2YCYv[3] (TP) 2x2x0,5mm^2 when extra protection is needed.

Network topology
RS485 cables shall be connected as a daisy-chain topology [5] as shown in Figure 2-5.

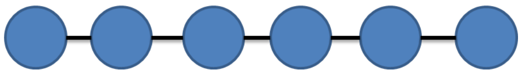


Figure 2-5: Network daisy-chain topology.

2.4 Conclusion

This chapter briefly introduced the SCADA history and its main components. An overview regarding the monitoring of PV plants was also stated. This first approach intended to join the generics of SCADA systems with the reality regarding equipment, facilities and field networks used in PV plants.

[1]Overall shielded low capacitance data transmission cable.
[2]Twisted-Pair.
[3]Li2YCY cable with reinforced outer sheath

It is possible to infer the inherent challenges regarding the integration of all the equipment presented in a monitoring system.

The main purpose of this chapter was to depict the reality that surrounds the PV plants monitoring, depict the importance of the commonly monitored equipment as well as the equipment used to monitor these devices.

The next chapter approaches all components that shall be taken into account for the monitoring platform for the PV plants development.

3. Requirements For a PV Plant SCADA System

3.1 Introduction

The process that led to the selection of the development framework used to build the SCADA application is depicted on this chapter. Some market solutions are enumerated.
In this chapter are stated the main requirements that a monitoring platform for the PV plants shall include. Requisites for variables, calculation, storage, GUI and other components are depicted along this chapter.
At the chapter's end, a special focus on the SCADA database is given. Subjects as database management, features and optimisation are stated in this chapter.

3.2 SCADA Survey

3.2.1 Development Software

In order to develop a new SCADA System, the following main aspects were considered:

- Low cost;
- User programmable;
- No tag limit;
- SQL compatibility;

- Remote monitoring;
- Number of supported protocols;
- Good technical support;
- Training.

Several SCADA development software manufacturers have been surveyed and Table B-1, B-2 and B-3 (Appendix B) depict the general features of each of the evaluated tools.
From the data gathered and from the tests realised, it was decided that the monitoring platform would be created using Movicon™ 11 [6] [7].
A complete Movicon™ 11 feature survey can be found in the software documentation [8–13].
Some of the features that led to Movicon™ 11 selection as development tool against other options are presented in the next paragraphs.

Intelligent Editor
One of the characteristics that the development software shall have is an intelligent editor: a fully integrated, flexible and intuitive editor. This flexibility should never undermine the potential of the software. In applications of this size, development times are a significant share of the total cost of monitoring systems. By decreasing development time, the cost of the system reduces and, consequently, this increases the developed solution competitiveness.

Graphics
The production process visualisation is paramount in any supervision system. The quality of the graphical interface is crucial for any monitoring system. A more transparent interface can promote the efficient platform operation. Therefore, the development software shall demonstrate its superiority in terms of powerful graphics features and speed.

Flexibility
The flexibility is an important requirement to fill. Adapting to the needs of the project without sacrificing work or know-how is an important requirement in the modern automation. Thus, the software development shall be all-in-one. It shall hold not only a wide range of tools for creating powerful monitoring platforms, but must also incorporate the most innovative technologies to facilitate the integration of the application with the “rest of the world”. In short, all the project needs shall to be satiated with features present on the development platform.

Tag Database and Connectivity
The reliable communication and high rate acquisitions are critical in any supervision system. The monitoring platform represents the meeting point off all acquired data, therefore Open

Database Connectivity (ODBC) in realtime shall be available. A rich library of native built-in Input/Output (I/O) Drivers plays a strategic role in the selection of software development. The software shall have purposely designed tools to promote more fast, smooth and transparent flow of information. Fully integrated OPC technology both in OPC Client and OPC Server modalities for data access hall be present in the development platform. Alarm and events management shall be another included feature. The platform shall allow intuitive alarm configuration as well as its notification via various channels (email, visual, others).

Security
The development platform shall guarantee maximum security and reliability. The User and Password management shall be complete and robust.

Web Access
The final application shall be web-enabled to guarantee openness and multi-platformness while maintaining performances, security and bi-directionality.

3.2.2 Other Solutions

It is important to be aware of other monitoring systems in the market. The next paragraphs depict some existent monitoring system commercial solutions.

Piensa Solar
"Piensa Solar" is a tool with which PV plant users can read, analyse and collate data. The manufacturer states that this monitoring system is able to optimise production, critical points analysis as well as communication with equipment like PLC, inverters and energy meters [14].

PVGuard
The "PVGuard" is a tool for PV systems remote monitoring and maintenance. Specially designed for PV plants in the MegaWatt range, "PVGuard" provides fast access to the operating data. Features as real-time visualisation of data, multi-plant managment from a single platform or alarm management with an integrated error log and error analysis are present in this tool [15].

SunPower
The monitoring system "SunPower" enables utility-scale solar power plant owners to visualise their PV solar arrays operation. Rapid commissioning and historical data reports are some of "SunPower" SCADA features [16].

These are some of the market solutions. It is hard to evaluate the presented solutions since the information available is not quite suitable. SCADA systems are usually commercial products,

property of the companies who developed them. Therefore, the systems specification is often published in a less scientific language but more commercial [17].
More inferences regarding these market analysis are given in this chapter conclusion.

3.3 Requisites

This dissertation objective is the development of a monitoring platform capable of collecting data from a photovoltaic plant. The system shall store data and allow their visualisation in the form of table or graph.
The SCADA software shall have functional features stated in the next subsections.

3.3.1 Software

The software development, configuration and calibration is requested to accomplish the system needs [18].
A SCADA system is broadly used to portray centralised control and management solutions in a wide range of areas.
A SCADA system includes several entities including hardware (input and output devices), controllers, networks, communications equipment and a high level part comprising general software and human machine interface (HMI), i.e., the user interface. These pieces all together can be seen as the central system - the SCADA system.
Further information about the monitoring software is stated in Section 4.2 and 4.3.

3.3.2 SCADA architecture

The system provides monitoring capabilities for all the devices included in the PV plant. It shall provide local and remote (via internet) client access, showing data from the physical installations, energy production, meteorological data conditions and others, converting this system into a powerful tool to take preventive and corrective actions.
All this information shall be processed and presented in a user friendly and comprehensible way, by means of tools developed for the specific plant. The SCADA data acquisition frequency shall be the fastest possible without losing information or compromising the system health.

3.3.3 Variables calculation and storage

Storage
The variables data acquisition from equipments shall be made at a minimum of one minute period.
Errors, events and alarms shall be acquired whenever they occur (as fast as possible).
Stored variables are important for photovoltaic plant operation and monitoring. It is important

to perform this task in such a way that will give to the PV plant operator the best overview of the installation and, at the same time, give important guidelines for solving possible errors or problems.

The variables shall be calculated according to defined standards where the raw data is acquired at a given frequency.

Calculated or correlated variables shall be stored with 10 minutes period.

The Table 3-1 presents the referred periods.

Table 3-1: Variables storage period and type.

Variable	Period	Type	Notes
Energy	10 min	Sum	last 10 minutes
Irradiance	10 min	Average	from minute 1 to 10
Power	10 min	Average	from minute 1 to 10
Wind Speed and Direction	10 min	Average	from minute 1 to 10
	10 min	Maximum	from minute 1 to 10
Ambient Temperature	10 min	Average	from minute 1 to 10
	10 min	Maximum	from minute 1 to 10
	10 min	Minimum	from minute 1 to 10
Module Temperature	10 min	Average	from minute 1 to 10
	10 min	Maximum	from minute 1 to 10
	10 min	Minimum	from minute 1 to 10
Pluviosity	10 min	Average	from minute 1 to 10
Humidity	10 min	Average	from minute 1 to 10

Calculation

It is important to note that the calculation performed depends on the variable type. For instance, energy is incremental. Therefore, to calculate the produced energy during 1 hour, it is necessary to subtract the value at minute 0 from the value at minute 60. Concerning irradiance or power (among others), for 10 minutes, values are averaged and shall be based on last 10 minutes, i.e., from 00:01 to 00:10 and excluding minute 00:00.

Table 3-2 presents the reference method for performing variable calculation.

Table 3-2: Calculation method and storage of acquired variables.

Period	Type	Calculation	Shown as
T min	Sum	$value\_minute_T - value\_minute_0$	10 min, hour, day, month, year
10 min	Average	$\frac{\sum_{i=1}^{10} value\_minute_i}{10}$	00:10, 00:20, ..., 01:00
10 min	Maximum	$MAX([value\_minute_1; value\_minute_{10}])$	00:10, 00:20, ..., 01:00
10 min	Minimum	$MIN([value\_minute_1; value\_minute_{10}])$	00:10, 00:20, ..., 01:00
1 hour	Average	$\frac{\sum_{i=00:10}^{01:00} value\_10minute_i}{6}$	00:00, 01:00, ..., 23:00
1 day	Average	$\frac{\sum_{i=01:00}^{00:00} value\_hour_i}{24}$	day 1, day 2, ..., day n^*
1 day	Sum	$value\_minute_n - value\_minute_1$	day 1, day 2, ..., day n^*
1 month	Average	$\frac{\sum_{i=1}^{n^*} value\_day_i}{n^*}$	month1, month2, ..., month12
1 year	Average	$\frac{\sum_{i=1}^{12} value\_month_i}{12}$	year 1, year 2, ..., year n

These calculations shall be taken into account for photovoltaic plant variables. As stated, acquiring data from photovoltaic plant equipment must be made according to specified methods, not only presented on this thesis but also based on existent standards.

3.3.4 Variables, Interface and Screens

3.3.4.1 Variables

The following data shall be monitored, in real-time, by the SCADA software:

- All data provided from the inverters;
- All data provided by the energy meter and energy analyser;
- Meteorological information;
- Total system performance and malfunction;

* The value is not constant. It depends on the number of days a month may have.

- DC power production;
- AC power production;
- Accumulated, daily, monthly, and yearly power production;
- AC power output;
- Sunlight conversion efficiency to AC power;
- Sunlight conversion efficiency to DC power;
- Inverter DC-to-AC power conversion efficiency;
- Avoided pollutant emissions, for example, CO_2;
- Any other variables not mentioned that may be important to the monitoring task.

3.3.4.2 Interface

For better visualisation of all the variables, some graphical and informative windows shall be present.
The graphics and reports should be dynamic, where the variables shall be selected from a list including all the variables present in the database, organised by equipment. It shall be possible to present variables from different devices.

3.3.4.3 Screens

The SCADA software shall present data to the user by means of screens. The following items enumerate which information shall be presented in main screens.

Plant Location Screen
This screen shall include:

- The plant name;
- The plant country;
- The plant GPS coordinates;
- The plant map with equipments and devices location in its respective location;
- The meteorological data (Solar radiation, ambient temperature, panel temperature, wind speed, wind direction and pluviosity);
- The yield Energy (from the energy meter);

- The active Power (from the energy meter).

Production
This screen shall include a table with the following data:

- The timestamp;
- The energy meter energy yield;
- The sum of inverters energy yield;
- The sum of Junction Boxes energy yield;
- The irradiation for each irradiance sensor;
- The maximum wind velocity;
- The average, maximum and minimum ambient temperature.

By default, the information shall be populated with the current data and according to the timestamp interval chosen by the operator. For example, to show the daily production, the information shall be populated with the current daily data. To show the monthly production, the information shall be populated with the current month data and so on.
The user shall be able to select a specific timestamp in order to check historical data. It shall be able to generate a graphic and export this data to a file.

Performance Ratio
This screen shall include a table with the following data:

- The last update timestamp;
- The last hour Performance Ratio;
- The daily Performance Ratio;
- The monthly Performance Ratio;
- The annual Performance Ratio.

Performance ratio calculation shall be made according to Equation 3.1 (adapted from [18]).

$$PR = \frac{E_{prod}(\Delta\tau)[kWh] + E_{cons}(\Delta\tau)[kWh]}{\frac{G_{total,generator\_surf}(\Delta\tau)\left[\frac{kWh}{m^2}\right]}{G_{STC}\left[\frac{kW}{m^2}\right]} \times P_p[kWp]} \times 100 \qquad (3.1)$$

Where:

- $\Delta\tau$ is the period of time where the calculation is referred to;

- $E_{prod}(\Delta\tau)[kWh]$ is the energy produced by the installation during the period in kWh (from energy meter at Medium Voltage(MV) side);
- $E_{cons}(\Delta\tau)[kWh]$ is the energy consumed by the PV equipment, in kWh, measured by the energy analyser (from auxiliary services) during the installation production period (night energy consumption shall be excluded);
- $G_{total,generator\_surf}(\Delta\tau)[\frac{kWh}{m^2}]$ is the total irradiance on the PV modules plan. The measured value is obtained from the average of all the irradiance sensors installed on the same level of the photovoltaic modules;
- $P_p[kWp]$ is the installed peak power defined by contract and paid by the costumer;
- $G_{STC}[\frac{kW}{m^2}]$ is the Standard Test Conditions (STC) irradiance value which specifies a temperature of 25°C and an irradiance of 1000 W/m^2 with an air mass of 1.5 (AM1.5) spectrum.

Performance Ratio formula to be included on the software is highly dependent on the project, contract or even client. Equation 3.1 depicts a calculation that is commonly accepted as the main formulation for the PV systems.

Alarms and Events
All alarms and events that occur on photovoltaic plant installed equipments shall be presented on a specific menu build for this purpose as well as stored in the database.

Devices
The data present on each device (Junction Boxes, Inverters, etc.) dependant screen shall be realtime data.

Users
The SCADA interface shall have accounts with passwords, in which different users have different permissions (a user will only have the basic monitoring data, according to its permissions). The monitoring can be done through a web page by entering a username and password.

The following users and their respective privileges shall exist in the SCADA software:

- Simple user: It shall only have access to the global synoptic;
- Normal user: It shall have access to the synoptic and all the functionalities of the system, like checking stored data, graphics, etc. (It shall not have access to the power control, Performance Ratio menu nor administration menus);

- Advanced user: It shall have access to the synoptic and to all the system functionalities, like checking stored data, graphics and Performance Ratio Menu as well as access to the Advanced User Control Panel. It shall not have access to the Administrator Control Panel;
- Administrator: It shall have access to all the SCADA software functionalities.

The mentioned users are those commonly considered in SCADA systems.

Administrator control panel
There shall exist in the SCADA software an Administration Control Panel. This Control Panel shall have the following features:

- Set the sensors calibration values;
- Set the photovoltaic plant power (for Performance Ratio Calculation);
- Set the global plant parameters (project name, address, country, position coordinates);
- Add and remove users, as well as to reset users password.

For data visualisation, a web server shall be installed in the SCADA server to allow web browser connections.

3.3.5 SQL Database

All data, variables, warnings, errors and alarms shall be present in a SQL database.

3.3.5.1 Structured Query Language

SQL language and relational database is a technology present in almost all the computers industry. It is considered the standard computer database language. Two of the largest software companies in the world - Microsoft and Oracle - have SQL as core of their enterprise products [19]. SQL is used for database management. It works with a database type - relational database. A Database Management System (DBMS) is required to control a database. SQL works as depicted in Figure 3-1.

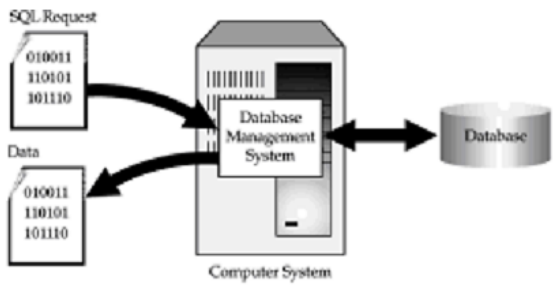


Figure 3-1: SQL for database access [19].

The DBMS processes requests and returns data from the database. This data exchange approach is called *query*.
SQL goes beyond of just being a query language. It is responsible for controlling all DBMS provided functions. Such function are [19]:

- Data definition;
- Data retrieval;
- Data manipulation;
- Data sharing;
- Data integrity;
- Data control.

SQL is used to communicate with the DBMS. Table 3-3 presents the main SQL features and benefits.

Table 3-3: SQL features and benefits (adapted from [19]).

Features	Benefits
Vendor Independence	SQL is offered by all of the leading DBMS vendors.
Portability	SQL based databases run on computer systems from mainframes to handheld devices. Economical personal computers can be used to prototype a SQL-based database application before moving it to an expensive multi-user system.
Standards	SQL standard was published by the American National Standards Institute (ANSI) and the International Standards Organization (ISO) in 1986, and was expanded in 1989 and again in 1992.
ODBC and ADO	Desktop and server versions of Windows provide standardised relational database access through Open Database Connectivity (ODBC). Microsoft has enhanced ODBC support with higher-level, more object-oriented database access layers as part of Active/X (Active/X Data Objects, or ADO)
Relational Foundation	The relational databases table structure is intuitive to users, keeping the SQL language simple and easy to understand.
High Level, English Structure	SQL is easy to learn and understand because its statements look like simple English sentences.
Interactive Ad-Hoc Queries	Due to this feature, data becomes more accessible and that represents that users can get answers in minutes or seconds. That is a contrast to the long time that would take to program custom reports.
Programmatic Database Access	All-in-one tools for programmatic access and query facility.
Multiple Views of Data	This feature can be used to enhance the database security and custom it to particular need of individual users.
Complete Database Language	SQL feature go beyond just data retrieval. SQL provides a complete, consistent language for creating a database, managing its security, updating its contents, retrieving data, and sharing data among many concurrent users.
Dynamic Data Definition	The database structure can be changed and expanded dynamically, even when the database is being access by other users.
Client/Server Architecture	Link between “front-end” computer systems optimized for user interaction and “back-end” systems specialised for database management. This provides, for example, access to corporate data from personal computer applications.
Internet Database Access	SQL is an internet data access standard. SQL have been established as standard link between the application and database tiers.

3.3.5.2 SQL Version

In order to make the SCADA application competitive, the Microsoft SQL Server Express 2012 was used. The overall cost is an important issue to take in account but, definitely more important, is the software quality. The decision to use an EXPRESS edition would be not taken if that would mean a bad quality final result. The EXPRESS edition was experimented in a real application and performed good. EXPRESS edition presents the main same features as the full version despite some limitations.

The Microsoft SQL Server Express is free to download, distribute and use. It includes several GUI tools for database management:

- SQL Server Management Studio Express;
- SQL Server Configuration Manager;
- SQL Server Surface Area Configuration Tool;
- SQL Server Business Intelligence Development Studio;
- SQL Server Profiler.

The SQL EXPRESS edition main limitations are:

- The Maximum database size of 10 GB per database;
- No SQL Server Agent service;
- Single physical CPU, but multiple cores allowable [20];
- 1 GB of RAM (runs on a system with any RAM amount, but uses only at most 1 GB).

Taking in account the large amount of data to be stored, the maximum database size of 10 GB per database represents a considerable limitation. The solution to this issues is presented in the next section.

3.3.5.3 Database Layout

The development software - Movicon™ 11 - includes a native support for ODBC. The real-time data storage is accomplished by ODBC link. ODBC is a Microsoft standard and the ODBC manager files (drivers) are property of the respective owner of each single database application [8].

When developing the monitoring platform, an ODBC link shall be configured between the SCADA project and the SQL database. In this way, a “main” database is created. This database shall have one or more tables to store data regarding:

- Alarms;
- Equipment;
- System messages.

Alarms

An historical record about the PV plant alarms shall be stored in the database table. Normally, the alarm table structure is managed by the development software. This origins a table with excess of information. This information is not very "user friendly". A view shall be made to guarantee an optimised alarm visualisation. Table 3-4 depicts the layout for the alarm view.

Table 3-4: Alarm view example.

Timestamp	Equipment	Code	Description	Status	Duration	Details
2014-06-26 10:33:18	Inverter 3		Solar Voltage Faulty	Inactive	0 Days, 0:04:30	Alarm
2014-06-25 14:28:31	Inverter 2		Mains Not Connected	Active		Alarm

It is important to state that for this kind of system, warnings, errors and alarms shall be stored in real time.

Equipment type

There shall be one table per equipment type (see Table 2-1). Since there can be more than one individual device per equipment type (for example, 60 junction boxes), the table shall have an ID column to identify the device. The timestamp column content shall be according to the time period to which the data relates to. For example, if the time interval refers to 1 minute or 10 minutes, the timestamp format shall be "yyyy-mm-dd hh:mm". If the time interval refers to 1 day, the timestamp format shall be "yyyy-mm-dd". In case of 1 month, it shall be "yyyy-mm" and "yyyy" in case of 1 year. Table 3-5 depicts a table example for the Weather Station.

Table 3-5: Equipment data table example.

Timestamp	ID	Irrad Module Plane(W/m2)	...
2014-06-26 12:40	Weather Station T1	1002,68	...
2014-06-26 12:50	Weather Station T1	1012,72	...
2014-06-26 13:00	Weather Station T1	1012,3	...
2014-06-26 13:10	Weather Station T1	1018,57	...
...	...	...	...

System messages

The system messages shall not be accessible for the SCADA operator. It shall only be accessible for the system developer. The purpose for this messages in table format is to have proper debug messages for hipotetic system errors. It shall also provide auditing regarding system booting/shutdown, as well as logged users among other relevant information. Table 3-6 shows a layout example for the mentioned database table.

Table 3-6: System messages table example.

Timestamp	Message
2014-06-26 10:33:18	Error Number: -2147467259 Error Desc: Transaction ...
2014-04-23 14:23:18	Error Number: -2147217833 Error Desc: Arithmetic overflow ...
2014-03-03 09:13:18	Error executing Basic Script ... (line 129, offset 56) ...

Databases Organisation

As stated in subsection 3.3.5.2, the SQL EXPRESS edition has a maximum database size of 10 GB. It will be impossible to store all the data in one database due the large number of variables and the amount of time that the PV plant will be operational. To overcome this limitation, multiple interconnected databases were used. Figure 3-2 depicts the databases organisation that shall be implemented.

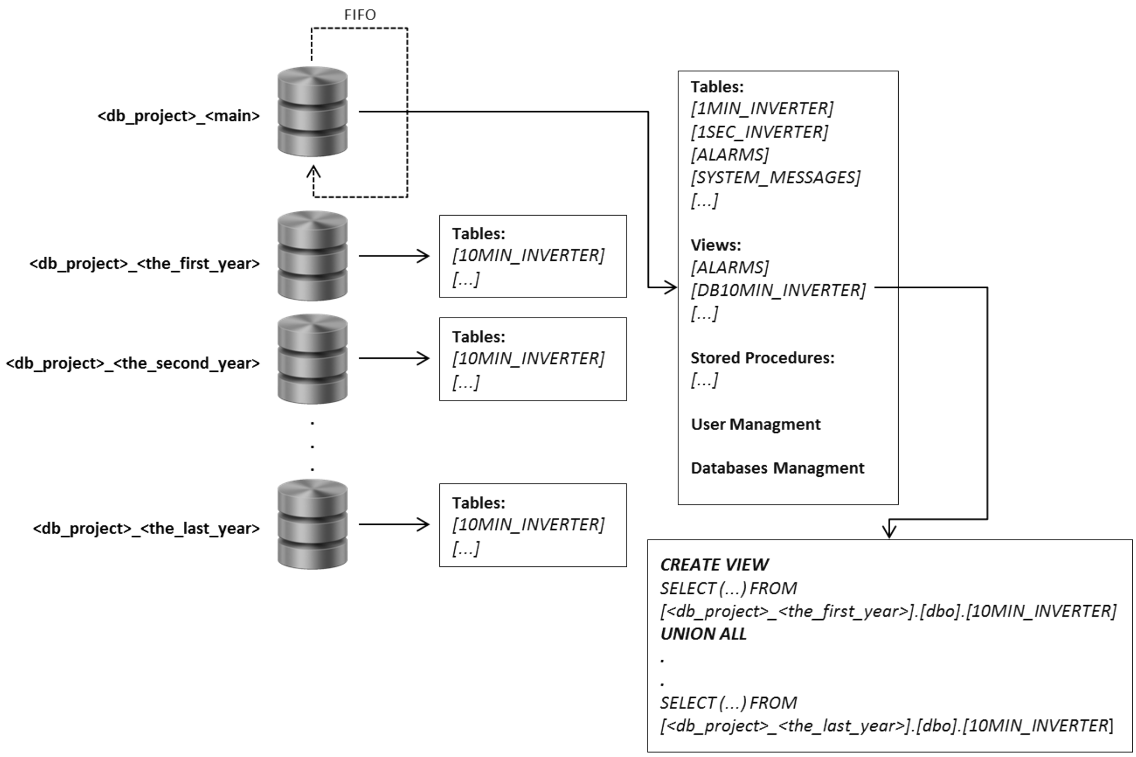


Figure 3-2: SQL organisation.

Regarding the field variables data storage, there shall be two types of databases:

- Main database
  - In this database, the data directly acquired from the devices is stored;
- Year database

- In this database, data resulted from calculations mentioned in subsection 3.3.3 is stored. There shall be one database per year. The year identification shall be on the database name. This database shall have information regarding its year;

A minimum of 20 databases (so, 20 years) shall be created. If a system goes online in 2013, then there shall be database "from" *database_2013* to *database_2032*.

Views, per equipment/table, shall be created in order to access all 10 minute data from all the yearly databases obtained from the main database. For example, all yearly databases have a table named *10MIN_INVERTER* where 10 minute data (for the specific year and equipment) is stored. The view *DB10MIN_INVERTER* gathers the information from all tables, per database, using the UNION ALL statement as depicted in Figure 3-2. Only the main database shall be visible to other users. For non-privileged users, this organisation works as if all data is stored in only one database element.

The view depicted in Table 3-4 shall be created in the main database as well as stored procedures. User and database management queries shall be fired against the main database.

As stated, each database has a size limitations. Therefore, the SCADA application shall delete the older data from the database in order to never reach its limit. The data from acquisitions shall be in the database for, at least, three months. It shall only be deleted, after three months, if the 10 minute calculation had already been stored in the yearly database.
The deleted data shall not be permanently lost since the databases shall have monthly backups. Each monthly backup shall be saved in an independent file. This method will prevent the new backup to override the previous one and therefore the data that had been erased three month ago will be present in the last month backup.

It shall be possible to export all the SQL database data to third party software (for example Microsoft Excel).

The use of multiple interconnected databases increases, even more, the importance of efficiently use the SQL database. Therefore, it is imperative to optimise the database build, management and usage. Moreover, it is also important to define correct maintenance routines for the database.

3.3.5.4 SQL Optimisation and Maintenance

The SQL database is a vital element for the monitoring platform. When it is efficiently used, the results are highly scalable, flexible and manageable system.
The data gathered from the PV plant is stored in more than one individual database. Moreover,

the monitoring platform fires a quite large number of queries against these databases. Queries with statements as SELECT, UPDATE, INSERT or DELETE fired by the SCADA shall be efficiently built in order to enhance the SQL database performance. The databases tables shall also be correctly built.

The SCADA application shall be able to evaluate the database performance and take maintenance tasks periodically.

Optimisation

Optimisation brings vast improvements in the performance of the application. The following optimisation measures shall be implemented:

- Pre allocating database file space:
  - This can improve the performance for loading large data quantities and it keeps the database files more adjoining. The 10 GB limitation per database is a premise, hence it shall not be defined a database autogrowth; it can lead to excessive file fragmentation on the disk.
- Create table indexes:
  - This is a way to speed up searching in the database. Indexing the right columns can prevent SQL from searching an entire table where SELECT statement with WHERE clause is fired against. Achieving the right number of indexes requires database testing and monitoring to find the best balance. Indexing can have drawbacks, tables that are frequently updated cause the indexes to change and this can cause data fragmentation.
- Efficient built query:
  - The SCADA application shall dynamically build a query (columns selection, data filtering, etc.) in order to retrieve data from the database. The writing of the query shall be made in order to optimise the search. It shall keep a narrow search using, for example, WHERE clauses. When applicable, stored procedures shall be used instead of heavy queries in order to reduce data traffic. The use of clauses such as TOP or UNION ALL instead of just UNION optimise the final query. The use of SQL cursores shall be avoided. When this features is necessary, it shall be done by VB scripts in the SCADA application (using FOR cycles, for example). Some of the queries that shall be built dynamically shall be tested using the SQL *query plan* tool. This tool helps to evaluate the query cost for the SQL server. It shall be especially used to evaluate INSERT queries used for data calculation and storage.

In order to ensure the database optimisation during the plant life cycle, maintenance tasks shall be created.

Maintenance
The SCADA application shall be capable to provide maintenance tasks for the SQL database. The following maintenance features shall be implemented:

- Manual and automatic (periodic) databases backup:
  - The monitoring platform shall provide an interface that enables the operator to backup the database. Moreover, it shall provide a feature that automatically creates database backups in a predefined time interval.
- Intelligent table index rebuilding/reorganisation:
  - Due to heavy INSERT, UPDATE, and DELETE operations on the database tables, index fragmentation may occur. High index fragmentation, increases either scanning/seeking times. Thus, data retrieval operations perform slow. The SCADA system shall be able to evaluate the index fragmentation of a table and, if necessary, fire a query against the specific table in order to reorganise or rebuild its indexes.
- Check size of database files:
  - The databases size shall be periodically checked. This feature allows the system user to evaluate if the database size is growing accordingly to the expected.
- Database growth management:
  - Excessive and unexpected database growth can occur. If this growth threatens the database health, the SCADA shall start to erase the older data (in case of the main database). If this situation happens in the yearly database, the system shall inform its administrator.
- Intelligent database selection to store data:
  - Since there will be one database per year, the monitoring system shall dynamically infer in which database to store the data. This shall avoid a new “hand made” system commissioning every time the year changes.

A SQL database optimisation and maintenance represents a quite vast range of actions. It were depicted a few features that shall be implemented in the SCADA system in order to make the database management as free as possible from man intervention.

3.4 Conclusion

To develop the monitoring platform, a development software is required and, for this work, MOVICON ™ 11 was selected. It is an robust and complete software that fulfilled the pre-requisites. Another SCADA market solutions were mentioned. SCADA systems are proprietary solutions. It is difficult to evaluate them since the information provided by the developer companies have commercial connotation instead of a more scientific one.
Another approach could be to subcontract a company to develop the SCADA system following provided technical specifications. Contracting other companies to develop the solution implies know-how transmission. This know-now is not free of falling in the contractor company's competitors hands. Moreover, any future upgrade or correction in the SCADA system results in considerable costs. For these reasons, it is necessary to change paradigm. The adopted solution is to develop an own internal monitoring system instead of searching the market for suited solutions.

The main requisites for the platform were stated. These requisites do not represent the final features present in the developed monitoring system. Instead, they represent the key characteristics that the SCADA shall have. More features, screens or KPI end up being created for the final solution.

The data storage is a key factor for a SCADA system. In this chapter all concerns regarding the SQL database implementation were stated. It is a vital element for the final developed platform. Besides being responsible for all data storage from the PV plant, it will also be the interface for the Martifer Solar's Operation Management System (OMS).

The following chapter presents the developed monitoring platform for photovoltaic plants.

4. The Developed Monitoring Platform

4.1 Introduction

Monitoring and performance analysis of PV plants become extremely important requirements nowadays. During the plant equipment life cycle, it is imperative to consider the costs of operation, costs of maintenance and reducing yield due to the performance degradation. It becomes essential to ensure high performance, low downtime and fault detection in a PV plant. On the plant site, data from the equipment like weather stations and inverters need continuous monitoring and performance analysis. A SCADA system provides the proper field equipment integration and communication as well as data integrity.

This thesis output is a tool developed with the purpose of equipment monitoring, data storage and visualisation. It provides graphical display for monitoring plant production and equipment status. The developed monitoring platform includes screens with data tables, trend graphics and alarm management. This interface can be accessed on a local station at the plant site. This interface can also be accessed remotely by authorised users through a web client interface.

This chapter aims to depict the monitoring platform synoptics and features. It shall be stated the purpose/functionalities of the main synoptics. Alongside, this chapter presents the main challenge faced to implemented the referred and enumerated features. Through this chapter, images regarding the monitoring platform will be shown. These images may sometimes not represent the whole screen but instead a relevant part of it. Some of the images were taken from an application server that was not in production and, therefore, the variables do not necessarily represent real values.

4.2 Operational Graphic User Interface

Entering the monitoring platform, the user is able to navigate between synoptics. Each synoptic has relevant information for the PV plant performance analysis.

4.2.1 Accessing

The monitoring platform can be accessed on a local station or through a web client interface. In order to access the system through a web client interface user shall open an internet browser and type the provided URL, for example: http:\\www.smartmsyst_location.com.

The plant monitoring system operation and management requires user authentication. The platform grants access only after an user's authentication has been verified and confirmed. The system has two types of users: operator and administrator. Each user has an exclusive password and access level. User access privileges are hierarchical, meaning that the administrator user has full access to the system followed by the operator user. Either accessing the system on a local station or through a web client interface, the user shall authenticate by using its credentials.
Loaded all configurations, a login screen appears, as depicted in Figure 4-1.

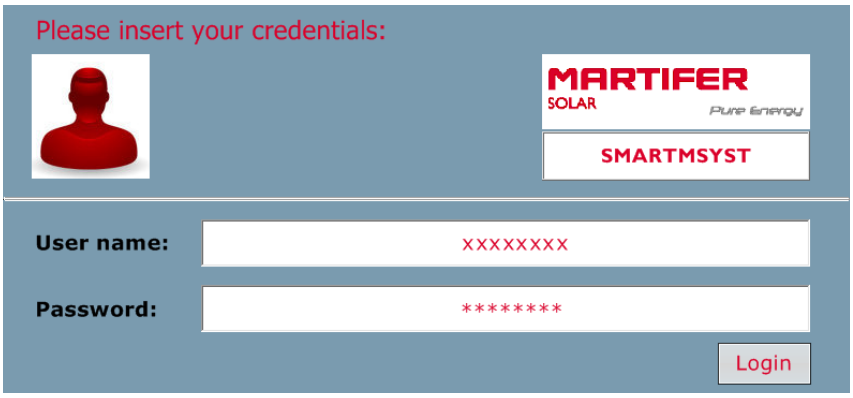


Figure 4-1: Monitoring platform login.

Figure 4-1 illustrates the fields that shall be filled with valid user credentials. If authorised, after the login the user will be redirected to the platform home screen. If unauthorised, a message indicating invalid credentials is shown. Without valid credentials an user have no access to the SCADA platform.

4.2.2 Home

Once logged into the platform, the home screen is the first synoptic presented to the operator. Figure 4-2 depicts the home synoptic layout.

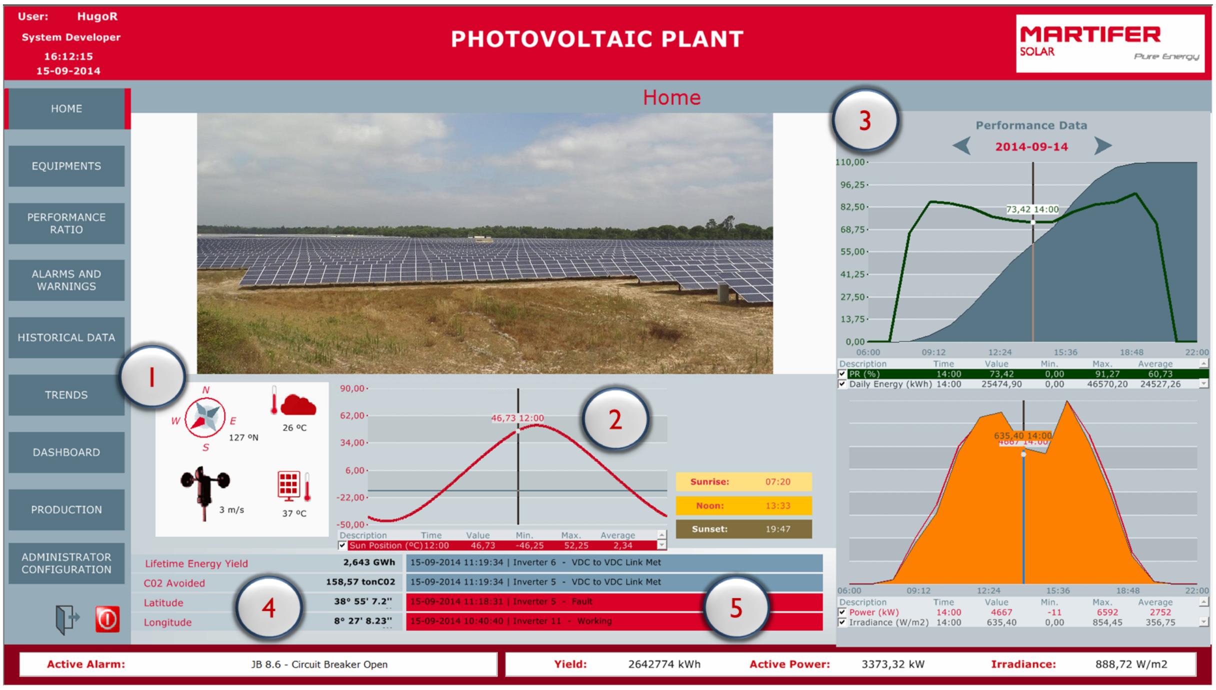


Figure 4-2: Home screen.

The home screen is divided into several areas. There are three specific areas - not enumerated in Figure 4-2 - that are always presented through all the synoptics: the header, the footer and the navigation menu. The header shows information such as current user, time and project name. The footer presents realtime yield energy, active power, irradiance and last active alarm. The navigation menu on the left offers the possibility to navigate between all synoptics.

On home screen area 1 is possible to check the principal meteorological variables: wind speed, wind direction, ambient temperature and PV module temperature.

In area 2 is depicted a graphic that illustrates the sun elevation angle during the present day. It is also possible to check the sunrise, sunset and solar noon time. All data present on area 2 is calculated using astronomical algorithms [21].

In area 3, two trend plots depict data from current day production. The first above plot depicts the daily produced energy and Performance Ratio. The second one depicts the solar irradiance and inverters supplied power. The data is one hour based. The one hour statistic calculations are made according to the Tables 3-1 and 3-2.

In area 4, plant coordinates, lifetime yield energy and avoided CO_2 emissions information is presented.

The area 5 presents the last four occurred alarms. Each message background color changes according to its alarm severity.

4.2.3 Equipments

The equipment screen depicts the PV plant layout as well as the system main realtime variable values. Figure 4-3 presents the mentioned screen.

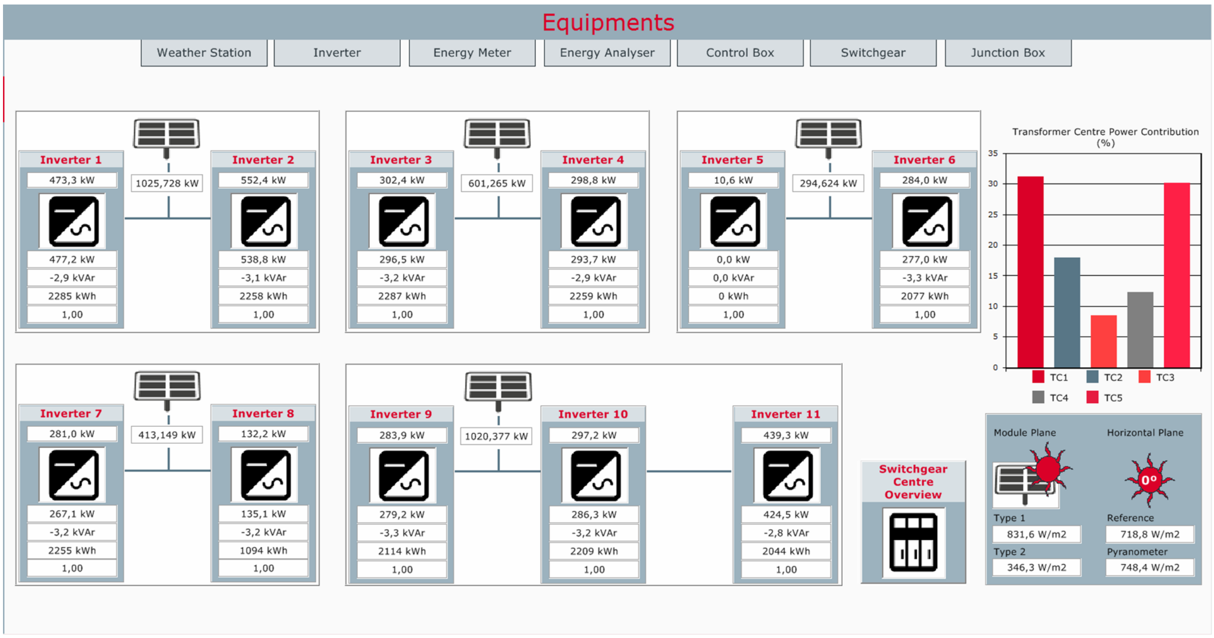


Figure 4-3: Equipment screen.

This screen shows the main devices grouped by its corresponding facilities. Placing the mouse over the *Switchgear Centre* object (bottom-right of Figure 4-3), a pop-up window appears showing the main variables of the devices placed in this facility. These devices are the energy meter, energy analyser, switchgear protection and the power plant controller (control box).

On the upper part of this synoptic, there are tabs that enable the operator to navigate between individual equipment synoptics. Each of these synoptic enables the operator to check real time data for the corresponding equipment.

4.2.4 Realtime Equipment Interface - Inverter Example

This type of synoptics intend to show realtime data from one individual device. There shall be a realtime equipment interface per equipment type (Inverter, Weather Station, etc.). Figure 4-4 depicts this interface for the Inverter.

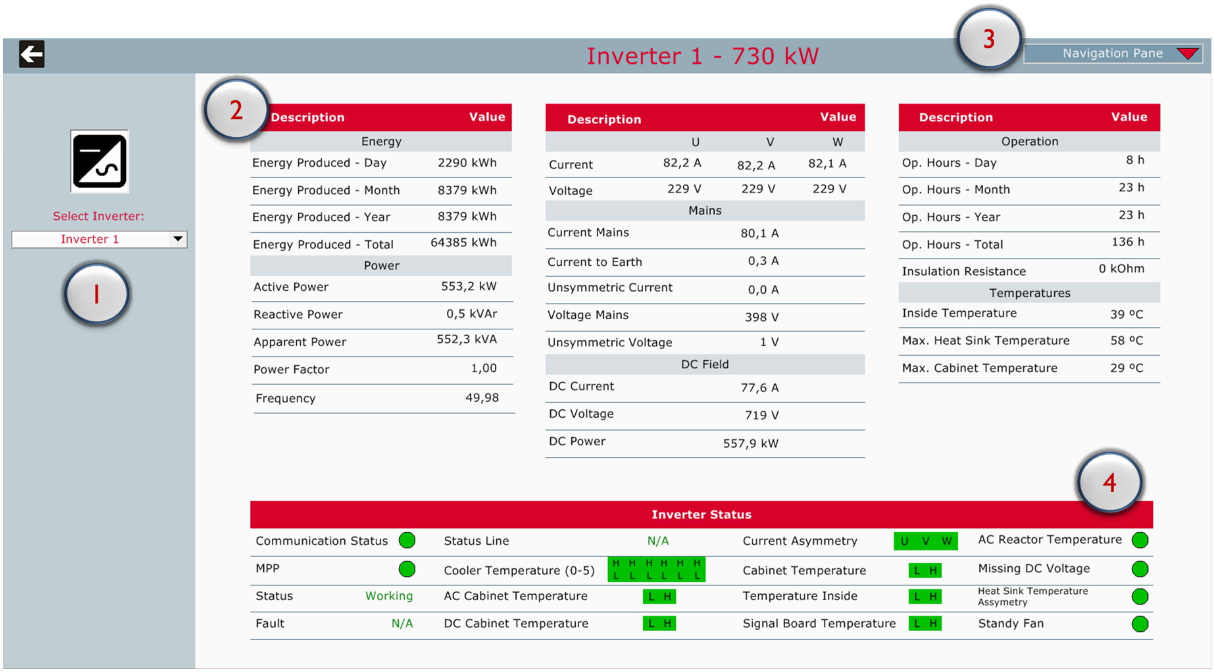


Figure 4-4: Inverter - realtime data synoptic.

The variables monitored and shown in realtime interface screens are equipment dependant. The synoptic working space is composed by four specific areas:

1. Menu for equipment selection - A drop box allows the user to choose from a list of existing options. The list of options consists in all plant equipments. Taking the inverter data as an example, the available options in the combo box will consist in a list of the inverters present on the plant. The data visualised in the screen is related to the select equipment in the drop box (see area 1 in Figure 4-4).

2. Tables for showing monitored data - After selecting the equipment, area 2 will present information about the previously selected equipment. Each table has two columns, a description column of the variable and a column with its respective physical value. When there is a significant number of variables, more than two tables will be presented. When the number of required tables cannot fit in the screen, page control buttons will appear on the top centre, between the two tables. These control arrows allow user to navigate between tables. Page 1 shows table 1 and 2, page 2 shows table 3 and 4 and so on.

3. Equipment navigation pane - Enable the operator to navigate between individual equipment synoptics (see area 3 in Figure 4-4). Figure 4-5 depicts the available options

when clicking this button. The option is present in all realtime equipment interface screens.

4. Tables for showing equipment status data - A table on the bottom of the page shows the equipment digital variables status (see area 4 in Figure 4-4). The status of the variable is shown in a red or green coloured circle. For example, a red circle following the text "Missing DC Voltage" means that no DC voltage is being supplied to the select Inverter.

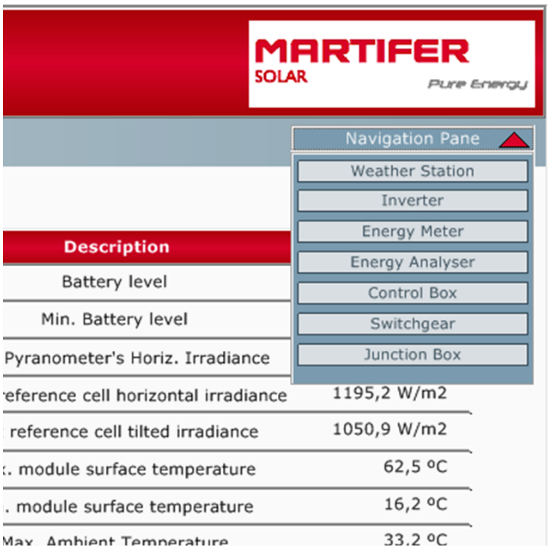


Figure 4-5: Navigation pane.

4.2.5 Performance Ratio

The performance ratio is obtained by the output AC Energy delivered as a proportion of the total DC Energy which the solar modules should be able to deliver under certain meteorological conditions.

This synoptic intends to show in a simple manner the actual performance ratio (in an hour basis) as well as the daily, monthly and annual performance ratio.

Besides the numeric representation, the performance ratio is represented by horizontal gauges: grey gauges symbolise current performance ratios and dark blue gauges symbolise the target performance ratio. The partial synoptic element depicted in Figure 4-6 gives the user a graphical tool to compare target performance ratio (%) against current performance ratio (%).

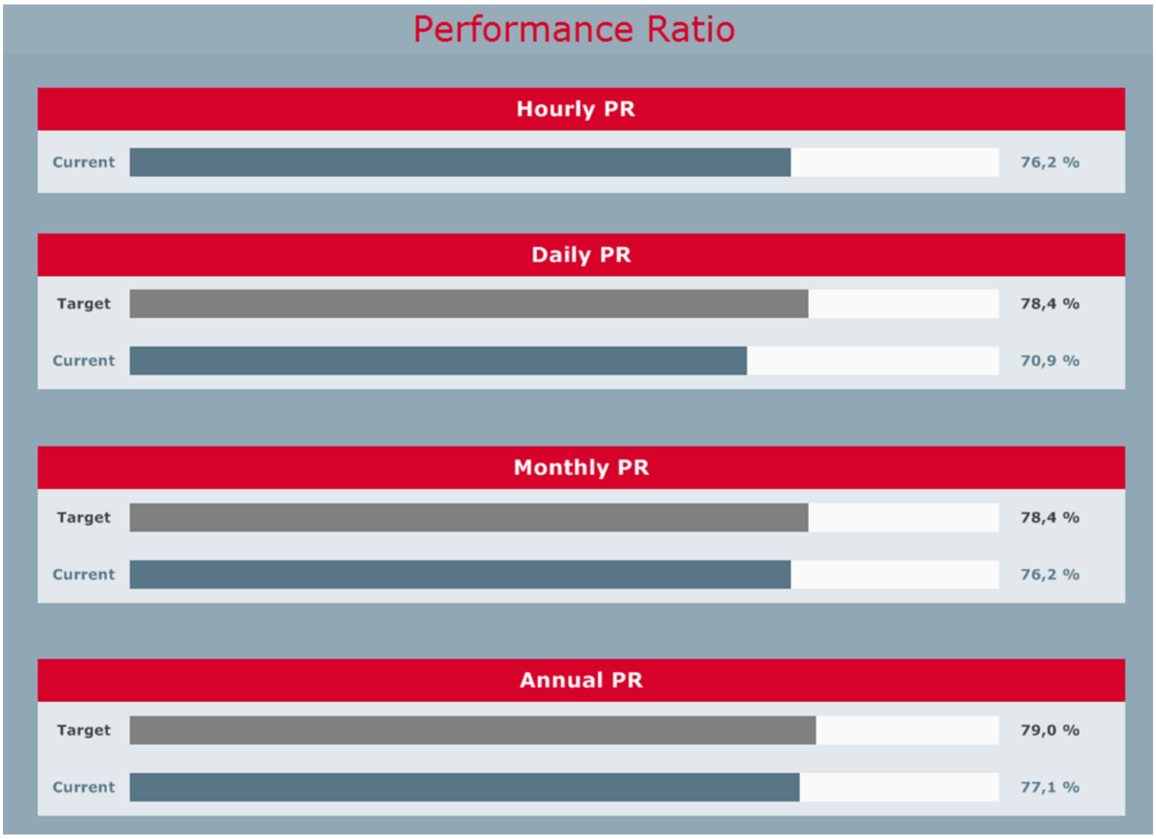


Figure 4-6: Performance ratio screen.

The target performance ratio values are obtained from the preliminary PV Plant design by means of simulations. The current performance ratio values are calculated using the actual measured of production and meteorological data.

4.2.6 Alarm Management

4.2.6.1 Alarms and Warnings - Realtime

Alarm messages present to the user information about equipment status. The main objective is to detect abnormal situations as soon as possible. Figure 4-7 shows alarm management screen.

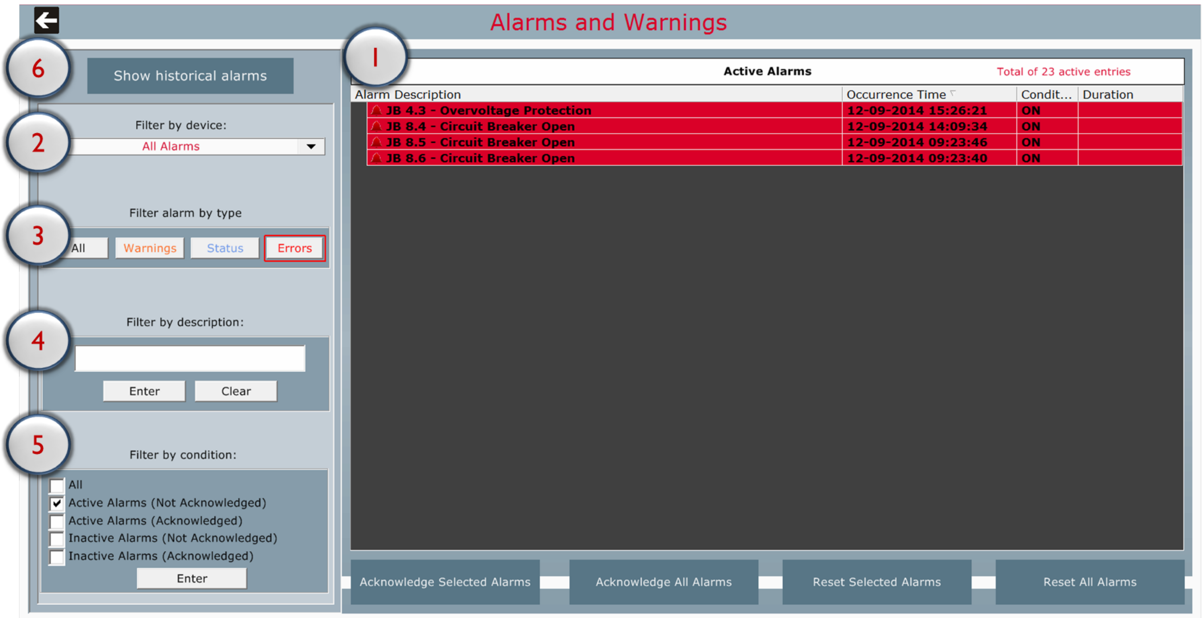


Figure 4-7: Alarm window details.

The working area of the Alarms and warnings screen is composed by six specific areas:

1. The alarm window;
2. The area to filter alarms by device type;
3. The area to filter alarms by type;
4. The area to filter alarms by text;
5. The area to filter alarm by condition;
6. The button to see the alarms historical information.

The alarm window displays alarm messages. Alarm messages are ordered chronologically by default. In order to better distinguish between alarm severities, different background colours were assigned to each alarm type text message, as described in Table 4-1.

Table 4-1: Alarm colour.

Type of alarm	Colour
Error	red
Warning	yellow
Status	blue

The alarm window has auxiliary buttons that allow operation like acknowledge or reset one or various alarm and turn on or off a sound alert that is fired whenever an alarm is activated. When an alarm occurs it will be displayed in the alarm window with the text “ON” in the “Condition” column. When an alarm switches from the “ON” condition to the “OFF” condition, the text in

the “Condition” column will also change to “OFF”. Even with the “OFF” condition, the alarm will remain displayed in the alarm window until the user resets this alarm.
In order to provide the user with a more organised method for searching the alarm window, filters were created. If a several number of alarms are triggered inside a small time period or a several number of “not reset” alarms are present in the alarm window, it may be possible to filter these alarms.
Filters are located on areas 2, 3, 4 and 5, as shown in Figure 4-7.

Filter by device - area 2
The “Device alarm filter” option allows user to filter the alarm by the equipment type.
If the user wants to see all alarms from inverters, the option “Inverter Alarm” shall be selected. Only alarms related to inverters will be shown in the alarm window.

Filter by alarm type - area 3
As mentioned in Table 4-1, there are three types of alarms. The “Type alarm filter” option allows the user to filter the alarm by its type: error, warning or status.
If the user only wants to see warnings, the “Warnings” filter button shall be hit and only warning alarms will be shown.

Filter by text - area 4
It is possible to filter an alarm by its description. To do so, the user shall type in the text box - area 4 - the alarm description, or part of it.
This is proved to be a very useful filter because it may offer the user the possibility to filter an alarm of a specific equipment. Assuming that there are a great number of equipments, supposing that each equipment triggers an alarm, the number of alarms shown in the alarm window would be extensive. This functionality restricts the number of shown alarms. Knowing the identification/description label of one specific equipment, it is possible to filter alarms triggered by this specific equipment.

Filter by condition - area 5
Alarms presented in the alarm window may have up to four different conditions:

- Active alarms (not acknowlegded);
- Active alarms (acknowlegded);
- Inactive alarms (not acknowlegded);
- Inactive alarms (acknowlegded).

To filter alarms by condition the “Filter by condition” shall be used. This filter works by checking the boxes. Once the selection is made, the user shall hit on the “Enter” button.
It is important to mention that all the described filters can be applied at the same type.

4.2.6.2 Historical Alarms and Warnings

Historical alarms table can be accessed hitting "Show historical alarms" on area 6 in Figure 4-7. This table allows the user to search the historical alarms stored in the database. This table has information such as the alarm description, the occurrence time and its duration. A filter allows the user to select events time interval. This screen is shown in Figure 4-8.

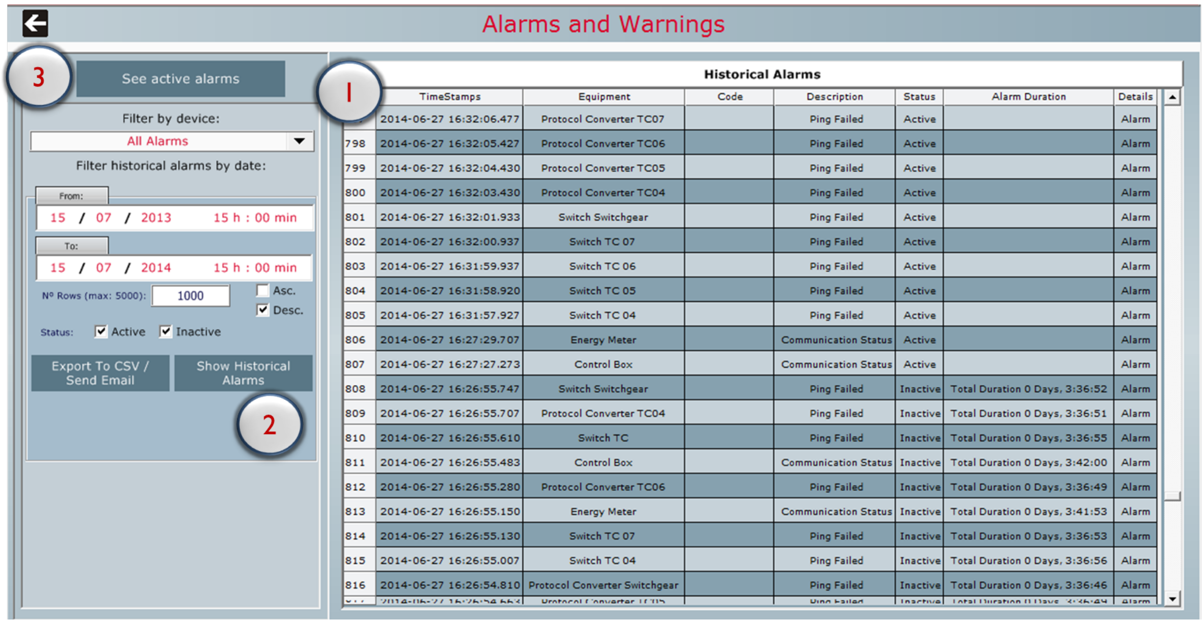


Figure 4-8: Historical alarms and warnings details.

The working area of the Alarms and warnings screen is composed by three specific areas:

1. Alarm historical data;
2. Filter historical alarms by date;
3. Active alarms button.

The output table layout is according to the one referred in Table 3-4.
The user can select the time interval hitting the white rectangle where the date is shown (area 2), then a calendar appears allowing search between a certain period of time.
The calendar, shown in Figure 4-10, allows the user to select two specific dates: the start date and the end date. All alarms information shown is inherent to the time interval delimited by the start and the end date.
The user can sort data by ascend or descend chronological order. Any of the mentioned options can be activated checking the respective fields, as shown in Figure 4-9, where the sort in descending option is checked. When sorting in ascending, the data in the first row of the table will be related to the time stamp inherent to the start date (or the nearest date). When sorting in descending, the data in the first row of the table will be related to the timestamp inherent to the end date (or the nearest date).

Figure 4-9: Filter historical alarms by date menu.

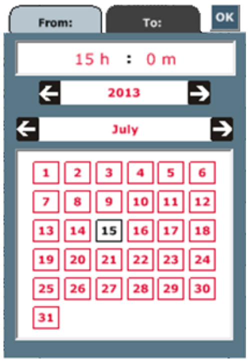


Figure 4-10: Calendar to build dates.

The number of rows in the table can be configured to a maximum of 5000 rows. This feature improves the tool performance and allows the user to select only a certain limit for the shown data. The maximum number of rows is defined in the respective field as shown in Figure 4-9.

The operator is able to send by email the alarm table in *CSV* file format. After a search is made, the operator can hit the button "Export to CSV/ Send Email". Afterwards, the operator is asked if he wants to send the exported file by email. If yes, the operator shall fill the necessary fields and, if the entered data is valid, an email will be sent, with the file attached, to the inserted address. Figure 4-11 depicts the dialog box used to send an email with the exported file attached.

Figure 4-11: Send email - dialog box.

Figure 4-12 shows an email example that an operator can received from the monitoring platform.

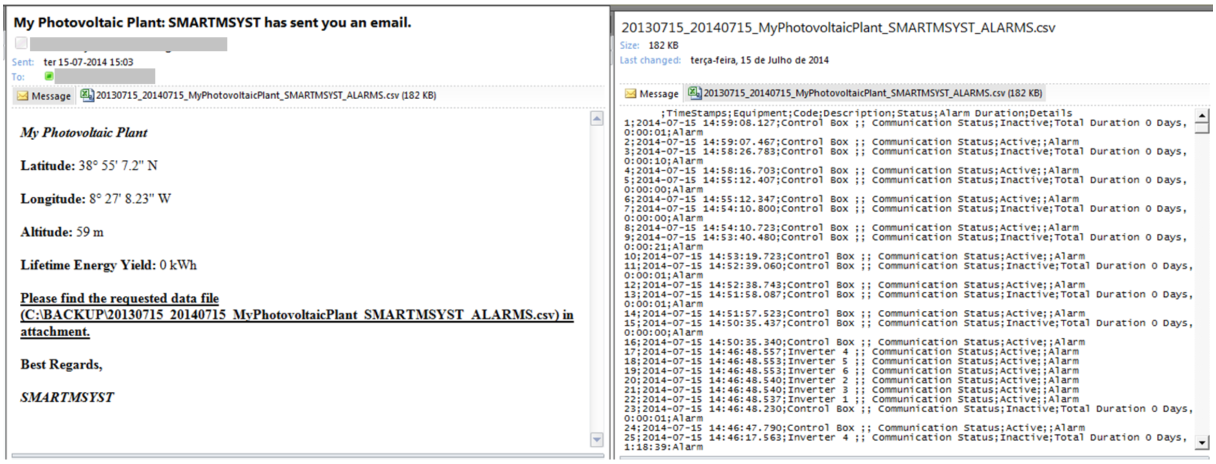


Figure 4-12: Example of a received email from SCADA - example.

There are several features on the monitoring platform that use the email send tool. All specification regarding the email send implementation are stated in Appendix C.

4.2.7 Historical Data

Historical data screen (see Figure 4-13) allows user to select variables from all the different PV plant devices. The main purpose of this screen is to populate a sheet with data from variables previously selected by the user.

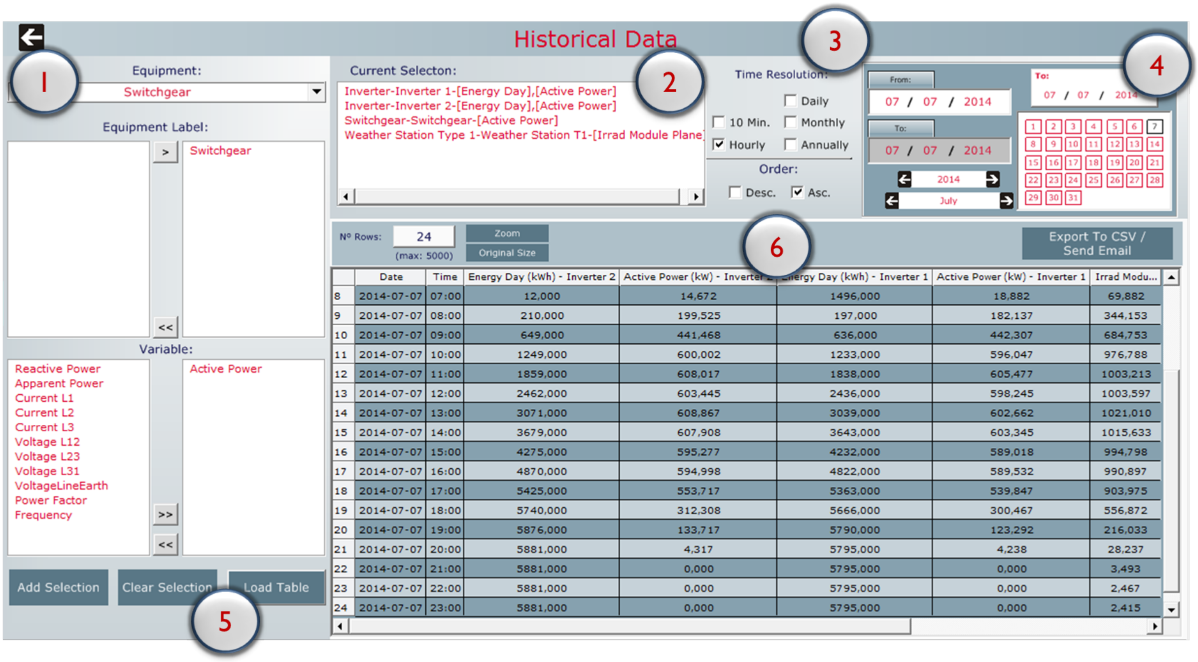


Figure 4-13: Historical data.

This synoptic allows the operator to compare data between all device variables. The data is present in a grid. This grid receives a SQL query and, using an ODBC connection, retrieves the

data and populates its cells.
The SQL database layout is based on one table per equipment type and, this table may have more than one distinct device entry (see Table 3-5). Since the objective is to enable the user to compare any variable, the query to be built may become very complex. It shall be built dynamically according to the user selection. The need to cross data from different tables led to the use of Common Table Expression (CTE) and *Join* SQL statements.
In order to give input to the Visual Basic for Applications (VBA) functions that shall build the final query, the user shall create a *slot*. Each *slot* relates to one (or more) variables from one distinct device.
The process listed below serves as an example:

1. Area 1, on the *Equipment* drop-down, the user shall select *Weather Station Type 1* equipment;
2. Area 1, on the *Equipment Label* left drop-down are listed all *Weather Station Type 1* type of devices present on the PV plant. The user shall select *Weather Station T1* to the drop-down on the right;
3. Area 1, on the *Variable* left drop-down are listed all *Weather Station T1* available variables. The user shall select *Module Temperature*, *Irrad Module Plane* and *Irrad Pyranometer* to the drop-down on the right;
4. Area 5, click *Add Selection*;
5. Area 1, on the *Equipment* drop-down, the user shall select *Inverter* equipment;
6. Area 1, on the *Equipment Label* left drop-down are listed all *Inverter* type of devices present on the PV plant. The user shall select *Inverter 1.1* to the drop-down on the right;
7. Area 1, on the *Variable* left drop-down are listed all *Inverter 1.1* available variables. The user shall select *Active Power* to the drop-down on the right;
8. Area 5, click *Add Selection*;
9. Area 3, check *10 Min.* box as well as *Asc.*;
10. Area 4, select time interval being *2014-02-10 00:00:00* to *2014-02-10 23:59:00*;
11. Area 5, click *Load Table*.

At this point, the platform uses developed code to generate the query to be fired against the SQL server. The results returned populate the grid. For the selection stated above, the resultant query is depicted on Appendix D.
Additional functions were developed in order to dynamically find the variable units to be associated with the variable name on the grid columns. When statistic calculation are required

(for example, check *Hourly* box instead of *10 Min.* in point 9), an additional function was also developed in order to dynamically find the operation to be applied to the variable (average, maximum, maximum-minimum). These calculations are made according to stated in Table 3-2.
The grid content can be sent by email as a third party software compatible file. Specifications regarding the SCADA email notifications are stated in Appendix C.

4.2.8 Trend Plots

The Trend screen allows the user to check variables from all devices. The screen works in a similar way as the historical data screen. In this screen, data is shown graphically with a trend line instead of a grid (see Figure 4-14).

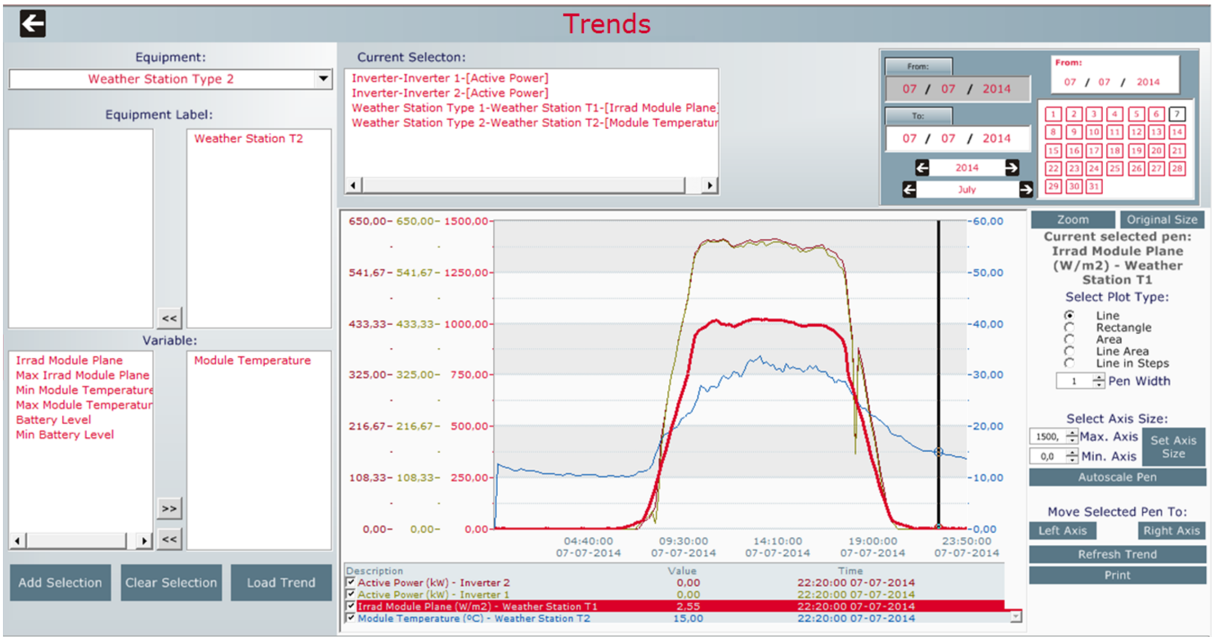


Figure 4-14: Trend screen details.

The trend object framework of Movicon™ 11 are optimised to work with only one SQL table associated. This would make it impossible for the operator to load data from any different equipment into the trend. To work around this problem, a text file is created with the query results. The query has to be build slightly different from the historical data synoptic in order to the output be trend compatible. After exiting this screen, the file is deleted.

4.2.9 Dashboard

The dashboard is an interface where the user can have access to the most relevant information of plant equipments. The monitoring platform dashboard consists in a number of objects where significant equipment data is shown. Figure 4-15 illustrates the dashboard screen.

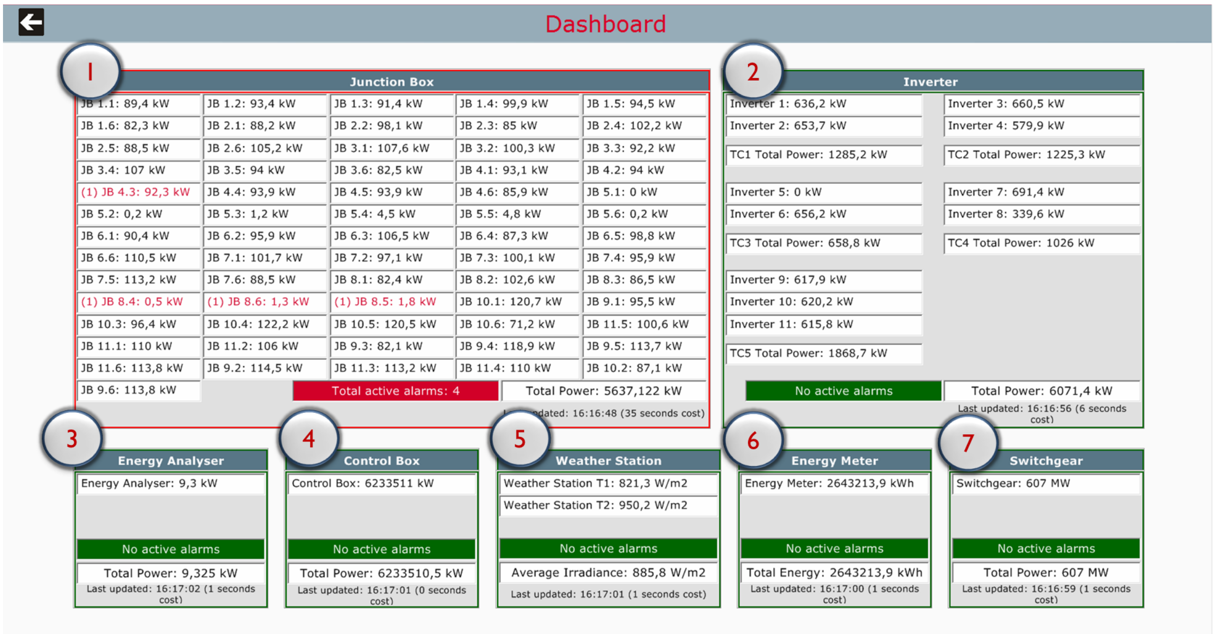


Figure 4-15: Dashboard screen.

Table 4-2 describes the dashboard equipments and the corresponding variables for each area referred in Figure 4-15.

Table 4-2: Dashboard equipment and variables.

Area	Equipment	Variable	Unit
1	Junction Box	DC Power	kW
2	Inverter	AC Power	kW
3	Energy Analyser	AC Power	kW
4	Control Box	AC Power	kW
5	Weather Station	Module Plane Irradiance	W/m^2
6	Energy Meter	AC Energy	kWh
7	Switchgear	AC Power	MW

Each area has text boxes. In each box is written the equipment identification followed by its variable value. In order to update data, the system reads all major variables. This process can take some seconds. On the right bottom corner of each area, the last update time and the time taken to update are present.

Another functionality of the dashboard is to check the equipment status. When no alarms are active, the area border is set to the green colour and a text appears on the area bottom: "No Active Alarms". If any alarm is active, the border of the respective equipment area is set to the red colour. The user can simultaneously know which specific equipment has an alarm. Let's take for example the "Inverter" area. Let's suppose that the plant has 5 inverters being monitored. The "Inverter" area will have 5 text boxes, one for each inverter. If Inverter 2 and Inverter 5 have an active alarm, besides the area border, also the respective text will have its text

red coloured. On the area bottom, "Total of 2 active alarms" text would appear, because each of the two Inverters, Inverter 2 and Inverter 5, triggered one alarm each.
In addition to the red text, equipment text box which has an active alarm has in the beginning the total amount of alarms that this specific equipment has triggered. This is an useful feature since a single equipment can trigger more than one alarm at the same time.
On the bottom of each area a field gives the user a summary information of all the equipments. If the area is showing data as Power, the summary information will be the sum of all the Power values of each equipment in the respective area. If the area is showing data as Irradiance, the summary information will be the averaged value of all the values of each irradiance sensor.

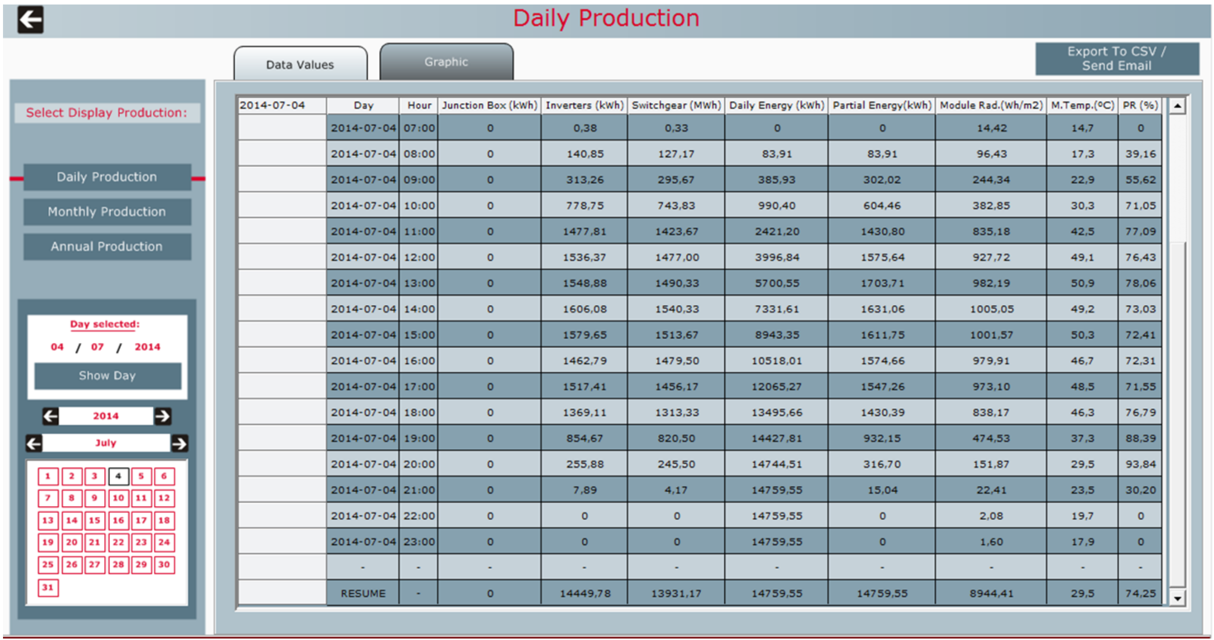
4.2.10 Production

Production screen shows production data. The user is able to check data either on a grid or a chart. Data shown in this screen is stated in Table 4-3.

Table 4-3: Equipments and Data.

Equipment	Data	Unit
Junction Box	Sum of junction boxes yield energy	kWh
Inverter	Sum of inverters yield energy	kWh
Switchgear	Sum of switchgear yield energy	MWh
Energy Meter	Energy meter yield energy	kWh
Weather Station	Sum of solar irradiance	Wh/m^2
Weather Station	Average module temperature	°C

Besides data mentioned in Table 4-3, the grid includes the performance ratio calculated at each timestamp. Performance ratio is also shown in a chart.
As illustrated in Figure 4-16, the grid is populated with the current daily data.



2014-07-04	Day	Hour	Junction Box (kWh)	Inverters (kWh)	Switchgear (MWh)	Daily Energy (kWh)	Partial Energy(kWh)	Module Rad.(Wh/m2)	M.Temp.(ºC)	PR (%)
	2014-07-04	07:00	0	0,38	0,33	0	0	14,42	14,7	0
	2014-07-04	08:00	0	140,85	127,17	83,91	83,91	96,43	17,3	39,16
	2014-07-04	09:00	0	313,26	295,67	385,93	302,02	244,34	22,9	55,62
	2014-07-04	10:00	0	778,75	743,83	990,40	604,46	382,85	30,3	71,05
	2014-07-04	11:00	0	1477,81	1423,67	2421,20	1430,80	835,18	42,5	77,09
	2014-07-04	12:00	0	1536,37	1477,00	3996,84	1575,64	927,72	49,1	76,43
	2014-07-04	13:00	0	1548,88	1490,33	5700,55	1703,71	982,19	50,9	78,06
	2014-07-04	14:00	0	1606,08	1540,33	7331,61	1631,06	1005,05	49,2	73,03
	2014-07-04	15:00	0	1579,65	1513,67	8943,35	1611,75	1001,57	50,3	72,41
	2014-07-04	16:00	0	1462,79	1479,50	10518,01	1574,66	979,91	46,7	72,31
	2014-07-04	17:00	0	1517,41	1456,17	12065,27	1547,26	973,10	48,5	71,55
	2014-07-04	18:00	0	1369,11	1313,33	13495,66	1430,39	838,17	46,3	76,79
	2014-07-04	19:00	0	854,67	820,50	14427,81	932,15	474,53	37,3	88,39
	2014-07-04	20:00	0	255,88	245,50	14744,51	316,70	151,87	29,5	93,84
	2014-07-04	21:00	0	7,89	4,17	14759,55	15,04	22,41	23,5	30,20
	2014-07-04	22:00	0	0	0	14759,55	0	2,08	19,7	0
	2014-07-04	23:00	0	0	0	14759,55	0	1,60	17,9	0
	-	-	-	-	-	-	-	-	-	-
	RESUME	-	0	14449,78	13931,17	14759,55	14759,55	8944,41	29,5	74,25

Figure 4-16: Production - grid load with daily data.

The Performance Ratio is calculated according to Equation 3.1.
The Daily Energy column presents the daily energy produced measured by the energy meter at each timestamp (in the case depicted in Figure 4-16, at each hour). The Partial Energy columns states the energy produced during the specific hour. For example, at 13:00, the value in this column is the value measured by the energy meter at 13:00 minus the value measured at 12:00. This calculation is made due to the fact that the acquired energy value (from the energy meter) is incremental.
The values in the other columns that state Energy units are calculated from their Power values. Based on Table 3-1, the system acquires data at 1 minute period and then calculates and stores the 10 minute averaged value. In case of Power values, when dividing this 10 minute averaged value per 6, the obtained value represents the Energy produced during those 10 minutes (since 10 minutes represents 1/6 of an hour). Finally, summing the last result, the energy produced in 1 hour is obtained. The same approach is applied for the calculation of the irradiance (W/m^2) values. Summing the 10 minute Irradiance averaged values (e.g, $Irrad_{13:10}$ + ... + $Irrad_{14:00}$) and then dividing it per 6 results in the Radiance (Wh/m^2) value for 1 hour.

The user can choose between three time intervals in order to select data:

- Daily production - Production data with hourly intervals. This value is calculated by the average of the 10 minute data. The table shall have one row per hour. The last row shall summarise the selected day production;
- Monthly production - Production data with daily intervals. This value is calculated by the average of the daily production data. The table shall have one row per day. The last row shall summarise the selected month production;

- Annual production - Production data with monthly intervals. This value is calculated by the average of the month production data. The table shall have one row per month. The last row shall summarise the selected year production.

The time resolution as well as the date to be consulted can be selected on the menu left of the output table (see Figure 4-16).
Two tabs on top of the table enable the user to see the data either in table or chart format. When in chart view, two tabs allow the operator to toogle between a combined chart and a Performance Ratio chart. Figure 4-17 depicts the production charts.

Figure 4-17: Production - chart load with daily data.

The table content can be sent as *csv* file via email. The table content can then be visualised in a third party software.

4.3 Administrator Graphic User Interface

According to its privileges, an user can be able to access the monitoring platform administrator configurations and special features. Entering the administrator menu, the user is provided with the following options:

- Equipment configuration and communication status;
- System configurations;
- System diagnostics;
- Alarm recipients;
- Users management;

- File management;
- Backup databases;
- Database index fragmentation report;
- Network devices;
- FTP Push - configuration;
- Weather Station - Data back fill.

These options are depicted as buttons. Some of them take the user to another synoptic while others represent action buttons.

4.3.1 Equipment Configuration And Communication Status

In this synoptic is possible to configure the identification to give to each equipment. Additionally, it is possible to check the communication status with an equipment and if data from this equipment is being stored in the database. Figure 4-18 depicts a group of objects where it is possible to execute the mentioned actions.

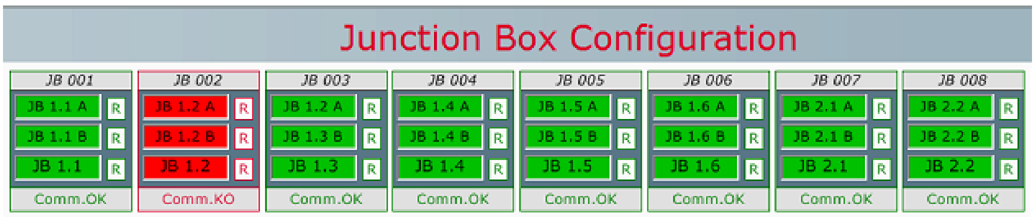


Figure 4-18: Junction box configuration.

When the communication is successful, the equipment name has green background. Moreover, if data is being recorder, the "R" text is depicted in green.

4.3.2 System Configurations

General configurations

General PV plant parameters are set in this synoptic. Plant name, system file paths, site coordinates, conversion factors or system power can be defined.

Performance ratio targets

Performance ratio targets can be defined. These targets are set per month and per PV plant. These parameters are used to be compared with the actual performance ratio values.

System email account credentials
The credentials for the email account that will be used by the monitoring platform are set here.

System internal messages recipients
In this field are defined the email addresses that shall receive email notification from system internal debug or errors.

Key performance indicators set points
This field is used to insert set point for KPI indicators. For example, if the system monitors solar trackers, this field is used to set the maximum admissible deviance between trackers position.
Another input is the maximum admitted deviation between string currents (inside the same junction box)

Backup disk definitions
Here it is possible to define backup paths to where data will be copied on backup routines. Figure 4-19 depicts the object used to define these configurations.

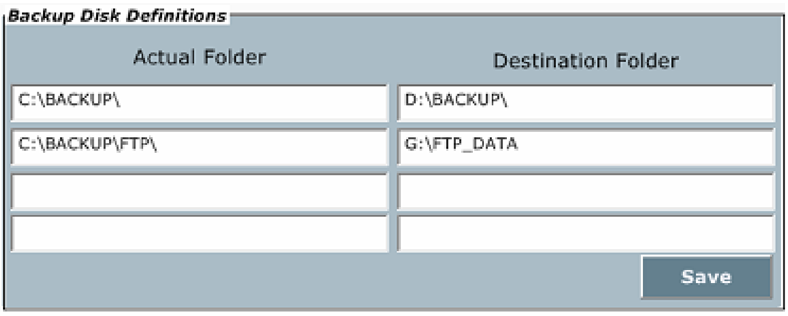


Figure 4-19: Backup disk definitions.

The monitoring platform executes periodically file backup routines. From the configuration depicted in Figure 4-19, every time the routine is executed, the content of *C:\BACKUP* shall be copied to *D:\BACKUP*.

Performance ratio calculation parameters
It is possible to configure if the performance ratio shall be calculated using Radiance data from one weather station or using the average values of more than one weather station. It is also possible to define a minimum Radiance value to execute the calculation.

Energy meter substitution - offset parameters
A malfunction can led to an energy meter replacement. The energy measured by the meter is incremental meaning that new energy data will have its energy values set to zero when new. In order to never loose track from the real energy produced by the PV plant, when a energy meter

replacement is required, the last energy measured by the old meter shall be added to the current energy measured by the energy meter.

This synoptic allows the system administrator to configure a new energy meter insertion in the monitoring plant. When necessary, the user shall enter in the system the energy offset to be added to the new readings. The system shall keep track of the number of substitutions made.

4.3.3 System Diagnostics

The purpose of this synoptic is to give a server and application overview. Figure 4-20 depicts the system diagnostics synoptic.

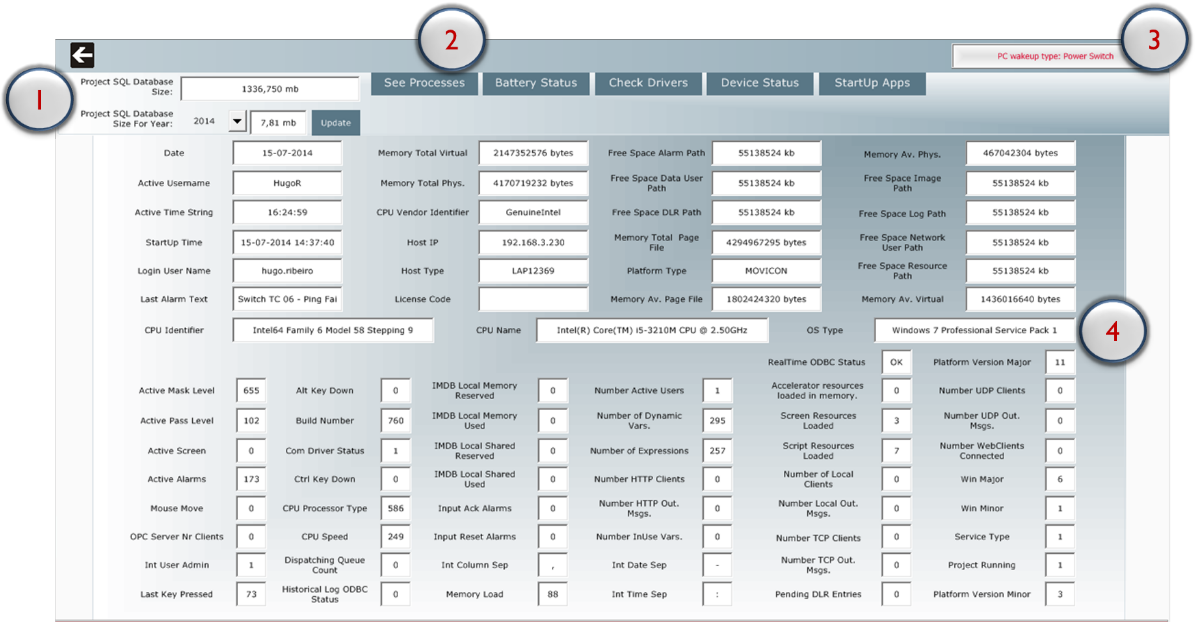


Figure 4-20: System diagnostic.

The area 4 depicted in Figure 4-20 states, mainly, information regarding the monitoring platform application.

Area 1 allows the user to check the system databases size. The size of a database can be found firing the SQL query depicted in Figure 4-21.

```
SELECT
a.FILEID,
[FILE_SIZE_MB] = CONVERT(DECIMAL(12,2),ROUND(a.Size/128.000,2)),
[SPACE_USED_MB] =CONVERT(DECIMAL(12,2),ROUND(FILEPROPERTY(a.Name,'SpaceUsed')/128.000,2)),
[FREE_SPACE_MB] =CONVERT(DECIMAL(12,2),ROUND((a.Size-FILEPROPERTY(a.Name,'SpaceUsed'))/128.000,2)) ,
Name = Left(a.Name,100),
FILENAME = Left(a.FILENAME,30)
FROM dbo.sysfiles a
```

Figure 4-21: Query example to check database size.

Areas 2 has buttons that allow the user to:

- Check the running processes on the server machine;
- Check the machine battery status (if applicable);
- Check disk drivers space usage;
- Check the devices status of the server;
- Check the application that run on server start up.

Area 3 states information about the last server boot type.
Area 2 and 3 features were developed using WMI queries. WMI stands for *Windows Management Instrumentation*. It is a Microsoft initiative to develop a standard technology for accessing management information in an enterprise environment. WMI enables machine management tasks with programming or scripting languages [22].
Appendix E presents a code example used to list all current running processes on the server. This is the code called by "See Processes" button (area 2 in Figure 4-20).

4.3.4 Alarm Recipients

Alarm notification is a main feature of a monitoring system application. The purpose of this synoptic is to allow the user operator to select a group of alarms from that he wants to receive notifications when active. Figure 4-22 depicts a layout for the mentioned synoptic.

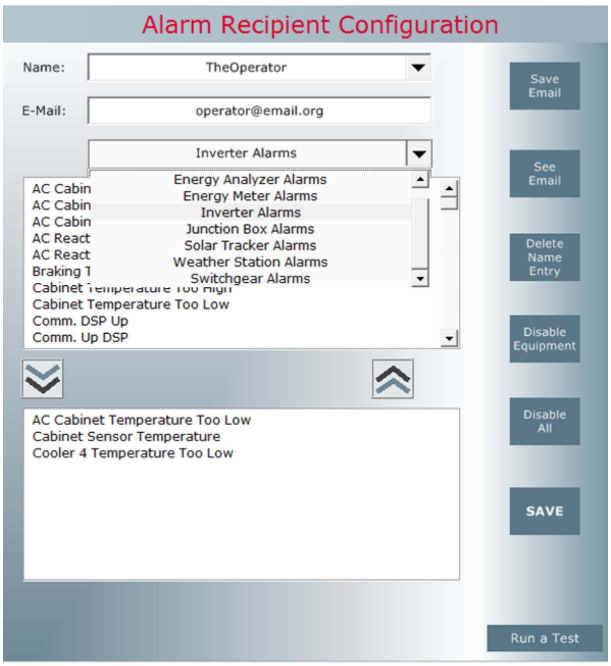


Figure 4-22: Alarm recipient configuration.

More considerations regarding this feature operation mode are stated in Appendix C.

4.3.5 Users Management

This synoptic enables the administrator to create, modify or delete users or user groups. User management is a critical part in order to secure the system. The developed interface groups with different privileges and associate users to this groups. Once created, the new user account becomes automatically available without need of system reboot. Figure 4-23 depicts the user management synoptic.

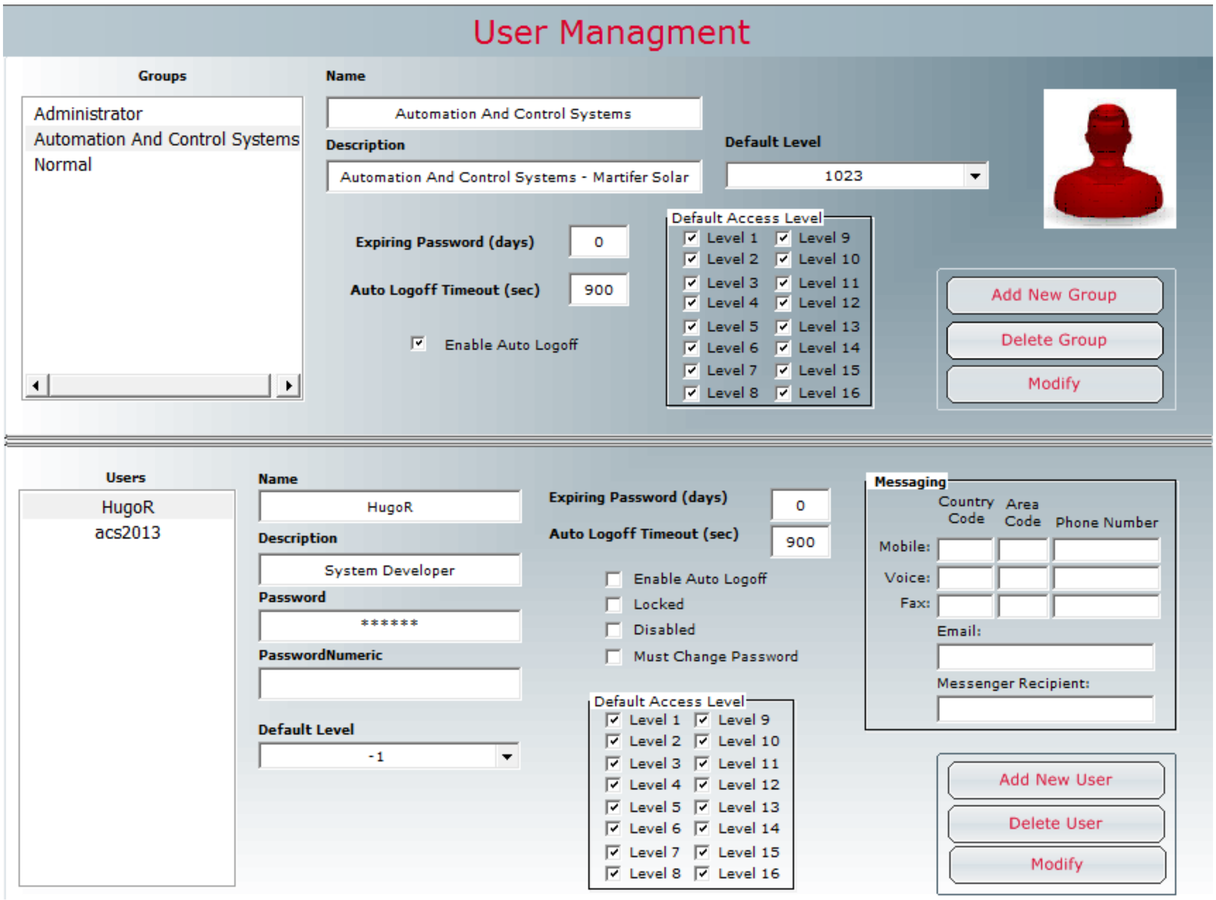


Figure 4-23: User management.

The development software (Movicon™ 11) has built libraries for user management. Despite of that, the available resources do not allow user management during runtime when accessing the system through the web. Since Movicon™ 11 is a XML based platform, the solution developed consists in manipulate the XML files related to user management configuration. In order to do so, scripts needed to be created using *Windows MSXML 4.0* library. Every time a user management configuration is made, the base XML file is manipulated and the changes become active.

4.3.6 File management

Accessing this synoptic, the user can manage remotely the files stored on the SCADA server (Figure 4-24).

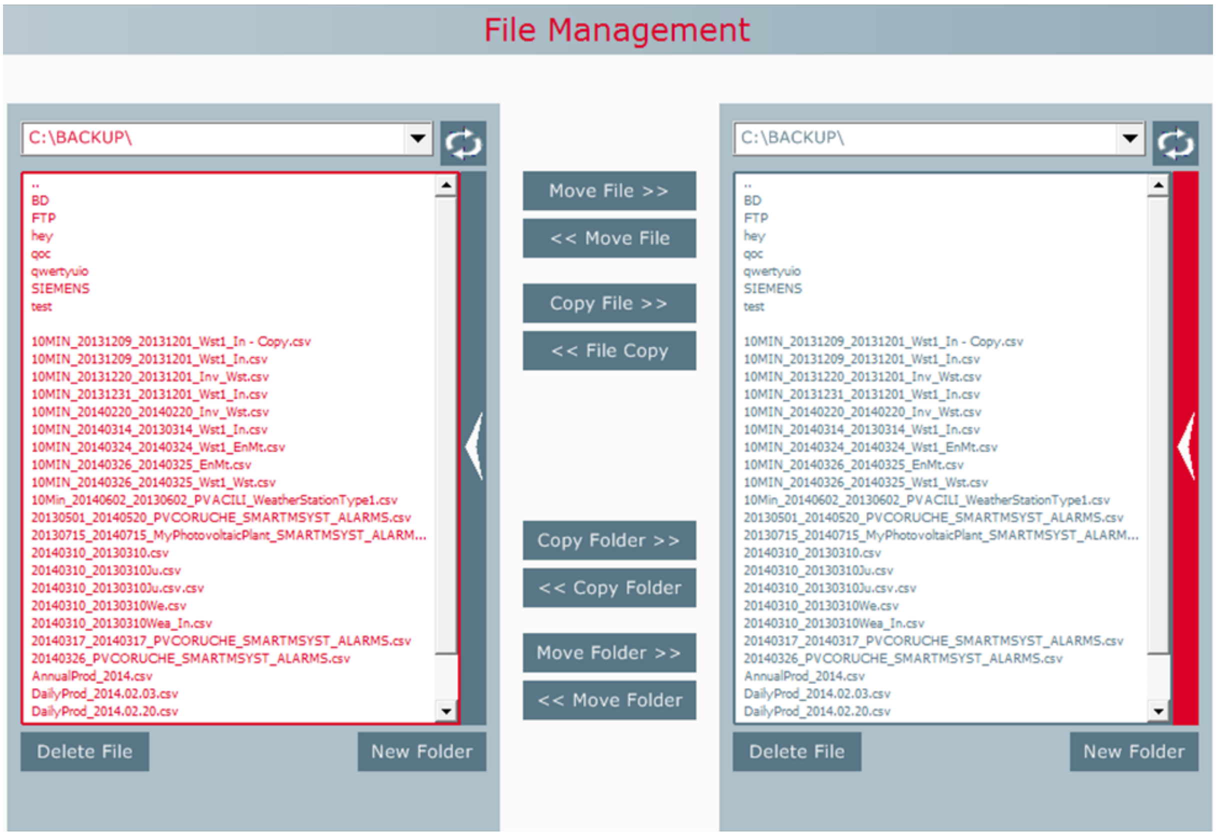


Figure 4-24: File management.

4.3.7 Backup Databases

This action button creates a backup for all system databases. The backup procedure originates a *.bak* file. A code example to do the mentioned action is depicted in Appendix F.

4.3.8 Database Index Fragmentation Report

When clicking this action button, the user receives a report informing about the table index fragmentation. Table 4-4 presents an example of the report.

Table 4-4: Index report.

Schema	Table	Index	avg_fragmentation_in_percent	page_count
dbo	UserLogins	LocalCol	66,67	3
dbo	1S_INVERTER	LocalCol	60,00	5
dbo	SysMsgs	LocalCol	55,56	18
dbo	Drivers	Drivers	53,85	13
dbo	1S_INVERTER	1S_INVERTER	53,66	41
dbo	Alarms	LocalCol	50,00	10
dbo	Drivers	LocalCol	50,00	2
dbo	1M_JB	1M_JB	50,00	2
dbo	SysMsgs	SysMsgs	27,54	69
dbo	Alarms	Alarms	2,75	109

In order to obtain the index fragmentation report, the following query depicted in Figure 4-25 shall be used.

```
SELECT dbschemas.[name] as 'Schema',
dbtables.[name] as 'Table',
dbindexes.[name] as 'Index',
indexstats.avg_fragmentation_in_percent,
indexstats.page_count
FROM sys.dm_db_index_physical_stats (DB_ID(), NULL, NULL, NULL, NULL) AS indexstats
INNER JOIN sys.tables dbtables on dbtables.[object_id] = indexstats.[object_id]
INNER JOIN sys.schemas dbschemas on dbtables.[schema_id] = dbschemas.[schema_id]
INNER JOIN sys.indexes AS dbindexes ON dbindexes.[object_id] = indexstats.[object_id]
AND indexstats.index_id = dbindexes.index_id
WHERE indexstats.database_id = DB_ID()
ORDER BY indexstats.avg_fragmentation_in_percent desc
```

Figure 4-25: Query example to check index fragmentation.

The first column of Table 4-4 (“Schemas”) presents the SQL schema that owns the table whose name is on the “Schemas” column. Schemas are a convenient way to separate database users from database object owners. The “Index” columns lists all the indexes configured in the database. Each index belongs to a table and each table can have more than one index. In the “avg_fragmentation_in_percent” is presented the fragmentation percentage for each index. Finally, in the “page_count” column is presented the index page count. In SQL, a page size is 8 kilobytes (128 pages per megabyte).
According to the result, maintenance operations shall be made to the analysed table database.

4.3.9 Network devices

The field network used by the monitoring platform has several equipment that use TCP/IP protocol. These equipment can be switches, routers, protocol converters, dataloggers or gateways. This synoptic allows the user to ping any IP address inside the SCADA network as well as check a pre-configured group of IP. Figure 4-26 illustrates an excerpt of the synoptic.

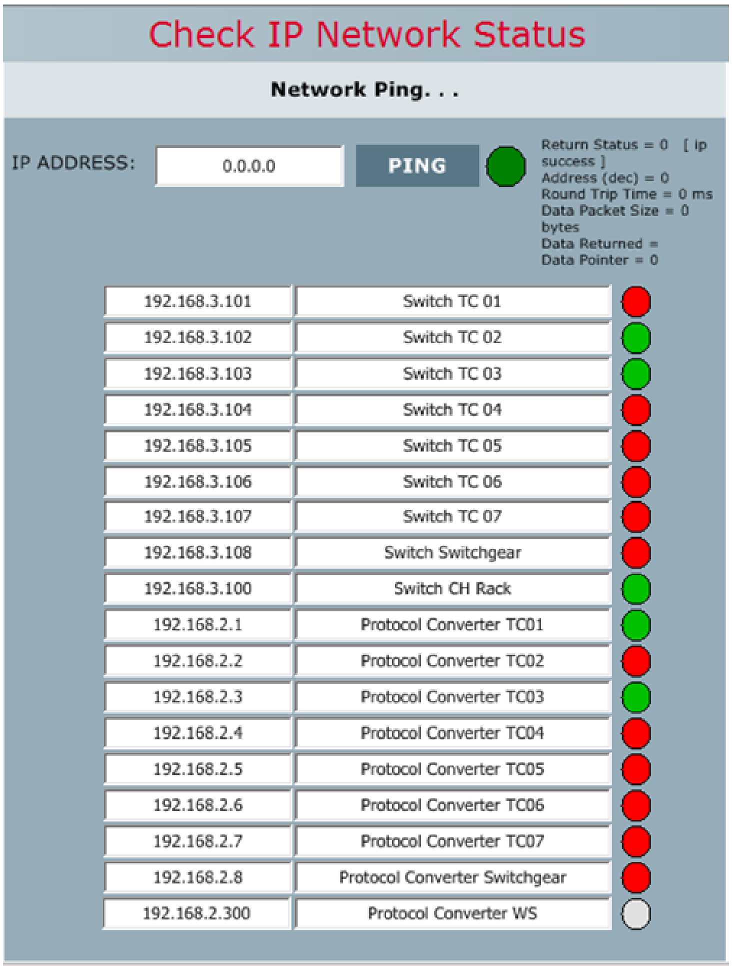


Figure 4-26: Check IP network status.

When the ping fails to any of the configured IP, an alarm is generated.

4.3.10 FTP Push - configuration

This synoptic has the purpose to set FTP account credentials. The entered parameters are use to configure a FTP Push feature that shall be responsible for sending equipment historical data in *csv* format to the insert FTP server address. Figure 4-27 depicts the mentioned synoptic.

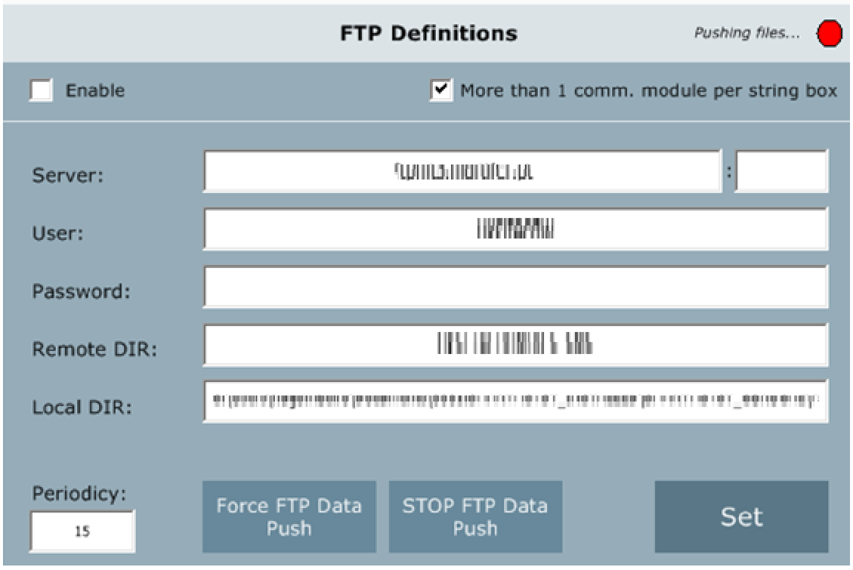


Figure 4-27: FTP push feature - configuration.

It is possible to test the FTP Push function as well as check if data is being sent to the FTP server. This feature will run in background, therefore it is possible to set its periodicity.

4.3.11 Weather Station - Data back fill

As stated in subsection 2.3.3.1, a datalogger is used to deal with all the Weather Station variables and make them available to the server. The datalogger has data storage capability and can provide the data in its memory via a text file.

Due to any malfunction, the monitoring system can break communications with the Weather Station. The synoptic employed to configure the database data back filling using the datalogger files is depicted in Figure 4-28.

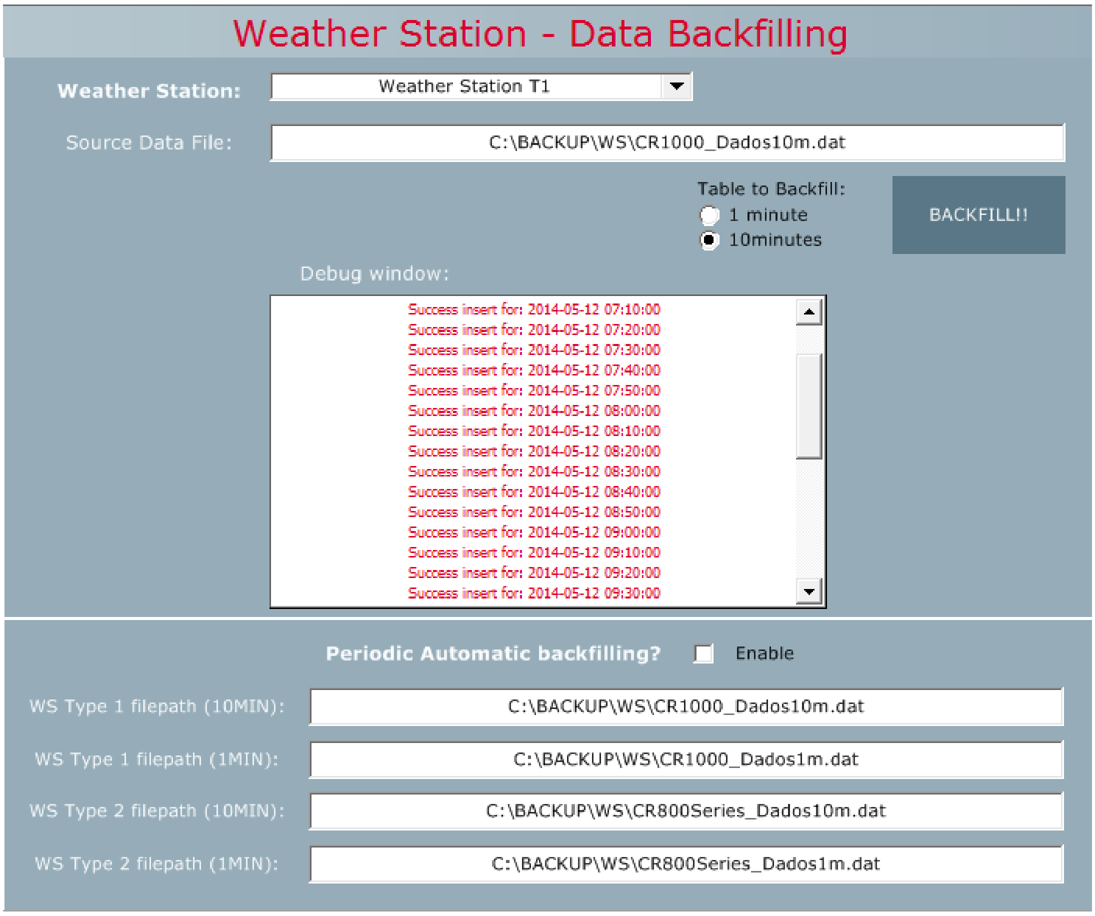


Figure 4-28: Weather Station data back fill - configuration.

The data back filling can be done manually or automatically (periodically). Either way, this feature uses the parameter set in Figure 4-28 where a file path is associated to a specific Weather Station. The monitoring system checks every row in the Weather Station data file. If the read timestamp is missing in the SQL database, the system inserts all its column values in the database. Otherwise, the row is ignored and the next one is checked.

4.4 Background Features

A SCADA system has more features than the ones depicted in this document. Several background functionalities are implemented in the developed monitoring platform. The objective is to optimise the system performance as well as give the user more information and possibilities.

4.4.1 Request Data by Email

This functionality allows the user to receive PV plant production data without accessing the system. The user needs to send an email to the system email address specifying the date from which he wants to receive the production data. Figure 4-29 shows the process of send an email to the monitoring platform and its reply.

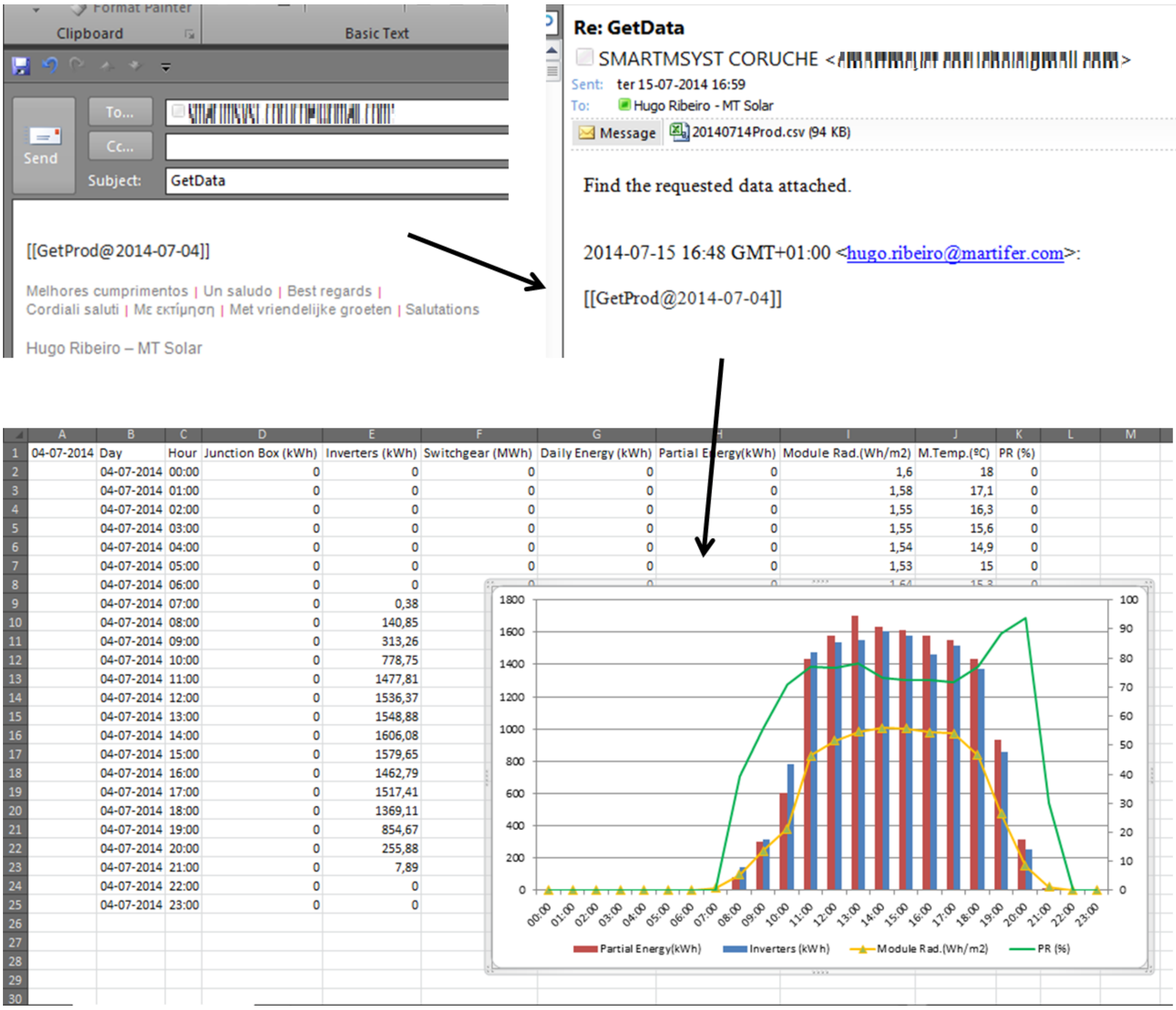


Figure 4-29: Get production data by email.

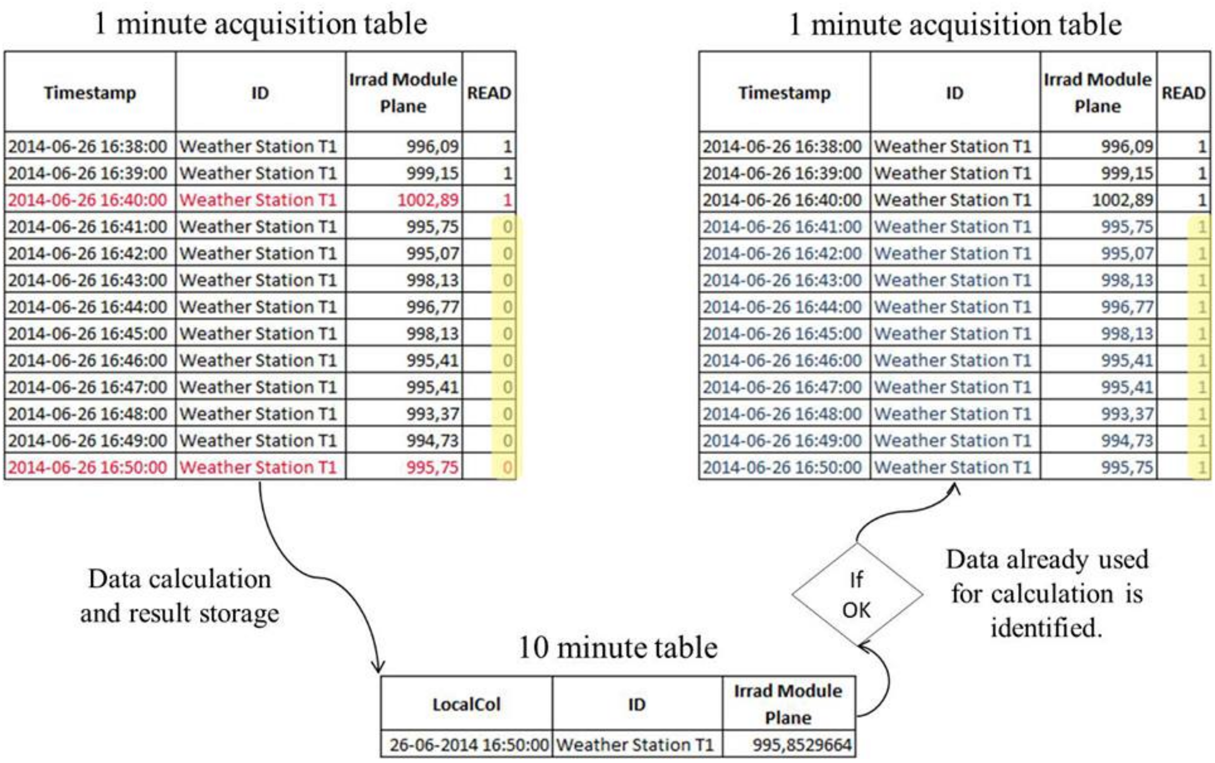
A routine was created that periodically reads the system email account inbox. The routine checks every unread email body searching for a specific text pattern. This text can be, for example, *[[GetProd@2014-01-01]]*, where the text after the "@" represents the date from which the user wants to receive the data. The monitoring platform retrieves the data from the email text and uses it in a query that is fired against the SQL database. The query results are saved in a *csv* file which is attached to the email reply. After this process, the routine sets the email status as read and moves to the next one.
In order to accomplish this feature, the *EAGetMailObj ActiveX Object 1.0* type library was used.

4.4.2 Export Data With High Acquisition Frequencies

Due to warranty issues, some equipment manufacturers request access to their equipment data with 1 second acquisition period. The practice states that for the majority of this type of system, 1 minute acquisition period is sufficient. Moreover, storing data every second would increase drastically the database size.
To overcome this issue, a new SQL table was created. When required, there is a table for 1 minute acquisition and another table for 1 second acquisition for the same equipment type. The 1 minute acquisition table is the monitoring system table. The 1 second acquisition table is an "outsider" table. Every day, after midnight, the monitoring system exports the data from the 1 second acquisition table to an individual *csv* file. The data is related to the previous day. If the exportation operation is successful, the content of the 1 second acquisition table is erased. Therefore, the database growth remains inside the predicted values.
The *csv* files are stored in a FTP folder. The equipment manufacturer has access to the FTP folder. The files stay in the folder for a defined time period and, after that, the oldest ones start to be erased in order to free disk space.

4.4.3 Data Calculations

This data calculation refers to the requirements stated in subsection 3.3.3.
All SQL equipment tables have one column named "Read" that is set as zero if no data calculation was ever performed to one specific row. Every 5 minutes the system scans each table to check if there are new entries ("Read" = 0) with 10, or more, minutes gap. If so, the system performs the calculation stated in Table 3-1 and insert the result row into another table - the 10 minute table. Figure 4-30 illustrates the calculation process for 1 column of the Weather Station Table.



1 minute acquisition table (before calculation)

Timestamp	ID	Irrad Module Plane	READ
2014-06-26 16:38:00	Weather Station T1	996,09	1
2014-06-26 16:39:00	Weather Station T1	999,15	1
2014-06-26 16:40:00	Weather Station T1	1002,89	1
2014-06-26 16:41:00	Weather Station T1	995,75	0
2014-06-26 16:42:00	Weather Station T1	995,07	0
2014-06-26 16:43:00	Weather Station T1	998,13	0
2014-06-26 16:44:00	Weather Station T1	996,77	0
2014-06-26 16:45:00	Weather Station T1	998,13	0
2014-06-26 16:46:00	Weather Station T1	995,41	0
2014-06-26 16:47:00	Weather Station T1	995,41	0
2014-06-26 16:48:00	Weather Station T1	993,37	0
2014-06-26 16:49:00	Weather Station T1	994,73	0
2014-06-26 16:50:00	Weather Station T1	995,75	0

1 minute acquisition table (after calculation)

Timestamp	ID	Irrad Module Plane	READ
2014-06-26 16:38:00	Weather Station T1	996,09	1
2014-06-26 16:39:00	Weather Station T1	999,15	1
2014-06-26 16:40:00	Weather Station T1	1002,89	1
2014-06-26 16:41:00	Weather Station T1	995,75	1
2014-06-26 16:42:00	Weather Station T1	995,07	1
2014-06-26 16:43:00	Weather Station T1	998,13	1
2014-06-26 16:44:00	Weather Station T1	996,77	1
2014-06-26 16:45:00	Weather Station T1	998,13	1
2014-06-26 16:46:00	Weather Station T1	995,41	1
2014-06-26 16:47:00	Weather Station T1	995,41	1
2014-06-26 16:48:00	Weather Station T1	993,37	1
2014-06-26 16:49:00	Weather Station T1	994,73	1
2014-06-26 16:50:00	Weather Station T1	995,75	1

10 minute table

LocalCol	ID	Irrad Module Plane
26-06-2014 16:50:00	Weather Station T1	995,8529664

Figure 4-30: Data calculation - 10 minute basis.

The 10 minute basis data can be consulted in the monitoring system historical data synoptic.

4.4.4 Key Performance Indicators Calculation

These indicators can be used for equipment troubleshooting or simply to evaluate the PV plant performance. The developed monitoring system calculates the following KPI:

- Junction Box string asymmetry
  - The monitoring platform calculates, for each Junction Box, the median Power produced per string. If a string instantaneous Power value is lower by a specific percentage than the median Power value of all strings, an alarm is triggered. For example, if string 1 and 6 of Junction Box 1.1 have blown fuses the following alarm message would appear: “JB 1.1 - string 1, string 6 Low Production”. This represents a tool to monitor string malfunctions or simulate fuse monitoring without extra-equipment.
- Solar Tracker position deviance (when applicable)
  - When a PV plant has Solar Trackers, this KPI represents a tool to detect tracking deviations. This deviations can be caused by bad solar Tracker programming or commissioning. It is possible to detect if a Solar Tracker is stopped inside the proximity switches limit. The system calculates the median position of all PV plant

Solar Trackers. If a specific Tracker's position differs by a percentage from the median value, an alarm is triggered: "Solar Tracker 123 - Position deviated comparing to the other trackers".

- Performance Ratio
  - It is the most relevant KPI. Considerations to the Performance Ratio are stated in subsection 3.3.4. The monitoring system has a Production summary table that is periodically update and one of its provided information is the Performance Ratio. An example of this table is depicted in Figure 4-16. To update the Production table, the system executes periodically the SQL Stored Procedure stated in Appendix G. The Stored Procedure output is then inserted in the Production Table.

4.4.5 Solar Calculations

The solar calculations are executed every day at midnight. The calculations are based on astronomical algorithms [21].
The purpose is to give the user the sunrise, sunset and sun noon time. Moreover, this calculation provides information regarding the sun elevation position (in degrees) during the day for the specific PV plant site. The sun elevation can be depicted in the application home screen as illustrated in Figure 4-2. When applicable, the solar elevation trend line can be compared with the Solar Tracker position trend line. This feature can help troubleshooting solar tracking related problems.

4.4.6 XML Manipulation

The *Windows MSXML 4.0* library is used to manipulate XML based objects. In cases when the development software (Movicon™ 11) did not have embed functions to execute some required actions, the creation of XML manipulation scripts were necessary. This way, it was possible to develop some features that supposedly would not be possible.
Scripts for XML manipulation allowed tasks as user management during system runtime or listing all alarm description configured in the monitoring platform.

4.4.7 Access Control and Logging

In order to keep track of all entities that access the monitoring platform, the system stores in the database information regarding the users that accessed the system. Information as login/logoff time, failed logins or session time are avaiable to user administrators.

4.4.8 Database Maintenance Tasks

Automatic backup routines
The system databases are set to automatically backup every month. In every backup operation,

a new backup file is created instead of overwriting the previous one.
The backup operation is also automatically performed before any other database maintenance task.

Intelligent table index rebuilding/reorganisation
The SCADA system monthly evaluates the index fragmentation of the database tables. If necessary, the system executes the index rebuilt or reorganisation. The decision to rebuild or reorganise is taken according to fragmentation levels [23].

Database size monitoring
Every 5 minutes the databases size is checked. If the current size represents 80% of the maximum stipulated size, an alarm is triggered in order to inform the system operator/administrator.

4.5 Conclusion

A monitoring system development represents a complex and exhaustive task. This chapter expounds the monitoring platform by its graphical and its background features.

This chapter presented the effort to fulfil the basic monitoring system requirements stated in section 3.3 and also the effort to develop some features that go beyond the required issues.

The principal features were stated. Not all coding or synoptic details could be depicted in order to not become this thesis very extensive and exhaustive.

In this chapter is stated the final result of all the work underlying in this thesis: the monitoring platform for photovoltaic plants. It is possible to infer the multi-disciplined subject that is the development of a SCADA system.

5. Conclusion And Future Works Perspective

5.1 Introduction

This chapter presents the general conclusions and the experience acquired from the work developed during this thesis. Moreover, it is presented some of the main difficulties encountered, as well as improvements and optimisation proposals for the developed system.

5.2 Conclusions

The developed work gave the author a greater knowledge in SCADA systems, databases, programming languages, communication protocols, etc. Motivated by the professional and academic challenges, all the main obstacles were overcome and, as result, a monitoring platform for PV plants was created.
This thesis subject comes from Martifer Solar need for having an internally developed monitoring system solution in order to not transmit know-how to subcontractors as well as reducing overall project cost.

This project started from scratch, without any reference. First of all, it was necessary to study the main features that a software framework for SCADA systems development should have. From the surveyed frameworks, Movicon™ 11 was selected.

The study of monitoring systems technical specifications was imperative to understand the major requisites for the developed platform. Additionally, it was also necessary to study photovoltaic plant projects, either electrical and monitoring, to better understand this specific automation work area.

PV plant monitoring differs from general industrial SCADA applications. Unlike industrial application, this kind of monitoring systems are not based on actuating valves, actuating other outputs based on system inputs or just managing alarms. Photovoltaic plant monitoring requires several data processing, data analysis, key performance indicators calculation as well as intelligent alarm management. For example, there are monitored equipment that are fed from PV prodution and, since that power is unavailable during night, the system shall ignore communication alarms from that equipment during that period. This management must be done dynamically. Sunset and sunrise time are not the same during the year and irradiance cannot be taken as the only input to distinguish day from night, because there can be a weather station sensor malfunction.
Data statistic calculations are another key element in photovoltaic plant monitoring. There are indicators that need to be presented in a time period higher than the acquisition ones, e.g, the average irradiance for a specific day, the maximum module temperature for a specific month, the energy produced in a specific month, the daily performance ratio or even the maximum auxiliary services power consumption for a day or month.

Taking this premisses and the transmitted experience from the Martifer Solar's Automation and Control Systems team, the monitoring platform development begun.

As stated, Movicon™ 11 is the framework where the monitoring platform is based. In order to this project succeed, all the framework capabilities need to be explored. Sooner it was depicted that - in order to build an optimised, dynamic and scalable GUI - the basic Movicon™ 11 tools would not be enough.
Movicon™ 11 was essentially used to "draw" the synoptics and, its most important feature, to acquire data from equipment. To do so, the framework uses drivers that shall be configured according to protocol needs. Another Movicon™ 11 main built-in feature is datalogging. This feature, after configured, stores acquisition data in the SQL database without any additional coding (e.g.: code to create ODBC connections).
Besides the mentioned features, all other features were implemented by "finger". VBA scripts were used to implement functions from filling a simple box with text to create dynamic complex SQL queries. Dynamic FTP batch files, ODBC connections, user management, KPI calculations, filling trends/grids as well as other "simple" synoptic actions were implemented using scripts.
Hundreds, if not thousands, source lines of code were written to create the monitoring platform. The SCADA system cannot have its processes stopped due to a programming code bug. For

this reason, it was necessary to write carefully the platform code. The scripts were thoroughly tested and debugged and, while coding, the most error situations tried to be predicted. Since it is impossible to foresee all hypothetical errors, the scripts were also written in order to not stop all the application due to an error. Depending on the error severity, the system tries to run the script again. If the situation persists, the system stops the specific script and informs the system developer by email and by logging the error message in the SCADA database.
All the mentioned features result from hours of developing. Several constraints were taken into account during the system development. It is not possible to enumerate all implemented script routines. A simple button used to fill a chart runs hundreds of code lines in order to dynamically build a query to retrieve the mentioned data.

The SCADA GUI developed using Movicon™ 11 is a main component of this thesis work. Nevertheless, the SQL database depicts itself as another main component. Creating the SQL database proved to be an interesting challenge since the author's lack of training/academic education regarding this subject. With hard work, this challenge has become gratifying since it allowed the expansion of the author knowledge about a so complex area.
The SQL database is organised in a simple and intuitive manner. It was designed in order to ease the SCADA application programming as well as the integration with Martifer Solar's central Operation and Management System.
Despite several monitoring platform component being developed at Martifer Solar's offices, substantial development/upgrades were performed on the first PV plant sites. Several conditions can be predicted during "office development" stage but it becomes impossible to predicted the monitoring system behaviour during production. Moreover, some equipment are only available on site for testing, for example, inverters or switchgear interconnection protection.
In order to install the monitoring platform, several tasks were performed:

- Configure the communication network (OF switches, protocol converters, etc.);
- Configure equipment communication, i.e, configure modbus stations, IP, OPC, among others. This task can depict itself as very exhaustive since sometimes it is necessary to configure manually individual equipment, by dozens or hundreds, that are distributed through the PV plant;
- Test weather sensors;
- Check monitoring cabinets connections;
- Configure the SCADA system server.

Alongside the mentioned tasks, several challenges can yet appear. The monitoring PV plant infrastructure is a very complex one. Several subcontractors are involved. When anomalies were detected it was necessary to manage all the corrective works between subcontractors.

Sometimes, it is necessary to "get hands dirty" in order to speed up all the entire monitoring system installation process and, therefore, to fulfil installation deadlines.
In addition to be the first installation of the developed platform, a greater challenge appeared: the SCADA application needed to be installed in six different PV plants nearly simultaneously due to common close deadlines. This challenge was successfully accomplished due to earlier performed work during development stage at the office and, mainly, due to the work excellence of Martifer Solar's Automation and Control Systems Area.
All the monitoring platforms were fully functional in each PV plant for the Performance Ratio tests[1]. This accomplishment, according to feedback from experienced people inside Martifer Solar, is not often achieved by other monitoring system subcontractors.

The developed monitoring system was named SMARTMSYST. It became a technical and commercial solutions for Martifer Solar, a global player in the PV sector with more than 560 MW of solar power installed worldwide.
Approximately one year after its first installation, SMARTMSYST monitors eight PV plants which corresponds to around 37 MW. Figure 5-1 depicts the monitored sites by the developed monitoring system.

[1]Period of time where the PV plant production is evaluated using the Performance Ratio indicator. In some cases, data from the SCADA system is used to perform the tests.

Figure 5-1: Monitored photovoltaic plants.

For the mentioned reasons, it is visible that, for Martifer Solar, the developed monitoring platform turned to be a valid solution, either technically and economically.

From the academic perspective, this thesis proved to be an excellent challenge. It allowed the author to broaden his knowledge and skills regarding a subject so multidisciplinary.

5.3 Future Developments Perspective

Although the results presented met purposed goals, the monitoring platform can be further developed in a number of ways:

Optimised web interface
SMARTMSYST web client interface use a Movicon™ 11 framework feature based on modern Java Thin Client technologies to share real-time data on Internet or Intranet network architectures. It does not require any installation or configuration procedures on the SCADA server, which are often found complex or tedious. Exploiting HTML pages, SMARTMSYST current web client technology allows the production process to be viewed from any part of the world by using a normal browser. The client can access the server without needing a local installation. Even though advantageous for certain aspects, this technology does have a few functionality restrictions where the client side is concerned [12].
Essentially, the web client can be depicted as a Java applet that shows a mirrored image of the application installed on the server.
Due to remote PV plant locations, sometimes the internet speeds are not satisfactory to fulfil the needs of that kind of Java application. Sometimes it is difficult to access the SCADA with the web client due to timeouts or even conflicts with the Java version installed on the machine that is trying to access.
For these reasons, it is proposed to develop a new independent web interface to access PV plant data. This web interface shall be based in a web page located on the SCADA server. The web page shall work as the already existing web client application. There are a number of ways to design the mentioned web page. A study to evaluate the best option shall be made.
The main objective is to developed a more optimised and adequate application for remotely accessing the monitoring platform.

PV Forecasting
When building a large PV plant, lots of questions can appear regarding the plant output and its variability at a proposed site. New methods are being developed that shall allow better plant output variability prediction.
There are software that make PV plant production estimations. The proposed upgrade consists in adding forecasting features to SMARTMSYST. This can be achieve using data from

simulation software, satellite or other study methodologies. The objective is to give the SCADA user a better understanding regarding the PV plant production expectations.

Operation modes

Operation modes are based in a set of guidelines that the monitoring system shall assume, under specific conditions.
It can be implemented the "Maintenance Mode". During this operation mode some configured equipment alarms shall be ignored. For example, during an equipment replacement there shall be no alarm triggered due to lack of communication with the equipment being replaced.
Another operation mode can be the "Night Mode". There are equipment powered directly from the PV plant production. During night, those equipment are turned off due to lack of power. During this mode of operation, any communication alarms from those equipment shall be ignored. Other situations shall be analysed in order to proper configure the mentioned operation modes or to create other.

Configurable reports

The creation of a report tool is proposed. This tool could be used to send to the system user reports with production, triggered alarms or weather condition from the PV plant.

KPI

More KPI calculation can be added to the monitoring platform:

- MTBF - Mean Time Between Failures: Calculation of the mean time between equipment or PV plant failures.
- MTBR - Mean Time Between Repairs: Provides information on operating reliability. Adapting this KPI to the PV plant reality would imply the calculation of the mean time spend on an equipment repair.

Implement "system intelligence" for error handling

Implement intelligence analysis between PV plant main variables. It is difficult to define static set points for the system analysis. For example, Fuzzy Logic could be used to evaluate if the difference between measured irradiance and inverter output power is significant enough for it to mean an equipment malfunction. Of course, this kind of analysis would not be that simple. For the mentioned example, other factors as the PV module temperature or the supposed anomalies time duration shall be taken into account.

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APPENDIX A

Table A-1: IEC directives description.

Directive	Description
IEC 60904-2	Photovoltaic devices - Part 2: Requirements for reference solar devices
IEC 60904-6	Photovoltaic devices - Part 6: Requirements for reference solar modules
IEC 61158	Industrial communication networks - Fieldbus specifications
IEC 61724	Photovoltaic system performance monitoring - Guidelines for measurement, data exchange and analysis
IEC 61784	Industrial communication networks - Profiles
IEC 61829	Crystalline Silicon Photovoltaic (PV) Array - On-Site Measurement of I-V Characteristics (1995)

APPENDIX B

Table B-1: SCADA survey - part(1/3).

Features	Critical Software	Control Maestro (ELUTIONS SCADA)	SoftPAC	Progea - Movicon 11	ZenOn	Ignition	Invensys Operations Management	Open Automation Software	Visu+ - Phoenix
Hardware Requirements									
CPU			multicore,32/64 bits	32/64 bits					Pentium/Celeron, 1.6 GHz
RAM									
SO			Win7 or Win XP	Win7, WinCE, HMI,					Win XP SP3, Win Vista, Win 7 Profissional (32/64bit)
Storage			on PC HD or network	On PC HD or Network					On PC HD or Network
Licences									
Developer	No	Yes	Yes	Yes - built-in native support to Microsoft Visual SourceSafe 6.0	Yes				
Runtime	Yes	Yes	Yes	Yes	yes				
Billing type	Licence	Licence	6	Yes - I/O Bytes exchanged with the field and in use		server license includes unlimited clients and			
Web-client		yes		Yes - Integrating with XML, SVG, Web Services, JAVA	yes				
Web server included	No	Yes							
Scalability		Yes		Yes - Total					
Re-usable		Yes							
Alarms				Alarms completely customizable					Alarms completely customizable
historical logging	yes	yes	yes	Yes	Yes	yes	yes	yes	Yes
alarm filters		yes	yes	Yes	Yes	yes	yes	yes	Yes
data archieve in DB	yes	yes		Yes	Yes	yes	yes	yes	Yes
alarm status identification	yes	yes	yes	Yes	Yes	yes	yes	yes	Yes
Notifications	yes	yes		Yes	Yes	yes		yes	Yes
send alarm by e-mail	yes	yes		Yes		yes			Yes
send alarm by SMS	no	yes		Yes					Yes
alarm filter by group	yes	yes		Speeching and Fax. Phone calls					Speeching and Fax. Phone calls
alarm acknoledgement	no	yes							
historical information of acknoledges	no	yes							

Table B-2: SCADA survey - part(2/3).

Features	Critical Software	Control Maestro (ELUTIONS SCADA)	SoftPAC	Progea - Movicon 11	ZenOn	Ignition	Invensys Operations Management	Open Automation Software	Visu+ - Phoenix
Data Storage									
Engine type	Critical Software	ODBC		ODBC				Cloud	ODBC
DB type	Not Included - SQL Server	SQL Server Express	Not included; purchase separately (OptoDataLink)	MS SQL Server, MySQL, Oracle 10 or Access	SQL Server	SQL			MS SQL Server, MySQL, Oracle 10 or Access
SQL Server included ?	No	Yes	Built-in, easy data transfer to Microsoft ® SQL Server, (only PAC Project Professional)						
Other formats		TXT and CSV files	Microsoft Access, MySQL, text files (only PAC Project Professional)	text formats					text formats
Filter		Yes							
Export to TXT and CSV		Yes							
Trends									
Graphs	Yes	Yes - TOTAL	Yes	Yes - Total		yes		yes	Yes - Total
Data Analysis	Yes	Yes		Yes - dynamical and historical		yes		yes	Yes - dynamical and historical
Reports	No	yes		yes		yes - Dynamic PDF		yes	yes
change colors	Yes	Yes							
more than 1 variable per trend	No	Yes							
continuous monitoring of data animation	No	Yes							
Export to CSV	No	Yes							
Connectivity									
PLC connection	limited	Yes		Yes	yes	yes		yes	Yes
OPC Server	no	Yes		Yes	yes	yes	yes	yes	Yes
OPC Client	no	Yes		Yes	yes	yes		yes	Yes
ODBC external link	no	Yes		yes	yes	yes		yes	yes
Modbus RTU	Yes	Yes							
Modbus ASCII	Yes	Yes							
Modbus TCP/IP	Yes	Yes							
IEC-60870-5-104	Yes	Yes							
DLMS/COSEM	Yes	Yes							
Siemens Profibus	No	Yes							
Siemens Profinet	No	Yes							

Table B-3: SCADA survey - part(3/3).

Features	Critical Software	Control Maestro (ELUTIONS SCADA)	SoftPAC	Progea - Movicon 11	ZenOn	Ignition	Invensys Operations Management	Open Automation Software	Visu+ - Phoenix
Remote access									
Licenses		Yes							
Max users		Yes							
User Access / security									
define permissions	No	yes - password, smartcard, token, fingerprint		Yes	yes	yes			Yes
levels of access	No	multiple -		1024 and/or 16 areas		yes			1024 and/or 16 areas
		Access Rights for Tags , Access Rights for Alarms, Access Rights for Menus and Modules , Access Rights for Objects in Images,							
		Implementation of the Access Rights on Microsoft and Web level							
specify layers/groups which will show to each user	No	Yes							
Specify which menus are accessible to each user	No	Yes							
Security system to block program and block keys and shortcuts, etc	No	Yes							
Programm starts with Windows and block other windows applications	No	Yes							
Language									
multilanguage	No	Yes		Yes					Yes
number of languages	1			Unlimited number of languages					
editor	1			VBA	VBA				VBA
TAGs									
Minimum and maximum values	No	100 to 65000							
Alarmes per tag	No	Yes							
get value from txt file	No	Yes							
Interface									
dynamic animation	No	Yes							
Others									
Internal development	No	Yes							
Protocol development	No	Yes							
Support without cost	No	Yes							
Training	Yes	Yes							

APPENDIX C

Introduction

This appendix describes the requirements for the Email notification feature of a Supervision Control and Data Acquisition (SCADA) System application.

A SCADA system shall provide a panoply of solutions in order to allow an operator to receive information about the monitored plant. Therefore, an email sending feature shall be implemented. This feature may be used for sending data files in attachments, system operational information or alarms notifications.

The objective and intent of this appendix is to provide information regarding the guidelines taken to develop the monitoring platform email sending application.

Scope

In order to send email, the monitoring plaform used the *Microsoft CDO Windows* Library. Figure C-1 depicts a function capable to send emails.

```
Public Function SendMyEmail(sTo As String, sCC As String, sBCC As String, _
                        sSubject As String, sTextBody As String, sAttach As String, _
                          ssmtp As String, sAccount As String,  sPass As String)
Dim Mail As New Message
Dim Config As Configuration
Dim sStatus As String
Set Config = Mail.Configuration
Config(cdoSendUsingMethod) = cdoSendUsingPort
Config(cdoSendUsingMethod) = cdoSendUsingPort
Config(cdoSMTPServer) = ssmtp'"smtp.gmail.com"
Config(cdoSMTPServerPort) = 25
Config(cdoSMTPAuthenticate) = cdoBasic
Config(cdoSMTPUseSSL) = True
Config(cdoSendUserName) = sAccount
Config(cdoSendPassword) = sPass
Config.Fields.Update

Mail.To = sTo
Mail.CC = sCC
Mail.BCC = sBCC
Mail.From = Config(cdoSendUserName)
Mail.Subject = sSubject
Mail.HTMLBody = sTextBody

        If sAttach <> "" Then
            Mail.AddAttachment sAttach
        End If

On Error Resume Next
Mail.Send

If Err.Number <> 0 Then
    sStatus = "Mail Send Failure"
Else
    sStatus = "Mail Send Successfull"
End If
End Function
```

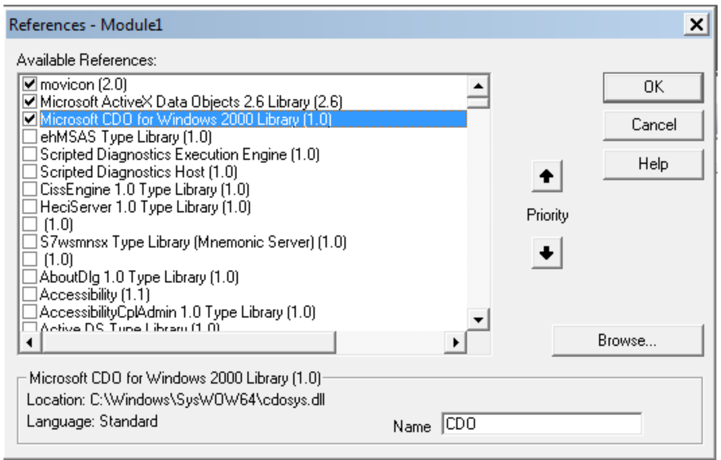

Figure C-1: Send email - code example.

This appendix specifies and provides information (mainly) for Monitoring and Control System about:

- Sending email notification about the SCADA system operational status

- Sending email with data files attached. Data files are filled with information from the system database. This is data files shall be compatible with a data to third party software (for example Microsoft Excel).
- Sending email notification with a list of active alarms select by an operator.

General Specifications

Email structure

The Email structure shall be composed by the following elements:

- Recipients
- Subject
- Body
- Attachments

Recipients
Recipients shall be user configurable. A system operator shall be able to select which email notifications he wants to receive as well as define the addresses in Carbon Copy/Blind Carbon Copy if applicable.
Subject
Subject shall be structured as follows:
<PV plant identification>: <SCADA system identification><><general sentence>.
An example of a subject sentence:
"PV plant ID: MySCADA has sent you an email."
Body
The Email body should make a brief approach to the subject.
Attachments
If applicable.

System operational status

This email notifications shall be sent on event. The information on this type of email shall be related to the system operation status. The operator shall be able to receive an email notification on:

- System boot;
- System shutdown;

- System error;

System boot
When the system boots the operator shall receive an email notification with the following body text:
<Date><><Time>- <PV plant identification>: <SCADA system identification>HAS BOOTED.

System shutdown
When the system Shuts down the operator shall receive an email notification with the following body text:
<Date><><Time>- <PV plant identification>: <SCADA system identification>WAS SHUTDOWN.

System error
A SCADA application is a complex system where a range of errors can occur. In order to easy the system debug, an operator shall be able to receive an email notification when a system error occurs. The body text of the email notification shall contain the error description. The email subject shall be written in order to clearly alert the operator that the message is related to a system error. for Example:

Subject:
<PV plant identification>: <SCADA system identification>has sent you an error message!
Body:
Error Number: -2147467259 Error Desc: Transaction (Process ID 296) was deadlocked on lock resources with another process and has been chosen as the deadlock victim. Rerun the transaction.Error Source: Microsoft OLE DB Provider for SQL Server

Sending Files

A SCADA application shall be capable to export database files to a third party software. A synoptic shall be implemented in a way that these exported files can be send by email. Figure C-2 depicts a synoptic example used for the mentioned matter.

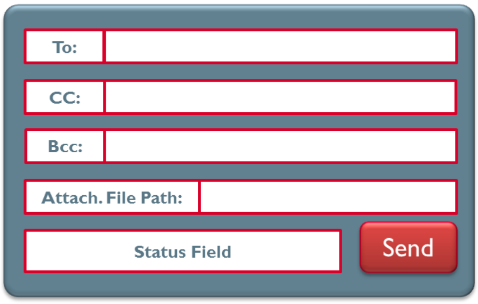

Figure C-2: Example of email sending configuration synoptic.

The email body text shall include some PV plant characteristics such as its identification, latitude, altitude and lifetime energy yield. If the attached file as a copy saved in the local server, its path shall also be included in the email text body. An example is shown below:

<**PV plant identification**>

Latitude: XX°XX’ XX,XX” N
Longitude: X°XX’ XX,XX W
Altitude: XXX m
Lifetime Energy Yield: XXXXXX,XXX kWh

Please find the requested data file
(C:\FOLDER\20140129 _20140131_Equip.csv in attachment.)

Best Regards,
<SCADA system identification>

Alarm notifications

Alarm notifications are a critical feature in SCADA application. This feature shall be implemented in a way to allow the operator to select a group of alarms from whom he wants to receive notifications when active. The user shall received an email like shown below:

System Operator,

You've configured <SCADA system identification>(<PV Plant ID>) to send you notifications from a selected group of alarms. Some of these alarms are active.

Please look at the following list:

Inverter 1.1 - #6, Current overload
Inverter 1.2 - #6, Current overload
Inverter 2.1 - #6, Current overload
Inverter 2.2 - #6, Current overload
Solar Tracker 2.5.2 - Tracker in Automatic Mode
Solar Tracker 1.7.2 - Tracker in Automatic Mode
Solar Tracker 1.2.2 - Tracker in Automatic Mode
JB 2.8.3 - String 1, String 2 - Low Production
JB 1.3.2 - String 2 - Low Production
Switchgear - RNE
Switchgear - Relay Status OK
Switchgear - Circuit-Breaker closed

Best Regards,
<SCADA system identification>

Figure C-3: Email alarm notification.

The alarm description in the email text body shall have a background color according to the correspondent alarm severity. Table C-1 shows the correspondence between color and severity.

Table C-1: Alarm severity correspondent colors.

Alarm Severity	**Color**
Warning	#FFCC00
Status	#597786
Error	#DB0029

Selecting alarms

A synoptic shall be created where an operator can insert an entry with all his data and a list of alarms from whom he wants to receive notifications. For better organisation, all the alarm descriptions shall be divided by equipment type. Figure C-4 depicts a layout for the mentioned synoptic.

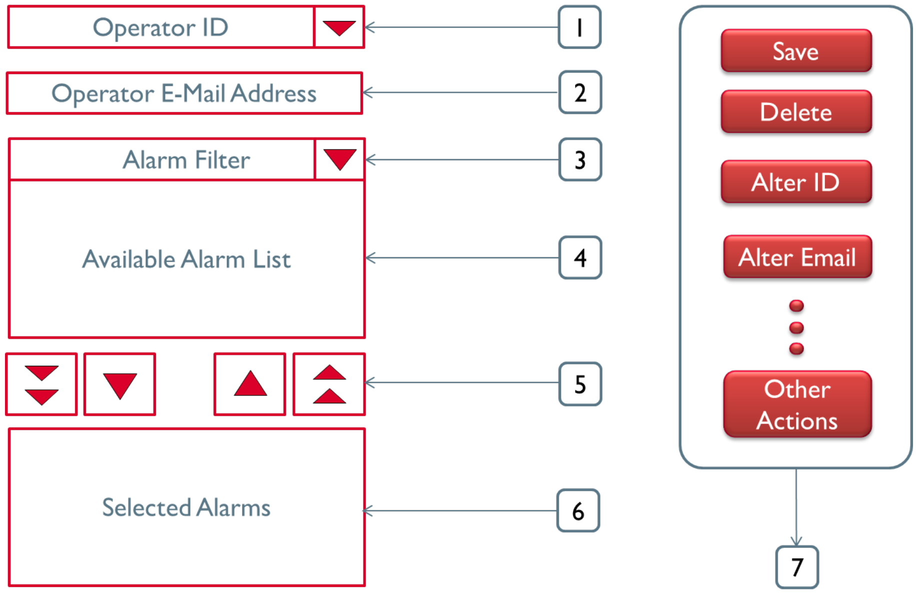

Figure C-4: Example of synoptic layout for selecting alarms.

Where:

1. In this field the operator ID is inserted. The operator will be address in the email by the content of this field.
2. Field to insert the email address associated with operator in field 1. It shall be possible to inserted more than one email addresses (e.g. separating them by ";").
3. Allows the system operator to filter the alarm description that will be filling field 4. In this case, alarms shall be filter by equipment.
4. List of alarms description present on the system. This field is subject to the filter on field 3.
5. Cursors to move alarm descriptions from the field 4 to field 5, the select alarms field.
6. Selected alarms are placed in this field. All the listed alarms in this field are subject to the button actions depicted in field 7.
7. Actions buttons. In this field shall be possible to save, alter or delete the alarms present in field 6. It shall also be possible to erase completely an operator configuration, among other features.

Processing the notifications

The SCADA application shall cyclically sweep all the alarm entries present in the system. If an active alarm description matches one of the select by the operator, an email shall be sent. There are some points to consider. For example, there shall not be repeated alarms listed in the email body neither the user shall receive twice in a row the same active alarm list. To better understand this matter please check figure C-5.

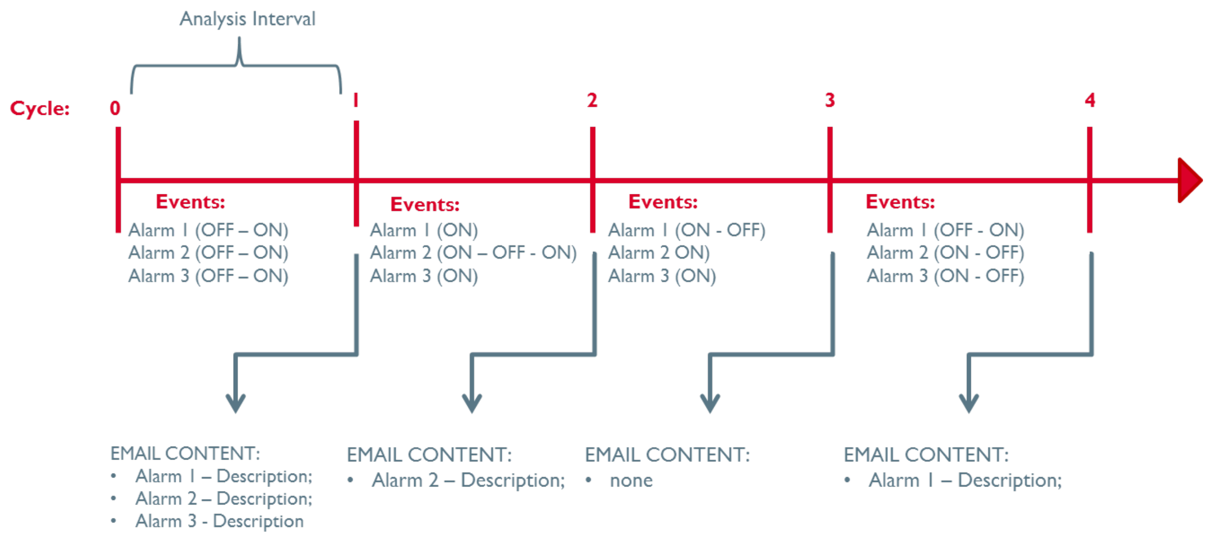

Figure C-5: Example of an alarm notification cycle process.

If a notification inherit to a specific alarm is sent at the *n* cycle, it shall not be sent on the *n + 1* cycle in case its state (ON/OFF) did not change. Only new alarm entries shall be sent.

APPENDIX D

```sql
WITH CTE1 AS
    (SELECT [DB10MIN_WEATHER_TYPE1].[LocalCol],
    [DB10MIN_WEATHER_TYPE1].[Module Temperature]
        AS [Module Temperature (ºC) - Weather Station T1],
    [DB10MIN_WEATHER_TYPE1].[Irrad Module Plane]
        AS [Irrad Module Plane (W/m2) - Weather Station T1],
    [DB10MIN_WEATHER_TYPE1].[Irrad Pyranometer]
        AS [Irrad Pyranometer (W/m2) - Weather Station T1]
    FROM [DB10MIN_WEATHER_TYPE1]
    WHERE [DB10MIN_WEATHER_TYPE1].[LocalCol] >= '2014-02-10 00:00:00'
    AND [DB10MIN_WEATHER_TYPE1].[LocalCol] <= '2014-02-10 23:59:00'
    AND [DB10MIN_WEATHER_TYPE1].[ID] = 'Weather Station T1'
    ),
CTE2 AS
    (SELECT [DB10MIN_INVERTER].[LocalCol],
    [DB10MIN_INVERTER].[Active Power]
        AS [Active Power (kW) - Inverter 1]
    FROM [DB10MIN_INVERTER]
    WHERE [DB10MIN_INVERTER].[LocalCol] >= '2014-02-10 00:00:00'
    AND [DB10MIN_INVERTER].[LocalCol] <= '2014-02-10 23:59:00'
    AND [DB10MIN_INVERTER].[ID] = 'Inverter 1.1'
    )

SELECT TOP 5000 CONVERT(VARCHAR(10),[CTE1].[LocalCol],120) as [Date],
    CONVERT(VARCHAR(2),[CTE1].[LocalCol],108)+':00' as [Time],
    CAST(ROUND(AVG([CTE1].[Module Temperature (ºC) - Weather Station T1]/1.0),3) as numeric(10,3))
        AS [Module Temperature (ºC) - Weather Station T1],
    CAST(ROUND(AVG([CTE1].[Irrad Module Plane (W/m2) - Weather Station T1]/1.0),3) as numeric(10,3))
        AS [Irrad Module Plane (W/m2) - Weather Station T1],
    CAST(ROUND(AVG([CTE1].[Irrad Pyranometer (W/m2) - Weather Station T1]/1.0),3) as numeric(10,3))
        AS [Irrad Pyranometer (W/m2) - Weather Station T1],
    CAST(ROUND(AVG([CTE2].[Active Power (kW) - Inverter 1]/1.0),3) as numeric(10,3))
        AS [Active Power (kW) - Inverter 1]
FROM [CTE1]
LEFT JOIN [CTE2] On
    CONVERT(VARCHAR(16),[CTE1].[LocalCol],120) = CONVERT(VARCHAR(16),[CTE2].[LocalCol],120)
GROUP BY CONVERT(VARCHAR(10),[CTE1].[LocalCol],120),
         CONVERT(VARCHAR(2),[CTE1].[LocalCol],108)
ORDER BY CONVERT(VARCHAR(10),[CTE1].[LocalCol],120) + ' ' + CONVERT(VARCHAR(2),[CTE1].[LocalCol],108)+':00' ASC
```

Figure D-1: Example of an historical data synoptic query.

APPENDIX E

```
Public Sub Click()

    sProcesses = ""
    Dim colDisks As Object
    Dim objDisk As Object
    Dim objSymbol As ListBoxCmdTarget

    Set colDisks = GetObject("Winmgmts:").ExecQuery("select * from Win32_Process")

    For Each objDisk In colDisks
        If InStr(objDisk.Caption,".exe") > 0 Then
            sProcesses =  sProcesses & objDisk.Caption & "|"
        End If
    Next

    sProcesses = Left(sProcesses,Len(sProcesses))
    Set colDisks = Nothing

    bShowProcesses = True


    Set objSymbol = GetSynopticObject.GetSubObject("proc").GetSubObject("lista").GetObjectInterface
    If objSymbol Is Nothing Then GoTo out
    objSymbol.RefillList

    out:
    Set colDisks = Nothing
    Set objDisk = Nothing
    Set objSymbol = Nothing
End Sub
```

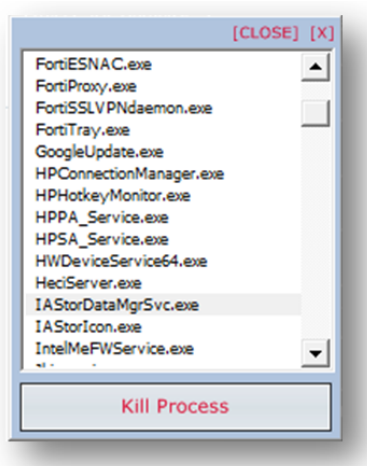

Figure E-1: Code to check server running processes - example.

APPENDIX F

```
Function BackupMyDB()
Dim Cnn As New ADODB.Connection
Dim Cmd As New ADODB.Command
Dim sDB_Name As String

        If DbOpenConnection(Cnn, DB_SQLSERVER) Then
            Set Cmd.ActiveConnection = Cnn
            Cmd.CommandType = adCmdText
            Cmd.CommandTimeout = 0

                Cmd.CommandText = "exec sp_executesql N'BACKUP DATABASE [" & DATABASE_NAME & "] TO  DISK = @P1 WITH  INIT" & _
                                  " ,  NOSKIP ,  NOFORMAT ',N'@P1 nvarchar(255)',N'" & FILENAME & "'"
                Cmd.Execute
            Call DbCloseConnection(Cnn)
        End If
        Set Cnn = Nothing

        Exit Function
ConnectionError:
    MsgBox("Error Number: " & Err.Number & vbCrLf & "Error Desc: " & Err.Description, vbCritical, GetProjectTitle)
End Function
Public Function DbOpenConnection(Cnn As Object, bSQLServer As Boolean, _
                            Optional bTrusted As Boolean = True, Optional nTimeout As Integer = 10) As Boolean
    DbOpenConnection = False

    On Error GoTo OpenConnectionError
    If Cnn.State = 1 Then GoTo ConnOpen
    'open DB connection
    If bSQLServer Then
        If bTrusted Then
            'Windows
            Cnn.ConnectionString =  "Provider=SQLOLEDB.1;Data Source=" & DB_SERVERNAME & _
                                        ";Initial Catalog=" & DB_DATABASE & _
                                        ";Trusted_Connection=Yes;"
        Else
            'SQL Server
            Cnn.ConnectionString =  "Provider=SQLOLEDB.1;Data Source=" & DB_SERVERNAME & _
                                        ";Initial Catalog=" & DB_DATABASE & _
                                        ";User ID=" & DB_USERNAME & _
                                        ";Password=" & DB_PASSWORD & ";"
        End If
    Else
        Cnn.ConnectionString  = "Provider=Microsoft.Jet.OLEDB.4.0;Data Source=" & GetDataLoggerRecipePath() & DB_DATABASE & ".mdb" & _
                                ";User ID=Admin;Password=;"
    End If

    Cnn.ConnectionTimeout = nTimeout
    Cnn.Open
ConnOpen:
    DbOpenConnection = True
    Exit Function
OpenConnectionError:
    MsgBox("Error Number: " & Err.Number & vbCrLf & "Error Desc: " & Err.Description, vbCritical, GetProjectTitle)
End Function
Public Function DbCloseConnection(Cnn As Object) As Boolean
    On Error GoTo CloseConnectionError
    DbCloseConnection = False
    If Cnn.State <> 0 Then Cnn.Close
    DbCloseConnection = True
    Exit Function
CloseConnectionError:
    MsgBox("Error Number: " & Err.Number & vbCrLf & "Error Desc: " & Err.Description, vbCritical, GetProjectTitle)
End Function
```

Figure F-1: Code to command database backup - example.

APPENDIX G

```
CREATE PROCEDURE [dbo].[PRODUCTION_CALC_HOUR]
(
@sDate  NVARCHAR(10)
,@fDate NVARCHAR(10)
,@dPeak FLOAT
,@MinIrrad INT
)
AS
BEGIN
SET NOCOUNT ON;



DECLARE @HOUR_PRODUCTION_TEMP TABLE
(
    [LocalCol] [datetime] NOT NULL,
    [JunctionBoxs] [decimal](18, 2) NULL,
    [Inverters] [decimal](18, 2) NULL,
    [Switchgear] [decimal](18, 2) NULL,
    [Radiation] [decimal](10, 2) NULL,
    [EnergyMeter] [decimal](18, 2) NULL,
    [EnergyMeter Daily] [decimal](13, 2) NULL,
    [EnergyMeter Partial] [decimal](12, 2) NULL,
    [PeakPower] [decimal](12, 2) NULL,
    [TempPanel] [decimal](10, 2) NULL,
    [PR] [decimal](30, 2) NULL
);

-- ENERGY METER + WEATHER STATIONS
WITH CTE AS(
SELECT [DB10MIN_WEATHER_TYPE1].[LocalCol] AS LocalCol
        ,([DB10MIN_WEATHER_TYPE1].[Irrad Module Plane] +
        ISNULL([DB10MIN_WEATHER_TYPE2].[Irrad Module Plane],[DB10MIN_WEATHER_TYPE1].[Irrad Module Plane])) / 2 as [Irrad Module Plane]
        ,[DB10MIN_WEATHER_TYPE1].[Module Temperature] as [Module Temperature]
       ,[DB10MIN_ENERGYMETER].[Lifetime Active Energy Exp] as [Lifetime Active Energy Exp]
       ,@dPeak AS [Peakpower]
       FROM [DB10MIN_WEATHER_TYPE1]
inner JOIN [DB10MIN_ENERGYMETER] ON
CONVERT(VARCHAR(16),[DB10MIN_WEATHER_TYPE1].[LocalCol],120) = CONVERT(VARCHAR(16),[DB10MIN_ENERGYMETER].[LocalCol],120)
inner JOIN [DB10MIN_WEATHER_TYPE2] ON
CONVERT(VARCHAR(16),[DB10MIN_WEATHER_TYPE1].[LocalCol],120) = CONVERT(VARCHAR(16),[DB10MIN_WEATHER_TYPE2].[LocalCol],120)
where convert(varchar(10),[DB10MIN_WEATHER_TYPE1].[LocalCol],120) >= @sDate AND
convert(varchar(10),[DB10MIN_WEATHER_TYPE1].[LocalCol],120) <= @fDate
and [DB10MIN_WEATHER_TYPE1].[Irrad Module Plane] > @MinIrrad
),

--PRODUCED ENERGY BY EACH HOUR (E.G 11:00,12:00,13:00)
CTE2 AS(
SELECT convert(varchar(13),LocalCol,120) + ':00' AS LocalCol
        ,MIN([Lifetime Active Energy Exp]) AS [Lifetime Active Energy Exp]
       from CTE
       group by convert(varchar(13),LocalCol,120)
       ),

--AUXILIAR
CTE3 AS(
SELECT DATEADD(HOUR,1,LocalCol) as LocalCol, [Lifetime Active Energy Exp] as [Lifetime Active Energy Exp]
FROM CTE2
),

--PRODUCED ENERGY DURING EACH HOUR
CTE4 AS(
SELECT [CTE2].[LocalCol] AS LocalCol, [CTE2].[Lifetime Active Energy Exp] as EN1
       ,[CTE3].[LocalCol] AS LocalColTEMP, [CTE3].[Lifetime Active Energy Exp] as EN2
       ,([CTE2].[Lifetime Active Energy Exp] - [CTE3].[Lifetime Active Energy Exp]) as DIFF
      FROM [CTE2]
INNER JOIN [CTE3] ON
[CTE2].[LocalCol] =  [CTE3].[LocalCol]
```

Figure G-1: Stored procedure to calculate the PV plant production summary - part (1/2).

```
--HOURLY RADIANCE
CTE5 AS(
select dateadd(hour,1,convert(varchar(14),dateadd(minute,-10,LocalCol),120) + '00') as LocalCol,
avg([Irrad Module Plane]) as [Irrad Module Plane],
avg([Module Temperature]) as [Module Temperature]
from CTE
group by convert(varchar(14),dateadd(minute,-10,LocalCol),120)),

--JUNCTION BOX
CTE6_6 AS
(SELECT dateadd(hour,1,convert(varchar(14),dateadd(minute,-10,LocalCol),120) + '00') as LocalCol
,[ID] as [ID]
,AVG([Power_Total]) as [Power]
FROM [dbo].[DB10MIN_JB]
where convert(varchar(10),[LocalCol],120) >= @sDate AND
convert(varchar(10),[LocalCol],120) <= @fDate
GROUP BY convert(varchar(14),dateadd(minute,-10,LocalCol),120), [ID]),

CTE6 AS(
SELECT LocalCol AS LocalCol, SUM([Power]) AS [Power] FROM CTE6_6
GROUP BY LocalCol),

--INVERTERS
CTE7_7 AS
(SELECT dateadd(hour,1,convert(varchar(14),dateadd(minute,-10,LocalCol),120) + '00') as LocalCol
,[ID] as [ID]
,AVG([Active Power]) as [Active Power]
FROM [dbo].[DB10MIN_INVERTER]
where convert(varchar(10),[LocalCol],120) >= @sDate AND
convert(varchar(10),[LocalCol],120) <= @fDate
GROUP BY convert(varchar(14),dateadd(minute,-10,LocalCol),120), [ID]),

CTE7 AS(
SELECT LocalCol AS LocalCol, SUM([Active Power]) AS [Active Power] FROM CTE7_7
GROUP BY LocalCol),

--SWITCHGEAR
CTE8 AS(
select dateadd(hour,1,convert(varchar(14),dateadd(minute,-10,LocalCol),120) + '00') as LocalCol,
avg([Active Power]) as [Active Power]
FROM DB10MIN_SWITCHGEAR
where convert(varchar(10),[LocalCol],120) >= @sDate AND
convert(varchar(10),[LocalCol],120) <= @fDate
GROUP BY convert(varchar(14),dateadd(minute,-10,LocalCol),120))--,


-- GATHER ALL DATA IN ONE TABLE
INSERT INTO @HOUR_PRODUCTION_TEMP ([Localcol], [JunctionBoxs],[Inverters],[Switchgear],[Radiation],
        [EnergyMeter],[EnergyMeter Daily],[EnergyMeter Partial],[PeakPower],[TempPanel],[PR])
SELECT CONVERT(VARCHAR(16),[CTE5].LocalCol,120) AS LocalCol
      ,ISNULL(CAST([CTE6].[Power] AS DECIMAL(7,2)),0) as [DC Power - JunctionBox]
      ,ISNULL(CAST([CTE7].[Active Power] AS DECIMAL(7,2)),0) as [Active Power - Inverter]
      ,ISNULL(CAST([CTE8].[Active Power]*1000 AS DECIMAL(7,2)),0) as [Active Power - Switchgear]
      ,ISNULL(CAST([CTE5].[Irrad Module Plane] AS DECIMAL(8,3)),0) as [Irradiation Module Plane]
      ,ISNULL(CAST([CTE4].[EN1] AS DECIMAL(20,2)),0) as [Total Energy]
      ,ISNULL(CAST([DB10MIN_ENERGYMETER].[Active Energy Exp Daily] AS DECIMAL(20,2)),0) as [Daily Energy]
      ,ISNULL(CAST([CTE4].DIFF AS DECIMAL(20,2)),0) as [Partial Energy]
      ,@dPeak AS [PeakPower]
      ,ISNULL(CAST([CTE5].[Module Temperature] AS DECIMAL(4,1)),0) as [Module Temperature]
      ,ISNULL(CAST([CTE4].DIFF * 100 / NULLIF(([CTE5].[Irrad Module Plane] * @dPeak / 1000),0) AS DECIMAL(30,2)),0) AS [PR]
FROM [CTE5]
left JOIN [CTE4] ON
[CTE5].[LocalCol] = [CTE4].[LocalCol]
left JOIN [CTE6] ON
[CTE5].[LocalCol] = [CTE6].[LocalCol]
left JOIN [CTE7] ON
[CTE5].[LocalCol] = [CTE7].[LocalCol]
left JOIN [CTE8] ON
[CTE5].[LocalCol] = [CTE8].[LocalCol]
left JOIN [DB10MIN_ENERGYMETER] ON
[CTE5].[LocalCol] = CONVERT(VARCHAR(16),[DB10MIN_ENERGYMETER].[LocalCol],120)
WHERE CONVERT(VARCHAR(16),[CTE5].LocalCol,120) < CONVERT(VARCHAR(16),GETDATE(),120) and
CONVERT(VARCHAR(10),[CTE5].LocalCol,120) >= @sDate and
CONVERT(VARCHAR(10),[CTE5].LocalCol,120) <= @fDate
ORDER BY CONVERT(VARCHAR(16),[CTE5].LocalCol,120) ASC
END

--OUTPUT
SELECT * FROM @HOUR_PRODUCTION_TEMP ORDER BY LOCALCOL ASC
```

Figure G-2: Stored procedure to calculate the PV plant production summary - part (2/2).