Requirements Specification

Cloud Tracking and Solar Forecasting for PV Power Prediction

Help: Text displayed in blue italics is included to provide guidance to the author and should be hidden before publishing the document. Check/un-check the visibility of hidden text on the screen when editing under Tools>Options>View. Check/un-check the visibility of hidden text when printing the document under Tools>Options>Print.  
  
This template guides you in the process of collecting requirements for the project. It contains the information required as input for a G1 and G2 assessments according to the ABB Gate Model.  
  
The contents of this document will refine over time, and therefore the document should be seen as a living document during the development lifecycle. However, it is important to point out in the project plan document which requirements will be realized in which increment.  
  
If a section in this document is not applicable for the actual project, do not remove the section, instead write that it is not applicable (N.A.) and why.

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Help: Requirements should be grouped into meaningful groups – data, algorithms, user interaction, persistency etc. Apart from functional requirements, there are nonfunctional (quality) requirements that should also be listed – performance, reusability, etc. and non-technical (business) requirements as time-to-market, required hardware and software platforms etc.  
  
After you collected the requirements, apply a prioritization scheme to the requirements. A suggested prioritization is: **must**, **should**, **would** (1, 2, 3). The prioritization should allow you to make a reasonable planning, and at the same time be able to do a system design that is ready for requirements that will not be realized in the first increment.  
  
A requirement always has a requirement description as well as a rationale – why the requirement is introduced and a validation criterion.

Explanations:   
**Identity**: Give each requirement a unique identity Use the subsection headers and a sequence number (e.g. Functions – F\_001, User Interface – UI\_001) as identification for your requirements.  
**Prio**.: Enter the priority of the requirement (1, 2 or 3).  
**Source**: Enter the source that demanded the requirement (can also be a reference to a document id and a requirement id).  
**Description-Headline**: Enter a headline in bold. This text will probably later appear in product structures, price lists etc. It is therefore important to enter a text that summarizes the requirement in a general way.  
**Description-Definition**: Define the requirement. Graphics are allowed. Do not include implementation details!  
**Description-Motivation**: Enter the motivation why we need to do this, what problems the product/component/function will solve.  
**Description-Validation**: Specify the method to be used for the validation.

# Introduction

## Purpose

Help: Describe the reasons for the product/component/function to be developed, refer to e.g. the Feasibility Study Report or the Project Proposal.  
Also, delineate the purpose of this document and specify the intended audience.

The purpose of this document is to specify the requirements for the Vision-based Sky Monitoring System (VISMO) system prototype to be developed for the ICOPS project.

The intended audience in this report is the management of the BU PSPG R&D Product Group Renewables and other relevant members of the product group.

## Scope

Help: Explain in short what the product/component/function will do and, if necessary, will not do. Describe the application very briefly.

VISMO is a vision-based sky monitoring system, stationed on the ground, with cloud tracking and solar forecasting capabilities. VISMO will continuously monitor the sky conditions by capturing sky images and delivering a sub-kilometer view of cloud shadows over a central PV plant. Through the use of measurements, computer vision algorithms, sky models, and prediction methods, VISMO will extract the information present in the sky images to provide estimates and short-term forecasts of solar irradiation levels for PV plants.

In a possible use case VISMO can provide predictive information to a smart grid optimization system to generate optimal power production forecasts and schedules for optimal distribution

# REQUIREMENTs

## Feature Requirements

Help: This template illustrates organizing the functional requirements for the product by system features, the major services provided by the product.  
(You may prefer to organize this section by use case, mode of operation, user class, object class, functional hierarchy, or combinations of these, whatever makes the most logical sense for your product.).

This section we specify the different features the prototype shall have. Priority features 1 are standard features whereas priority features 2 correspond to variants that may be optional. Additional features may be clarified during the execution of the project.

### Cloud Type Classification

Help: State the feature name in just a few words.

#### Description

Help: Provide a short description of the feature and indicate whether it is of High, Medium, or Low priority.

**High priority**. The cloud type classification algorithm

Identifies the type of cloud present in each image.

Differentiates between cloud and background in the image.

Performs operations such as background subtraction, adaptive threshold selection and binarization to aid in the pixel classification. Identifies designated cloud characteristics (i.e. features) such as, textual, contextual and/or physical features using classifiers.

#### Functional Requirements

Help: Itemize the detailed functional requirements associated with this feature. These are the software capabilities that must be present in order for the user to carry out the services provided by the feature, or to execute the use case. Include how the product should respond to anticipated error conditions or invalid inputs. Requirements should be concise, complete, unambiguous, verifiable, and necessary. Use “TBD” as a placeholder to indicate when necessary information is not yet available.  
  
Each requirement should be uniquely identified with a sequence number or a meaningful tag of some kind.

|  |  |  |  |
| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| CC\_001 | 1 | **Basic cloud pixel classification**  Definition: Binary classification of image pixels  Motivation: Differentiate between cloud and background (sky) in the image.  Validation: Visual Inspection  **input**: Multi-dimensional data array of RGB/Binary image format  **output**: Sets of multi-dimensional arrays. | CRC |
| CC\_002 | 1 | **Cloud features classification**  Definition: Classification of clouds according to their features. Refer to Figure 1 for a pictorial classification of clouds.  Motivation: Clouds can be differentiated using textures or level of brightness shown on the images.  Validation: Visual inspection  **input**: Multi-dimensional data array of RGB image/Binary format  **output**: Sets of multi-dimensional arrays. | CRC |



Figure 1 Cloud classification

### Cloud base height (CBH) estimation

#### Description

**Hi Priority**. The CBH estimation algorithm determines the altitude/CHB of the cloud present in the images. It performs statistical analysis to determine the overlapping (common) area of the two or more images of the overhead sky, obtained at different locations.

#### Functional Requirements

|  |  |  |  |
| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| CB\_001 | 2 | **CBH Estimator**  Definition: Estimate cloud base height  Motivation: CBH is an important parameter for estimation of irradiance.  Validation: Meteorological information, ceilometer measurement.  **input** : Multi-dimensional data array of RGB image/Binary format, Camera axis angles α1 , α2,… αN  **Output**: cloud base height (scalar value) | CRC |

### Cloud motion estimation and forecasting

#### Description

**High priority**. A cloud motion estimation algorithm shall be developed to estimate and forecast cloud velocity and direction of motion.

#### Functional Requirements

|  |  |  |  |
| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| CM\_001 | 1 | **Cloud Motion Estimation and forecasting**  Definition: The cloud motion estimation algorithm predicts the instant in which a cloud shadow will occlude the PV area.  Motivation: Predicting the instant in which cloud shadows occur adds essential information for the forecasting of irradiance.  Validation: Visual inspection  **input**: Multi-dimensional data array of RGB image/Binary format  **output**: Sets of multi-dimensional arrays | CRC |

### Irradiance estimation and forecasting

#### Description

An irradiance estimation algorithm shall be developed to estimate and forecast solar irradiance.

#### Functional Requirements

|  |  |  |  |
| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| IE\_001 | 1 | **Irradiance Estimation and forecasting**  Definition: Irradiance algorithm estimates and forecasts solar irradiance levels.  Motivation: Predicting solar irradiance levels is essential for power production forecasting.  Validation: Radiometer /pyrometer, PV output  **input**: Multi-dimensional data array of RGB image/Binary format  **output**: Sets of multi-dimensional arrays | CRC |

### Power estimation and forecasting

#### Description

An PV array model shall be developed to forecast power output.

#### Functional Requirements

|  |  |  |  |
| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| PM\_001 | 1 | **Power Estimation and forecasting**  Definition: PV array model forecasts power output.  Motivation: Required for power production forecasting.  Validation: measurements  **input**: forecasted irradiance and measurements  **output**: Multi-dimensional array | CRC |

## External Interface Requirements

### User Interfaces

Help: Describe the logical characteristics of each interface between the software product and the users. This may include sample screen images, any GUI standards or product family style guides that are to be followed, screen layout constraints, standard buttons and functions (e.g., help) that will appear on every screen, keyboard shortcuts, error message display standards, and so on. Define the software components for which a user interface is needed. Details of the user interface design could be documented in a separate user interface specification if applicable.

A user interface shall be developed to facilitate the operation of the prototype.

|  |  |  |  |
| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| UI\_001 | 1 | **User interface**  Simple GUI to invoke the main functionality import, estimate, forecast and display results, export.  Motivation: Support the usability of the prototype  Validation: Test of GUI by CRC. | CRC |
| UI\_002 | 2 | **Web User Interface**  Simple GUI. Displays on-line data, measurements vs forecast.  Motivation: Support the usability of the prototype  Validation: Test of GUI by CRC. | CRC |

### Hardware Interfaces

Help: Describe the logical and physical characteristics of each interface between the software product and the hardware components of the system. This may include the supported device types, the nature of the data and control interactions between the software and the hardware, and communication protocols to be used.

|  |  |  |  |
| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| HI\_001 | 1 | **Image Acquisition System (Automated full color sky camera)**  **minimum output resolution: 352×288 color, 24-bit**  **sampling rate max. one image/30sec**  Definition: A photographic/video camera shall record the sky images at a specified interval.  Motivation: The camera shall provide the sky pictures for image processing and analysis  Validation: Not required | CRC |
| HI\_002 | 1 | **Laptop Computer**  Definition: A laptop computer shall be used for data analysis and computation.  Motivation: . A laptop is required for portability/transportation between sites.  Validation: Not required | CRC |

### Software Interfaces

Help: Describe the connections between this product and other specific software components (name and version), including databases, operating systems, tools, libraries, and integrated commercial components. Identify the data items or messages coming into the system and going out and describe the purpose of each. Describe the services needed and the nature of communications. Refer to documents that describe detailed application programming interface protocols. Identify data that will be shared across software components.

|  |  |  |  |
| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| SI\_001 | 1 | **Image processing system (Computer Vision freeware)**  Definition: Conducts image processing on raw image output  Motivation: Required for .pre- and post-processing of images using the specified format.  Validation: commercial image processing software (e.g. Matlab Image Processing Toolbox) (optional) | CRC |
| SI\_002 | 1 | **Matlab programming environment**  Definition: Matlab programming environment shall be used for the implementation of the algorithms.  Motivation: Minimize the programming effort.  Validation: Not required. | CRC |
|  |  |  |  |

### Communication Interfaces

Help: Describe the requirements associated with any communications functions required by this product, including e-mail, web browser, network server communications protocols, electronic forms, and so on. Define any pertinent message formatting. Identify any communication standards that will be used, such as FTP or HTTP. Specify any communication security or encryption issues, data transfer rates, and synchronization mechanisms.

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| Identity | Prio. | Description | Source |
| CO\_001 | 1 | **802.3 (RJ45) 10/100Base-T Ethernet ports**  **Intranet (FTP) / Internet (http) access.**  Definition: Permits the communication between hardware and software  Motivation: Required for the retrieval, processing, and display of data from one or more instruments via the internet  Validation: Not required | CRC |

## Nonfunctional (Quality) Requirements

### Performance

Help: If there are performance requirements for the product under various circumstances (e.g., number of concurrent users, number of clients, execution speed), state them here and explain their rationale, to help the developers understand the intent and make suitable design choices. Specify the timing relationships for real time systems. Make such requirements as specific as possible. You may need to state performance requirements for individual functional requirements or features.  
  
Requirements on performance include Installation Performance (e.g. time to install), Configuration Performance (e.g. bulk data import), and Functional Performance (e.g. max no of logged values per second, display exchange frequency, etc). Requirements on capacity include Size of application (max. number of handled process signals, max number of process displays etc.) and Functional size constraints (e.g. max number of active alarms, max number of logged events, etc.).

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| Identity | Prio. | Description | Source |
| P\_001 | 1 | **Little computational effort as possible**  Definition: The image processing should require as little as possible computational effort, to ensure the execution of the short term forecasting.  Motivation: real-time estimation and short term forecasting  Validation: Execution time recording | CRC |
| P\_002 | 1 | **Fast computation**  Definition: The computation of the algorithms should be fast enough to be executed on-real time.  Motivation: Allow the testing of different tunings and reconfiguration within a couple of minutes.  Validation: Measure computation times on a state-of-the-art PC. | CRC |

### Safety Requirements

Help: Specify those requirements that are concerned with possible loss, damage, or harm that could result from the use of the product. Define any safeguards or actions that must be taken, as well as actions that must be prevented. Refer to any external policies or regulations that state safety issues that affect the product’s design or use. Define any safety certifications that must be satisfied.

|  |  |  |  |
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| Identity | Prio. | Description | Source |
| SA\_001 | 1 | **Operator Safety**  Definition: The safety of the prototype operator shall be enforced at all times. Hazards due to the site location and environment (PV panels installed on roofs) should be avoided. Safety rules should be followed to prevent accidents such as electric shocks or falls.  Motivation: Maintaining personal safety is priority  Validation: N/A | CCR |

### Security Requirements

Help: Specify any requirements regarding security or privacy issues surrounding use of the product or protection of the data used or created by the product. Define any user identity authentication requirements. Refer to any external policies or regulations containing security issues that affect the product. Define any security or privacy certifications that must be satisfied.

N/A

### Other Quality Attributes

Help: Specify any additional quality characteristics for the product that will be important to either the customers or the developers. Some to consider are: adaptability, availability, correctness, error and exception handling, flexibility, interoperability, maintainability, portability, reliability, reusability, robustness, testability, and usability. Write these to be specific, quantitative, and verifiable when possible. At the least, clarify the relative preferences for various attributes, such as ease of use over ease of learning.

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| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| QA\_001 | 1 | **Reliable and robust operation**  Definition: The prototype system should run smoothly and unsupervised for relative short periods of time, e.g. hours/days. Unexpected events, e.g. crashes or unplanned restarts, should be prevented if possible.  Motivation: Ensure long-term operation of the prototype. Low maintenance costs. High focus on robustness.  Validation: Test on CHCRC roof. | CRC |
| QA\_002 | 2 | **Easy applicability**  Definition: The prototype should be user-friendly and allow for a fast deployment  Motivation: Saving time and implementation efforts.  Validation: Validation of the prototype by project members. | CRC |

## Business Requirements

Help: Define any other requirements not covered elsewhere in the SRS. This might include database requirements, internationalization requirements, legal requirements, reuse objectives for the project, and so on. Add any new sections that are pertinent to the project.

The prototype should provide accurate predictive solar irradiance information to a smart grid optimization system to generate optimal power production forecasts and schedules for optimal distribution

End customer indicates that short term (intra-hours/minute-by-minutes) irradiance forecasts are required. However, it does not indicate the level of accuracy or precision either in the irradiance or the production forecast. Information regarding this requirement is expected to be compiled during the execution of the project.

### Project Requirements

Help: Define any requirements on e.g. time-to-market, funding, resources, infrastructure etc.

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| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| PR\_001 | 1 | **Availability of funding**  Definition: Funding is required to proceed to purchase the components of the prototype.  Motivation: prototype development.  Validation: N/A | CRC |
| PR\_002 | 1 | **Cost effective prototyping**  Definition: The prototype should be designed cost effectively, avoiding the purchase of expensive components.  Motivation: Drive capital cost down in case of commercialization  Validation: N/A | CRC |

### Design constraints

Help: What does limit the system design? Required hardware and software platforms? List all requirements that the product has towards a technology platform (e.g. AIP) with respect to performance, interfaces, availability, connectivity etc.

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| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| DC\_001 | 1 | **Components costs (Camera and Lens)**  Definition: Components costs limit the design of the prototype. Camera and lens costs contribute largely to the overall cost of prototype production.  Motivation: less expensive components are expected to reduce the quality of the forecast. A trade-off between low-cost of component and performance should be sought.  Validation: N/A | CRC |

### Databases and data sources

Help: Does the system use any databases as storage or configuration? Does the system use other data sources, eg, OPC?

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| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| DB\_001 | 1 | **Local Database**  Definition: A local database is required to store the images recorded by the image acquisition system for later processing  Motivation: Availability of the data and instrument information. Required for the storage of historical data and analysis.  Validation: N/A | CRC |
| DB\_001 | 2 | **OPC Server**  **MATLAB OPC Toolbox.**  Definition: For evaluation of prototype in a commercial PV plant an OPC server will be required.  Motivation: Retrieval and analysis of (historical electricity production) data.  Validation: N/A | CRC |

### Validation Environment

Help: Define the environment to be used when validating requirements that are depending on the environment. Examples of such requirements are requirements on performance, requirements on capacity and requirements on usability.

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| --- | --- | --- | --- |
| Identity | Prio. | Description | Source |
| VE\_001 | 1 | **CHCRC roof Validation**  Definition: Validation of prototype on a small PV system shall be performed in order to verify the performance under various test conditions.  Motivation: Ensure practical reliability before validating on commercial large-scale system.  Validation: NWP forecasts. | CRC |
| VE\_002 | 1 | **EKZ-ABB PV/Battery Pilot Validation**  Definition: At the end of the project a validation of the prototype on a small PV system, an additional validation shall be carried out in a commercial large scale PV system in order to verify the performance in a under various test conditions.  Motivation: Ensure practical reliability before productization  Validation: Tests results on small PV system. | TBD |

### Site adaptations

Help: How will the system be deployed?

The prototype shall be adaptable according to the site where validation takes place.

## Market Requirements

Help: Define any other requirements not covered elsewhere in the SRS. This might include database requirements, internationalization requirements, legal requirements, reuse objectives for the project, and so on. Add any new sections that are pertinent to the project.

In order to operate PV systems more efficiently and cost-effectively, utility operators require to understand the variability of power generation and be able to forecast this variability at different spatial and temporal scale. For next day power generation commitment (loads), operators often make use of hourly days-ahead (6h to few days) forecasts obtained with numerical weather prediction (NWP) models or satellite based observations. In this case, the quality (as indicated by the accuracy measure or skill score) of the forecast provided often suffice. For real time operation, however, updated conditions and short-term forecast are required to be able to dispatch generators, secure reserve and lock in imports and exports and the quality of the forecast obtained with the above methods may considerably decrease. VISMO is intended for this latter application and has the objective to provide higher quality short-term forecasts.

The accuracy measures for solar irradiance and PV forecast provided by VISMO shall be compared to the NWP counterpart and assed in terms of root mean square error (RMSE), mean absolute error (MAE) and mean bias error (MBE), which are defined as:







where  and represent the ith valid forecast and observation pair, respectively, and where the sums are carried out over all n such pairs within the short-term forecast period.

RMSE gives more weight to large errors, whereas MAE reveals the average magnitude of the error and bias indicates whether there is a significant (and corrigible) tendency to systematically over-forecast or under-forecast.

To facilitate comparison, the different accuracy measures shall be stated both in terms of absolute values and as percentages of a reference value: the mean irradiance for solar forecast and the DC standard Test Conditions (STC) array rating for PV forecast.

Forecasts shall also be benchmarked with respect to different reference models in terms of their MSE skill score, which can be defined as follows:



The skill score indicates the fractional improvement in the MSE over a reference model. A skill score of 1 indicates a perfect forecast, a score of 0 indicates no improvement over the reference, an a negative skill means that the forecast model tested performs worse than the reference.

Literature research indicates that the accuracy of global horizontal irradiance (GHI) (hourly) forecasts provided by NWP models range from 29 to 35 % RMSE with theoretical (persistence) models (e.g. clear sky) providing 40 to 50 % RMSE accuracy. On the other hand, PV output forecast accuracy indicated as RMSE percentage of rated power ranges from 14 to 18 % for persistence models and 8 to 14% for NWP models.

In order for VISMO to be attractive for commercialization, it would require to provide more accurate forecasts, with accuracy measures less than the 29 % RMSE currently offered by NWP forecasts. Similarly, a less than 8 % RMSE accuracy for PV forecast should be target in order for VISMO to appeal to potential customers.

# Change History

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| --- | --- | --- | --- |
| Rev. | Chapter | Description | Date / Dep. / Name |
| 0 | All | Initial document | 13-01-25 / CHCRC.C1 / L. Dominguez |
| 1 | All | Added market requirements | 13-02-05 / CHCRC.C1 / L. Dominguez |
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# Review History

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| --- | --- | --- | --- |
| Rev. | Chapter | Reviewer(s) | Date |
| 0 | All | M. Mercangöz /CHCRC.C1 | 13-02-05 |
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