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Operational Validation Report
EASY-DEL-D10.1

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1 INTRODUCTION

1.1 SCOPE

The goal of this document is the validation of EASY PV product, according to the indications described in the Grant Agreement (GA), WP10 called “Operational validation and logistics” hereinafter reported:

✓ Task 4.2-1: EASY PV Validation.

To provide any applicable data relevant to PV plants efficiency (and other performance measurements) available from previous test campaign;

To support EASY PV system verification by providing interpretation on test reports;

To perform the EASY PV solution validation and define new maintenance operational concept matching EASY PV system performance;

✓ Task 4.2-1: Logistics

To provide logistic support for test activities by allowing the consortium to physically access PV plants for test executions

1.2 APPLICABLE DOCUMENTS

ID	Title
[AD 1]	GRANT AGREEMENT NUMBER - 687409 - EASY Pv (25/11/2015)

Table 1-1 Applicable Documents

1.3 REFERENCE DOCUMENTS

ID	Title
[RD 1]	EASY-SIST- D5.2- EASY PV platform Architecture Design
[RD 2]	EASY-SIST-D6.2 - Maintenance and M&C platform user manual
[RD 3]	EASY-TOP D7.2 RPAS User manual
[RD 4]	EASY-ENTEC-DEL-D2.1 User Needs, Operational Concepts and System Requirements document.
[RD 5]	EASY-AAL-D9.1. Test and Verification Campaign Report
[RD 6]	Cilloccu, Dequal, Brovelli, Crespi, Lingua (2009) Ortoimmagini 1:10.000 e modelli altimetrici. Linee guida

Table 1-2 Reference Documents



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1.4 ACRONYMS

Acronym	Description
PV	Photovoltaic
RPAS	Remoted Piloted Aircraft System
IR	Infrared light
SC	Service Centre
POC	Point Of Contact
RGS	RPAS Ground Station
VTE	Visual Track Energy
PVT	Photovoltaic plant Test
IRSM	Infrared survey with Standard Methodology
EPV	Easy-PV system
IRSM-EPV	Infrared survey with Standard Methodology in the same environmental conditions
GNSS	Global Navigation Satellite System
RTK	Real Time Kinematic
OP	IR survey Operator
APP	Aerial Platform Position

Table 1-3 Acronyms



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2 EASY PV SYSTEM

2.1 SYNTHETIC DESCRIPTION

In this paragraph, the EASY PV concept is briefly summarized. An accurate description of system has been widely reported in the project documents [RD 1, RD 2, RD 3].

A RPAS model EPV100 equipped with a payload designed for this application composes the system. The main payload components are a GNSS RTK antenna and a thermal camera, which are connected with the RPAS through interfaces opportunely designed.

RPAS is able to perform missions flying over a photovoltaic (PV) field and collecting optical and thermal images (IR) through the sensors installed on board. Computer vision algorithms and GNSS data processing allow to geo-reference the PV plant modules and to tag the captured IR images. This information is sent towards the remote Service Centre (SC) in charge of thermal anomalies identification and management.

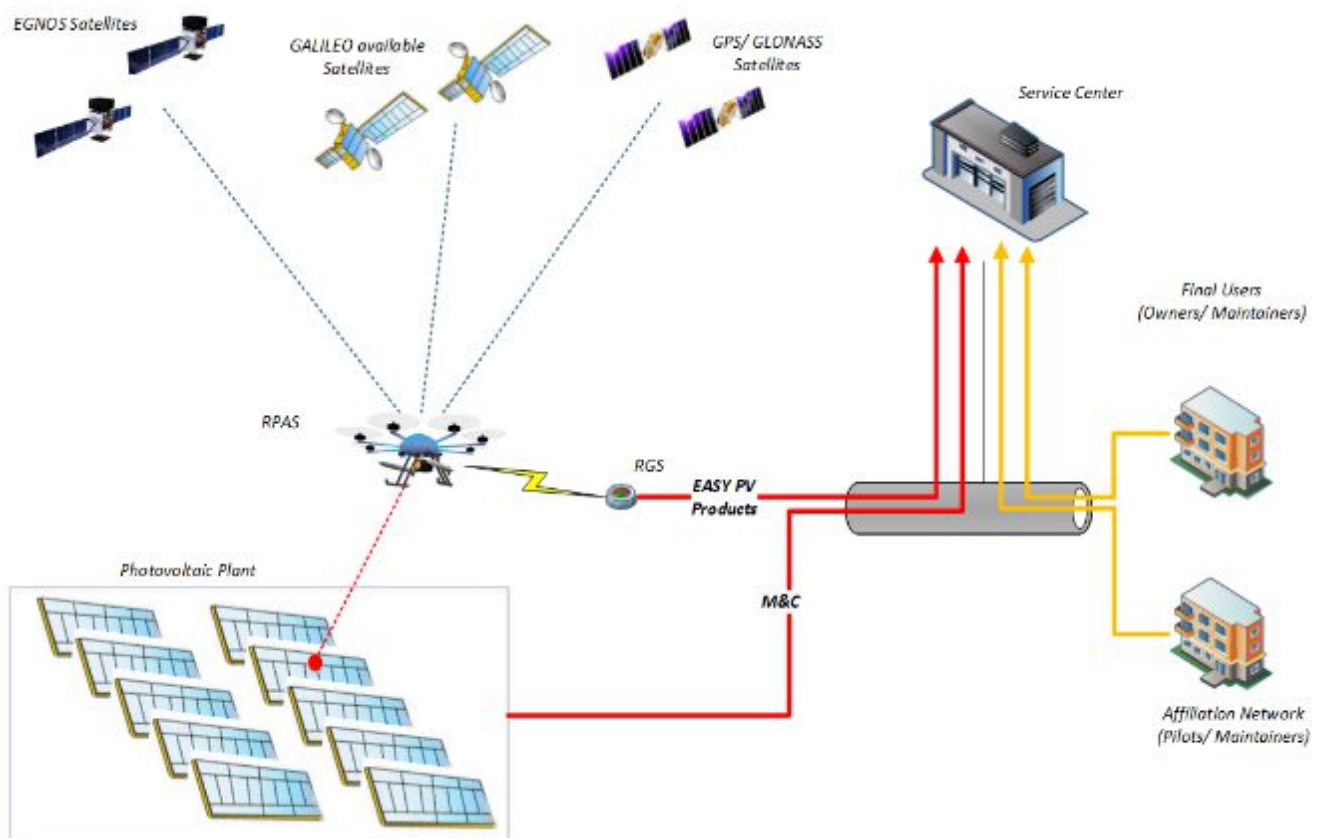


Figure 2-1 EASY PV Concept

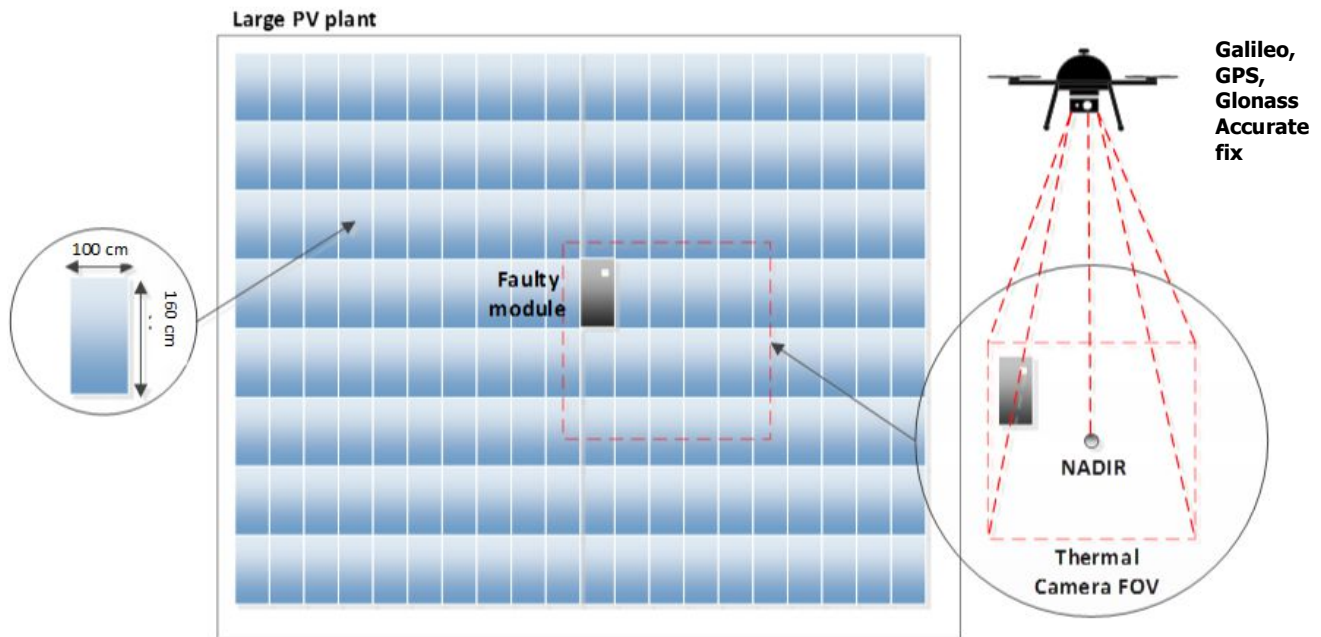


Figure 2-2 EASY PV Solution based on RPAS/GNSS/IR sensor technology

The accurate positioning provided by GNSS enhances the automation of the entire process when comparing the resolution of such GNSS positioning system with the physical dimension of PV modules to be inspected (see Figure 2-2) by the on board thermal camera. These features allow to increase the efficiency of IR inspection on PV plants, in particular to avoid problems usually observed during manual IR surveys [RD 4].

2.2 CONCEPT OF OPERATIONS

The Concept of Operations of Easy-PV platform will include different actors involved in, hereafter identified:

- ✓ RPAS Pilot: Professional Pilot in charge of PV Plant aerial survey with his RPAS equipment and payload;
- ✓ RPAS Operator: Aerial Operator allowed by national CAA to perform specialized aerial work over a PV plant.

RPAS Operator and RPAS Pilot may be the same person in case of a micro registered business. In the EASY-PV framework RPAS pilot and Operator are assumed to be the same role.

- ✓ Service Centre Operator: Back-end (Service center) Operator, in charge of Service Centre platform accounting;
- ✓ Thermographic Expert Operator: Person with experience in thermographic image analysis who is in charge to draw-up the final Report about the plant status;
- ✓ Plant POC: Point of Contact with PV Plant Owners/ Maintainer. He is in charge to manage contractual and commercial exchanges with the final Owner/ Maintainer.



The EASY PV operational chains are summarized in the diagram showed in Figure 2-3.

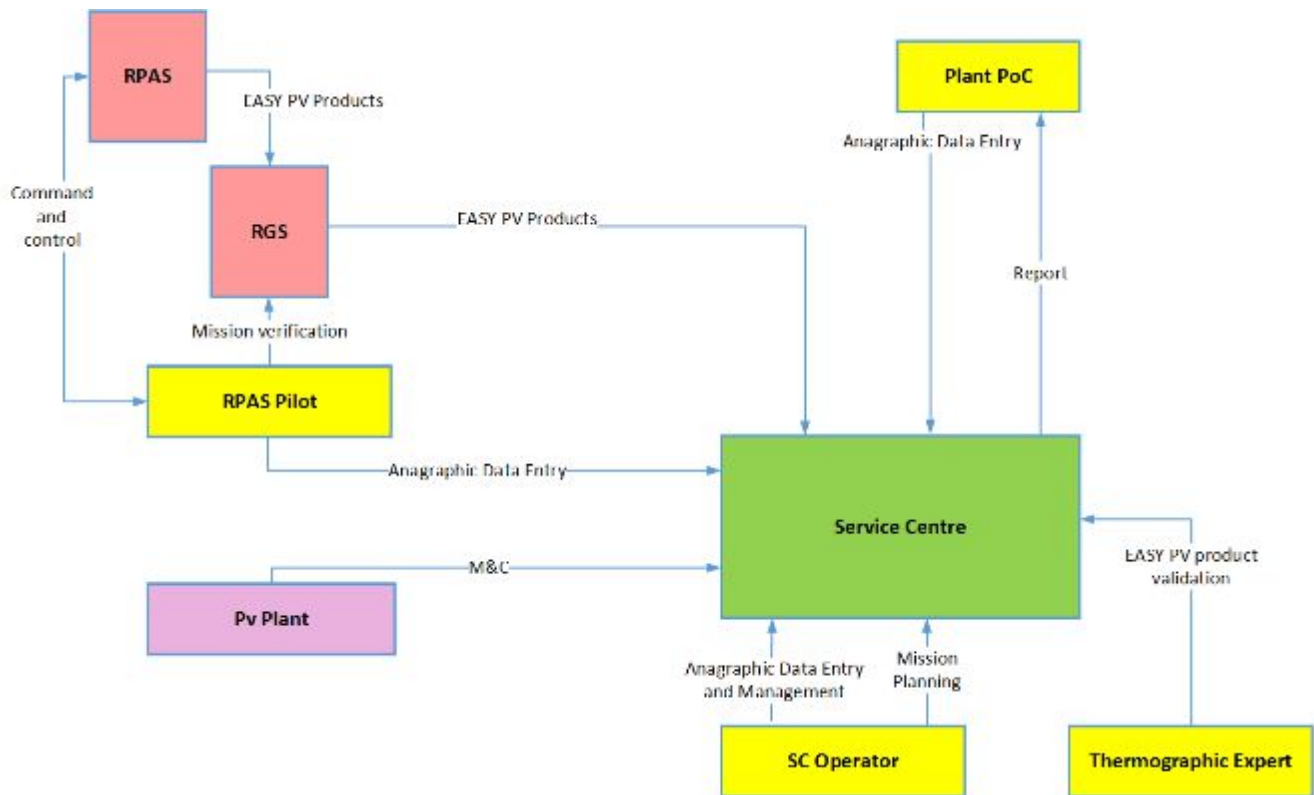


Figure 2-3 EASY PV operational chain

1. Data entry and management. During this phase the SC operator injects in the SC platform the PV plants data. Generally, this step is accomplished by the support of the PoC plant who knows the information to be inserted in the system DB. Note that also Pilot and PoC contact information are inserted in the DB.
2. Mission planning. This chain refers to mission organization for on field data collection. As both the PoC and the RPAS pilot have to attend, they communicate their availability to SC operator or directly by accessing the SC. Based on these information, the SC operator generates a date and relevant ancillary data to implement the mission.
3. Mission on field execution at RPAS side. The RPAS pilot executes the above assigned mission by command and controlling the RPAS flying over the target PV plant. Data are collected in several sessions (each lasting from 10 to 20 minutes depending on environmental conditions) where the RPAS takes off, collects data and lands to finally export the EASY PV products to the RGS (RPAS Ground Station), which implements a first elaboration. At this step the RPAS pilot is able to verify if the plant is completely covered and subsequently to send on field data to the SC.



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4. Data Management @ Service Centre Side. Once data of every PV plant in the DB are gathered at the SC side, the Thermographic expert is able to make analysis (including historical comparisons) and to finally generate a report to be finally managed by the PoC plant for commercial and contractual purposes.

2.3 OUTPUT RESULTS

Data collected and processed by the EASY PV system are saved in the SC, which allows to visualize the processed data through a web platform, called Visual Track Energy (VTE) platform. In this tool, the SC operator can easily visualize the PV modules automatically detected by the system on a georeferenced map (Figure 2-4).

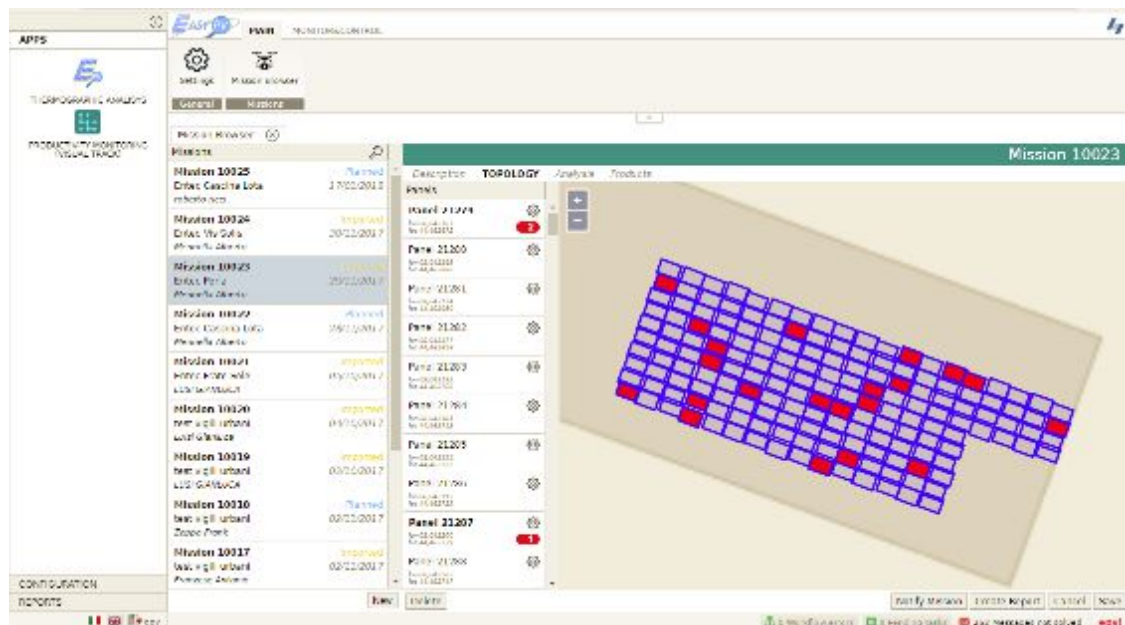


Figure 2-4 VTE Platform. Visualization of modules detected during an EASY PV mission over a PV plant

Modules affected by anomalies are highlighted with a red colour, in order to supply geolocated information to the user. VTE platform allows to consult the highlighted modules and to visualize the IR pictures associated (Figure 2-5).



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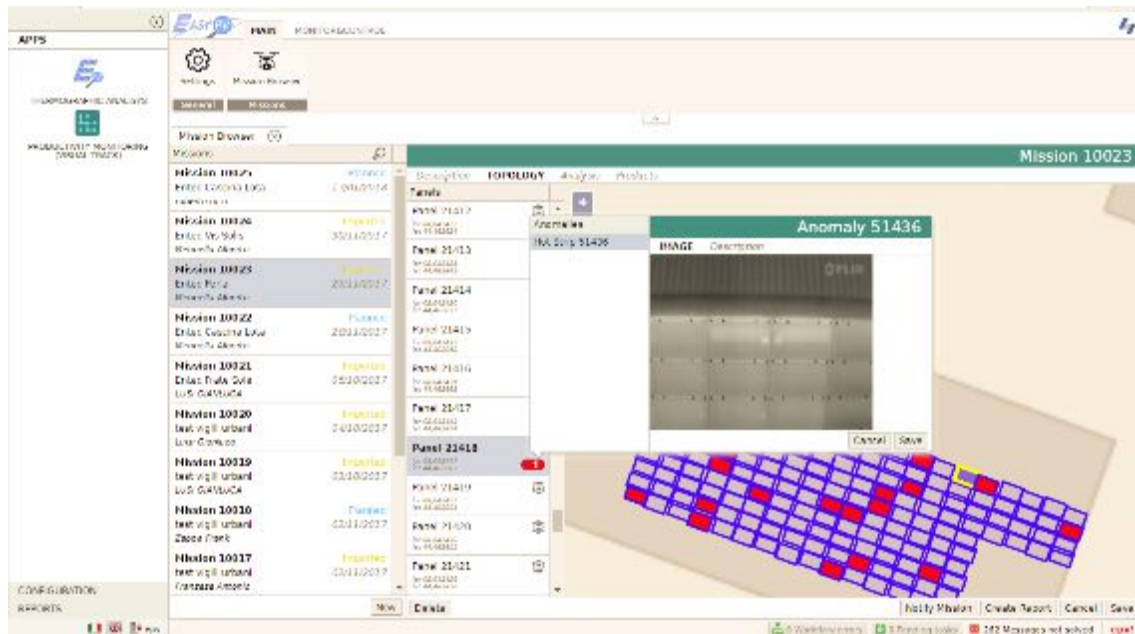


Figure 2-5 VTE Platform. Visualization of module with an anomaly

The processed data are summarized in a pdf report available for the PV plant owner or maintainer.

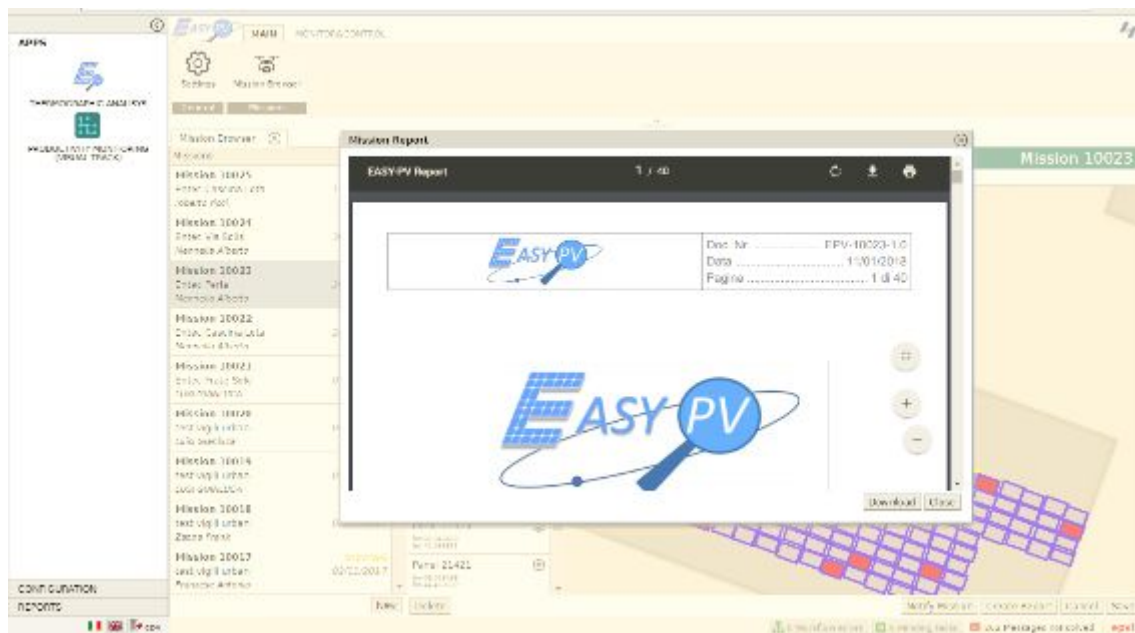


Figure 2-6 VTE Platform. Export of pdf report

In the next paragraphs the features of EASY PV system will be tested and validated, thorough the comparison with the achievements provided by standard IR surveys on three PV plants.



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3 EASY PV VALIDATION PROCESS

The validation activity concerns the EASY PV system performance analysis, that are carried out by means of the execution of tests on PV plants. The goal is the evaluation of the product features, in relation to the O&M market requirements [RD 4].

In the project flow chart, this activity is performed after the test and verification procedure, widely described in [RD 3]. Nevertheless, in order to carry out IR inspection in favourable environmental conditions (usually IR inspections on PV plants are carried out in the period May – September), validation tests have been performed in October 2017, with an “old” version of the platform (equipped with single frequency GNSS UBLOX).

The activities carried out for the validation of EASY PV system are hereafter summarized:

- identification and description of PV plants used for test analyses (PVT);
- execution of topographical surveys of the PVT;
- execution of IR surveys with standard methodology (IRSM) on the PVT, processing of collected data and production of output report;
- execution of IR surveys on the PVT with EASY PV system (EPV), in collaboration with Top View srl;
- execution of IRSM on the PVT in the same environmental conditions of EPV survey (IRSM-EPV);
- performance analysis of EPV output data

Every single activity will be described in the next paragraphs.

3.1 IDENTIFICATION AND DESCRIPTION OF PV PLANTS USED FOR TEST ANALYSES (PVT)

Entec spa has worked in the renewable energy field, in particular in the PV sector, since 2007. Nowadays, the company has designed, built and maintained hundreds of PV plants. During these ten years, the fast increasing of PV plants, due to the feed-in tariff released by the Italian government, has caused the development of related activities concerning monitoring and maintenance of plants. This scenario has allowed to develop a maintenance sector that currently is composed by five technicians who supervise the performance of costumers PV plants and carry out ordinary or extraordinary maintenance activities. One of the main maintenance activities carried out by Entec operators, is the IR survey of PV modules of a plant. This activity is usually performed once or twice per year on a PV plant, through inspection with IR cameras, as widely described in RD 4.

In order to test the performances of EASY PV system, ENTEC has selected three PVT between the costumer PV plants available. Hereafter the identification and the descriptions:

- PVT1. “Perla” PV plant on roof;
 - PVT2. “Vis Solis 1”. PV plant on the ground;
 - PVT3. “Fratesole”. PV plant on the ground.
-



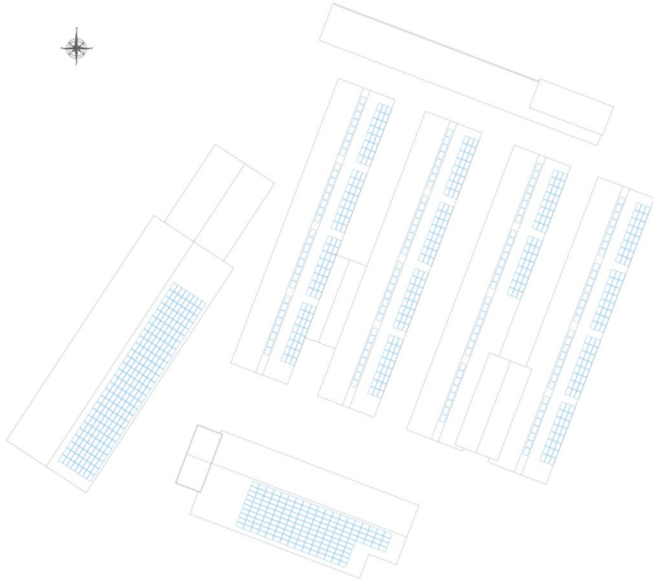


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3.1.1 PVT1 “PERLA”

PVT1 “Perla” is a PV plant located in the Murazzano village, at about 70 km south east from Turin, in Piedmont Region. The altitude of the area is about 800 m on the sea level. The area is easily accessible with means of transport. The plant was built in 2010. The complex power plant is 169.2 kWp. PV modules are located on the roof of six buildings used by the owner for goat farm and cheese production.

In the following table, the main plant features are summarized.

Plant Name	PVT1 “Perla”
Location	Fraz. Cornati snc, Murazzano (CN) – Piemonte (Italy)  
Geographic coordinates	44°27'46.9” N – 8°02'33.02” E. Elevation: 800 m on the sea level
Layout	



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Power	169.2 kW
Type of installation	Totally integrated
N° of roofs	6
Roof Heights (eaves)	Roof A: 2.70 m Roof B: 5.20 m Roof C1: 4.35 m Roof C2: 4.35 m Roof C3: 4.35 m Roof C4: 4.35 m
N° of modules	Roof A: 166 Roof B: 216 Roof C1: 128 Roof C2: 128 Roof C3: 80 Roof C4: 128 Total: 846
Module orientation	Roof A. Azimuth: +21° Tilt: 13° Roof B. Azimuth: -57° Tilt: 12° Roof C1. Azimuth: -69° Tilt: 13° Roof C2. Azimuth: -69° Tilt: 13° Roof C3. Azimuth: -69° Tilt: 13° Roof C4. Azimuth: -69° Tilt: 13°
Module model and main features	HYUNDAY HIS M200 SF



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	<table><tr><th colspan="2">Multi-crystalline Type</th><th colspan="7">HS-M□□□SF</th></tr><tr><th></th><th></th><th>194</th><th>197</th><th>200</th><th>203</th><th>206</th><th>209</th><th>212</th></tr><tr><td>Nominal output (Pmpp)</td><td>W</td><td>194</td><td>197</td><td>200</td><td>203</td><td>206</td><td>209</td><td>212</td></tr><tr><td>Warranted minimum power</td><td>W</td><td>188.2</td><td>191.1</td><td>194.0</td><td>196.9</td><td>199.8</td><td>202.7</td><td>205.6</td></tr><tr><td>Voltage at Pmax (Vmpp)</td><td>V</td><td>26.2</td><td>26.4</td><td>26.4</td><td>26.6</td><td>26.8</td><td>26.9</td><td>27.0</td></tr><tr><td>Current at Pmax (Impp)</td><td>A</td><td>7.5</td><td>7.5</td><td>7.6</td><td>7.7</td><td>7.7</td><td>7.8</td><td>7.9</td></tr><tr><td>Open circuit voltage (Voc)</td><td>V</td><td>32.9</td><td>33.0</td><td>33.1</td><td>33.3</td><td>33.4</td><td>33.5</td><td>33.6</td></tr><tr><td>Short circuit current (Isc)</td><td>A</td><td>8.1</td><td>8.1</td><td>8.2</td><td>8.2</td><td>8.2</td><td>8.3</td><td>8.3</td></tr><tr><td>Output tolerance</td><td>%</td><td colspan="7">±3</td></tr><tr><td>No. of cells & connections</td><td>pcs</td><td colspan="7">54 in series</td></tr><tr><td>Cell type</td><td>—</td><td colspan="7">6" Multi-crystalline silicon</td></tr><tr><td>Module efficiency</td><td>%</td><td>13.4</td><td>13.6</td><td>13.8</td><td>14.0</td><td>14.2</td><td>14.4</td><td>14.6</td></tr><tr><td>Temperature coefficient of Pmpp</td><td>%/K</td><td>-0.43</td><td>-0.43</td><td>-0.43</td><td>-0.43</td><td>-0.43</td><td>-0.43</td><td>-0.43</td></tr><tr><td>Temperature coefficient of Voc</td><td>%/K</td><td>-0.32</td><td>-0.32</td><td>-0.32</td><td>-0.32</td><td>-0.32</td><td>-0.32</td><td>-0.32</td></tr><tr><td>Temperature coefficient of Isc</td><td>%/K</td><td>0.056</td><td>0.056</td><td>0.056</td><td>0.056</td><td>0.056</td><td>0.056</td><td>0.056</td></tr></table>	Multi-crystalline Type		HS-M□□□SF									194	197	200	203	206	209	212	Nominal output (Pmpp)	W	194	197	200	203	206	209	212	Warranted minimum power	W	188.2	191.1	194.0	196.9	199.8	202.7	205.6	Voltage at Pmax (Vmpp)	V	26.2	26.4	26.4	26.6	26.8	26.9	27.0	Current at Pmax (Impp)	A	7.5	7.5	7.6	7.7	7.7	7.8	7.9	Open circuit voltage (Voc)	V	32.9	33.0	33.1	33.3	33.4	33.5	33.6	Short circuit current (Isc)	A	8.1	8.1	8.2	8.2	8.2	8.3	8.3	Output tolerance	%	±3							No. of cells & connections	pcs	54 in series							Cell type	—	6" Multi-crystalline silicon							Module efficiency	%	13.4	13.6	13.8	14.0	14.2	14.4	14.6	Temperature coefficient of Pmpp	%/K	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	Temperature coefficient of Voc	%/K	-0.32	-0.32	-0.32	-0.32	-0.32	-0.32	-0.32	Temperature coefficient of Isc	%/K	0.056	0.056	0.056	0.056	0.056	0.056	0.056
Multi-crystalline Type		HS-M□□□SF																																																																																																																																						
		194	197	200	203	206	209	212																																																																																																																																
Nominal output (Pmpp)	W	194	197	200	203	206	209	212																																																																																																																																
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Current at Pmax (Impp)	A	7.5	7.5	7.6	7.7	7.7	7.8	7.9																																																																																																																																
Open circuit voltage (Voc)	V	32.9	33.0	33.1	33.3	33.4	33.5	33.6																																																																																																																																
Short circuit current (Isc)	A	8.1	8.1	8.2	8.2	8.2	8.3	8.3																																																																																																																																
Output tolerance	%	±3																																																																																																																																						
No. of cells & connections	pcs	54 in series																																																																																																																																						
Cell type	—	6" Multi-crystalline silicon																																																																																																																																						
Module efficiency	%	13.4	13.6	13.8	14.0	14.2	14.4	14.6																																																																																																																																
Temperature coefficient of Pmpp	%/K	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43																																																																																																																																
Temperature coefficient of Voc	%/K	-0.32	-0.32	-0.32	-0.32	-0.32	-0.32	-0.32																																																																																																																																
Temperature coefficient of Isc	%/K	0.056	0.056	0.056	0.056	0.056	0.056	0.056																																																																																																																																
Module dimension	1476 x 983 mm																																																																																																																																							
PV surface	Roof A: 258 m ² Roof B: 338 m ² Roof C1: 200 m ² Roof C2: 200 m ² Roof C3: 125 m ² Roof C4: 200 m ² Total: 1321 m ²																																																																																																																																							

Table 3-1 PVT1 “Perla” - Technical features

The mean predicted production of PVT1 “Perla” is 180.000 kWh/year. The feed-in tariff is 0.443 €/kWh, therefore the mean annual income is about 80.000 €.

Hereafter, a synthetic photographic report of PV plant.



Figure 3-1 PVT1 - Roof A – South view



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Figure 3-2 PVT1 - Roof B – South-Est view



Figure 3-3 PVT1 – Roof B – Roof C1. West view



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Figure 3-4 PVT1 - Roof C1 – South-East view



Figure 3-5 PVT1 - Roofs C3/C4 – North-West view


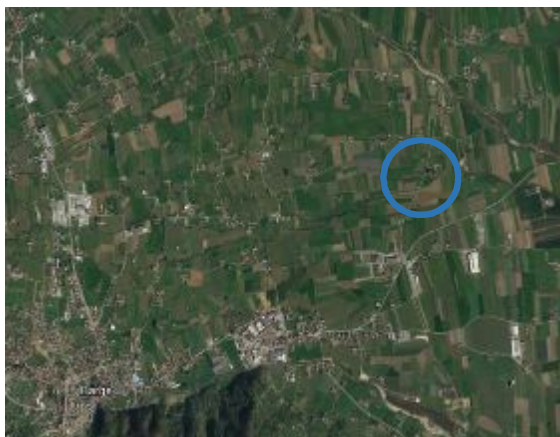
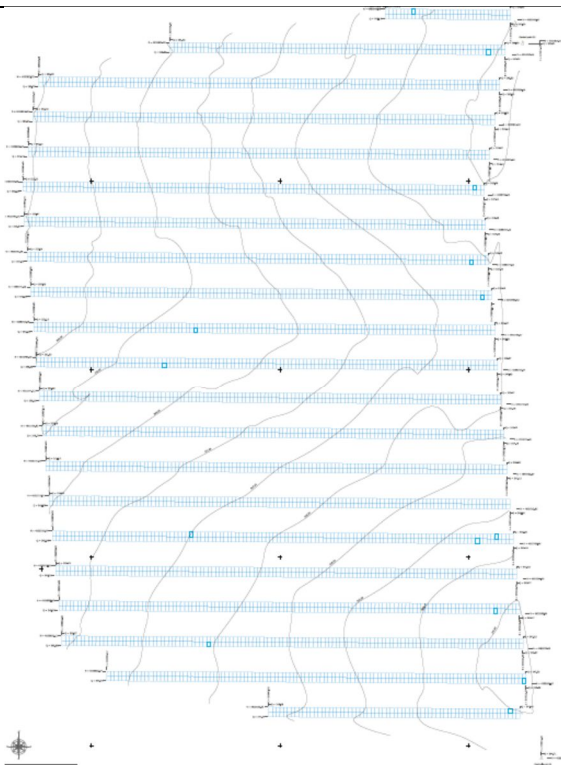


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3.1.2 PVT2 “VIS SOLIS 1”

PVT3 “Vis Solis 1” is a PV plant located in Barge village, at about 40 km southwest from Turin, in Piedmont Region. The altitude of the area is about 300 m on the sea level. The area is easily accessible with means of transport. The plant was built in 2009. The complex power plant is 941.6 kWp. PV plant is located on the ground, in a rural area.

In the following table, the main plant features are summarized.

Plant Name	PVT2 “Vis Solis 1”
Location	Via Becetto snc, Barge (CN) – Piemonte (Italy)  
Geographic coordinates	44°44'35.2” N – 7°21'24.4” E. Elevation: 300 m on the sea level
Layout	



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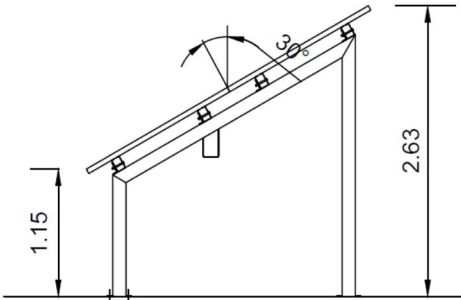
																																																																																																																																								
Power	941.6 kWp																																																																																																																																							
Structure heights: (South direction)	1.15 m																																																																																																																																							
Structure heights: (North direction)	2.63 m																																																																																																																																							
N° of rows	21																																																																																																																																							
N° of modules	4708																																																																																																																																							
Module orientation	Ground structure: Azimuth: 0° Tilt: 30°																																																																																																																																							
Module model and main features	<div><div>Multi-crystalline Type</div><table><thead><tr><th colspan="2"></th><th colspan="7">HIS-M□□□SF</th></tr><tr><th colspan="2"></th><th>194</th><th>197</th><th>200</th><th>203</th><th>206</th><th>209</th><th>212</th></tr></thead><tbody><tr><td>Nominal output (Pmpp)</td><td>W</td><td>194</td><td>197</td><td>200</td><td>203</td><td>206</td><td>209</td><td>212</td></tr><tr><td>Warranted minimum power</td><td>W</td><td>188.2</td><td>191.1</td><td>194.0</td><td>196.9</td><td>199.8</td><td>202.7</td><td>205.6</td></tr><tr><td>Voltage at Pmax (Vmpp)</td><td>V</td><td>26.2</td><td>26.4</td><td>26.4</td><td>26.6</td><td>26.8</td><td>26.9</td><td>27.0</td></tr><tr><td>Current at Pmax (Impp)</td><td>A</td><td>7.5</td><td>7.5</td><td>7.6</td><td>7.7</td><td>7.7</td><td>7.8</td><td>7.9</td></tr><tr><td>Open circuit voltage (Voc)</td><td>V</td><td>32.9</td><td>33.0</td><td>33.1</td><td>33.3</td><td>33.4</td><td>33.5</td><td>33.6</td></tr><tr><td>Short circuit current (Isc)</td><td>A</td><td>8.1</td><td>8.1</td><td>8.2</td><td>8.2</td><td>8.2</td><td>8.3</td><td>8.3</td></tr><tr><td>Output tolerance</td><td>%</td><td colspan="3"></td><td colspan="4">±3</td></tr><tr><td>No. of cells & connections</td><td>pcs</td><td colspan="3"></td><td colspan="4">54 in series</td></tr><tr><td>Cell type</td><td>—</td><td colspan="7">6" Multi-crystalline silicon</td></tr><tr><td>Module efficiency</td><td>%</td><td>13.4</td><td>13.6</td><td>13.8</td><td>14.0</td><td>14.2</td><td>14.4</td><td>14.6</td></tr><tr><td>Temperature coefficient of Pmpp</td><td>%/K</td><td>-0.43</td><td>-0.43</td><td>-0.43</td><td>-0.43</td><td>-0.43</td><td>-0.43</td><td>-0.43</td></tr><tr><td>Temperature coefficient of Voc</td><td>%/K</td><td>-0.32</td><td>-0.32</td><td>-0.32</td><td>-0.32</td><td>-0.32</td><td>-0.32</td><td>-0.32</td></tr><tr><td>Temperature coefficient of Isc</td><td>%/K</td><td>0.056</td><td>0.056</td><td>0.056</td><td>0.056</td><td>0.056</td><td>0.056</td><td>0.056</td></tr></tbody></table></div>			HIS-M□□□SF									194	197	200	203	206	209	212	Nominal output (Pmpp)	W	194	197	200	203	206	209	212	Warranted minimum power	W	188.2	191.1	194.0	196.9	199.8	202.7	205.6	Voltage at Pmax (Vmpp)	V	26.2	26.4	26.4	26.6	26.8	26.9	27.0	Current at Pmax (Impp)	A	7.5	7.5	7.6	7.7	7.7	7.8	7.9	Open circuit voltage (Voc)	V	32.9	33.0	33.1	33.3	33.4	33.5	33.6	Short circuit current (Isc)	A	8.1	8.1	8.2	8.2	8.2	8.3	8.3	Output tolerance	%				±3				No. of cells & connections	pcs				54 in series				Cell type	—	6" Multi-crystalline silicon							Module efficiency	%	13.4	13.6	13.8	14.0	14.2	14.4	14.6	Temperature coefficient of Pmpp	%/K	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	Temperature coefficient of Voc	%/K	-0.32	-0.32	-0.32	-0.32	-0.32	-0.32	-0.32	Temperature coefficient of Isc	%/K	0.056	0.056	0.056	0.056	0.056	0.056	0.056
		HIS-M□□□SF																																																																																																																																						
		194	197	200	203	206	209	212																																																																																																																																
Nominal output (Pmpp)	W	194	197	200	203	206	209	212																																																																																																																																
Warranted minimum power	W	188.2	191.1	194.0	196.9	199.8	202.7	205.6																																																																																																																																
Voltage at Pmax (Vmpp)	V	26.2	26.4	26.4	26.6	26.8	26.9	27.0																																																																																																																																
Current at Pmax (Impp)	A	7.5	7.5	7.6	7.7	7.7	7.8	7.9																																																																																																																																
Open circuit voltage (Voc)	V	32.9	33.0	33.1	33.3	33.4	33.5	33.6																																																																																																																																
Short circuit current (Isc)	A	8.1	8.1	8.2	8.2	8.2	8.3	8.3																																																																																																																																
Output tolerance	%				±3																																																																																																																																			
No. of cells & connections	pcs				54 in series																																																																																																																																			
Cell type	—	6" Multi-crystalline silicon																																																																																																																																						
Module efficiency	%	13.4	13.6	13.8	14.0	14.2	14.4	14.6																																																																																																																																
Temperature coefficient of Pmpp	%/K	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43																																																																																																																																
Temperature coefficient of Voc	%/K	-0.32	-0.32	-0.32	-0.32	-0.32	-0.32	-0.32																																																																																																																																
Temperature coefficient of Isc	%/K	0.056	0.056	0.056	0.056	0.056	0.056	0.056																																																																																																																																
Module dimension	1476 x 983 mm																																																																																																																																							
PV surface	Total: 28.000 m ²																																																																																																																																							

Table 3-2 PVT2 “Vis Solis I” - Technical features

The mean predicted production of PVT2 “Vis Solis I” is 1.250.000 kWh/year. The feed-in tariff is 0.353 €/kWh, therefore the mean annual income is about 440.000 €.

Hereafter, a synthetic photographic report of PV plant.



Figure 3-6 PVT3 - South-Est view



Figure 3-7 PVT3 - South view - row n° 1



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Figure 3-8 PVT3 - Structure particular



Figure 3-9 PVT3 - Structure particular


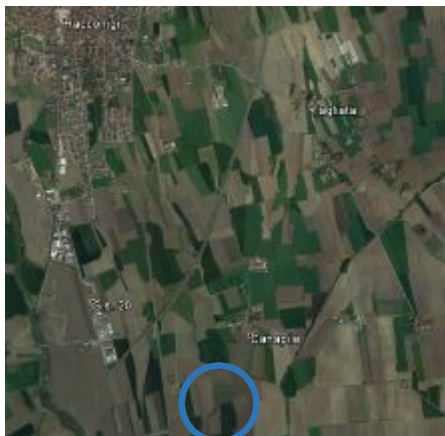


Figure 3-10 PVT3 - Rows position

3.1.3 PVT3 “FRATESOLE”

PVT3 “Fratesole” is a PV plant located in Racconigi village, at about 40 km southwest from Turin, in Piedmont Region. The altitude of the area is about 260 m on the sea level. The area is easily accessible with means of transport. The plant was built in 2011. The complex power plant is 901.6 kWp. PV plant is located on the ground, in a rural area.

In the following table, the main plant features are summarized.

Plant Name	PVT3 “Fratesole”
Location	Frazione Canapile snc, Racconigi (CN) – Piemonte (Italy)  



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Geographic coordinates	44°44'21.18"N – 7°41'41.14"E. Elevation: 260 m on the sea level
Layout	
Power	901.6 kW
Structure heights: (South direction)	0.99 m
Structure heights: (North direction)	2.67 m
N° of rows	16
N° of modules	3920



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Module orientation	Ground structure: Azimuth: 0° Tilt: 30°																																	
Module model and main features	<div>LDK 230P-20</div> <table><tr><th>TYPE</th><th>LDK-230P-20</th><th>LDK-235P-20</th></tr><tr><td>Nominal Output (Pmax) [Wp]</td><td>230</td><td>235</td></tr><tr><td>Voltage at Pmax (Vmp) [V]</td><td>29.3</td><td>29.5</td></tr><tr><td>Current at Pmax (Imp) [A]</td><td>7.88</td><td>7.98</td></tr><tr><td>Open Circuit Voltage (Voc) [V]</td><td>36.9</td><td>37.1</td></tr><tr><td>Short Circuit Current (Isc) [A]</td><td>8.43</td><td>8.50</td></tr><tr><td>Power Classification Range [Wp]</td><td>-0/+4.99</td><td>-0/+4.99</td></tr><tr><td>Tolerance on Nominal Output [%]</td><td>+/-3</td><td>+/-3</td></tr><tr><td>Maximum System Voltage</td><td colspan="2">IEC EN: 1000 V / UL: 600 V</td></tr><tr><td>Cell Efficiency [%]</td><td>15.75</td><td>16.09</td></tr><tr><td>Module Efficiency [%]</td><td>14.09</td><td>14.40</td></tr></table>	TYPE	LDK-230P-20	LDK-235P-20	Nominal Output (Pmax) [Wp]	230	235	Voltage at Pmax (Vmp) [V]	29.3	29.5	Current at Pmax (Imp) [A]	7.88	7.98	Open Circuit Voltage (Voc) [V]	36.9	37.1	Short Circuit Current (Isc) [A]	8.43	8.50	Power Classification Range [Wp]	-0/+4.99	-0/+4.99	Tolerance on Nominal Output [%]	+/-3	+/-3	Maximum System Voltage	IEC EN: 1000 V / UL: 600 V		Cell Efficiency [%]	15.75	16.09	Module Efficiency [%]	14.09	14.40
TYPE	LDK-230P-20	LDK-235P-20																																
Nominal Output (Pmax) [Wp]	230	235																																
Voltage at Pmax (Vmp) [V]	29.3	29.5																																
Current at Pmax (Imp) [A]	7.88	7.98																																
Open Circuit Voltage (Voc) [V]	36.9	37.1																																
Short Circuit Current (Isc) [A]	8.43	8.50																																
Power Classification Range [Wp]	-0/+4.99	-0/+4.99																																
Tolerance on Nominal Output [%]	+/-3	+/-3																																
Maximum System Voltage	IEC EN: 1000 V / UL: 600 V																																	
Cell Efficiency [%]	15.75	16.09																																
Module Efficiency [%]	14.09	14.40																																
Module dimension	1642 x 994 mm																																	
PV surface	Total: 24.100 m²																																	

Table 3-3 - PVT4 “Fratesole” - Technical features

The mean annual predicted production of PVT4 “Fratesole” is 1.100.000 kWh/year. The feedin tariff is 0.276 €/kWh, therefore the mean annual income is 303.600 €.

Hereafter, a synthetic photographic report of PV plant.



Figure 3-11 PVT4 - Est view



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Figure 3-12 PVT4 - Structure particular



Figure 3-13 PVT4 – West view



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Figure 3-14 PVT4 - Structure particular



Figure 3-15 PVT4 - Structure particular



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Figure 3-16 PVT4 – South view



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3.2 EXECUTION OF TOPOGRAPHICAL SURVEYS ON THE PVT.

Topographical surveys on PVT plants have been carried out in order to define rigorously their geometry and to produce an “as built” PVT layout. Survey operations have been performed with a double frequency GNSS receiver Topocon HyperPro II, of ENTEC property. The accuracy of this instrument in RTK condition (connection with SPINN GNSS network – Servizio di Posizionamento Interregionale GNSS Piemonte Lombardia) is centimetric, therefore the “quality” of surveyed data allows to perform accuracy analyses of the geometric data provided by EASY PV system.

For each plant, the corners of some modules have been surveyed with GNSS receiver, in order to define position and orientation of row modules and to check them with the layout project, already available. The coordinate reference system is the National Geodetic Reference System ETRF2000 - Rete Dinamica Nazionale (according to the Italian Ministerial Decree of 10.11.2011). For each PVT one or more Ground Points (GP) have been surveyed, in order to set the position of EPV GNSS ground Station. In the next figures the layout of PVT plants are showed. The red points represent the GNSS surveyed in the field.

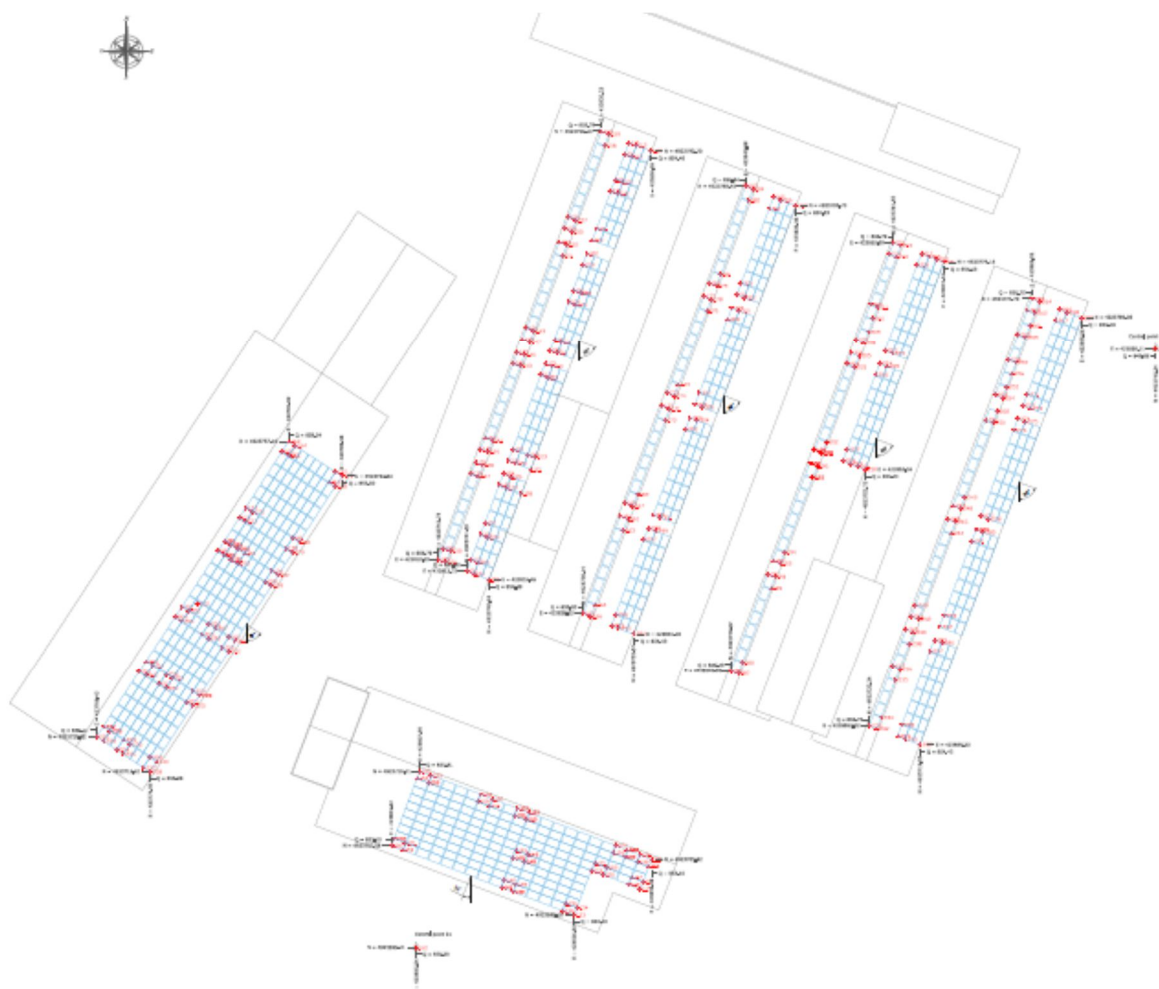


Figure 3-17 PVT1. Geometrical layout with indication of GNSS points surveyed (in red colour)



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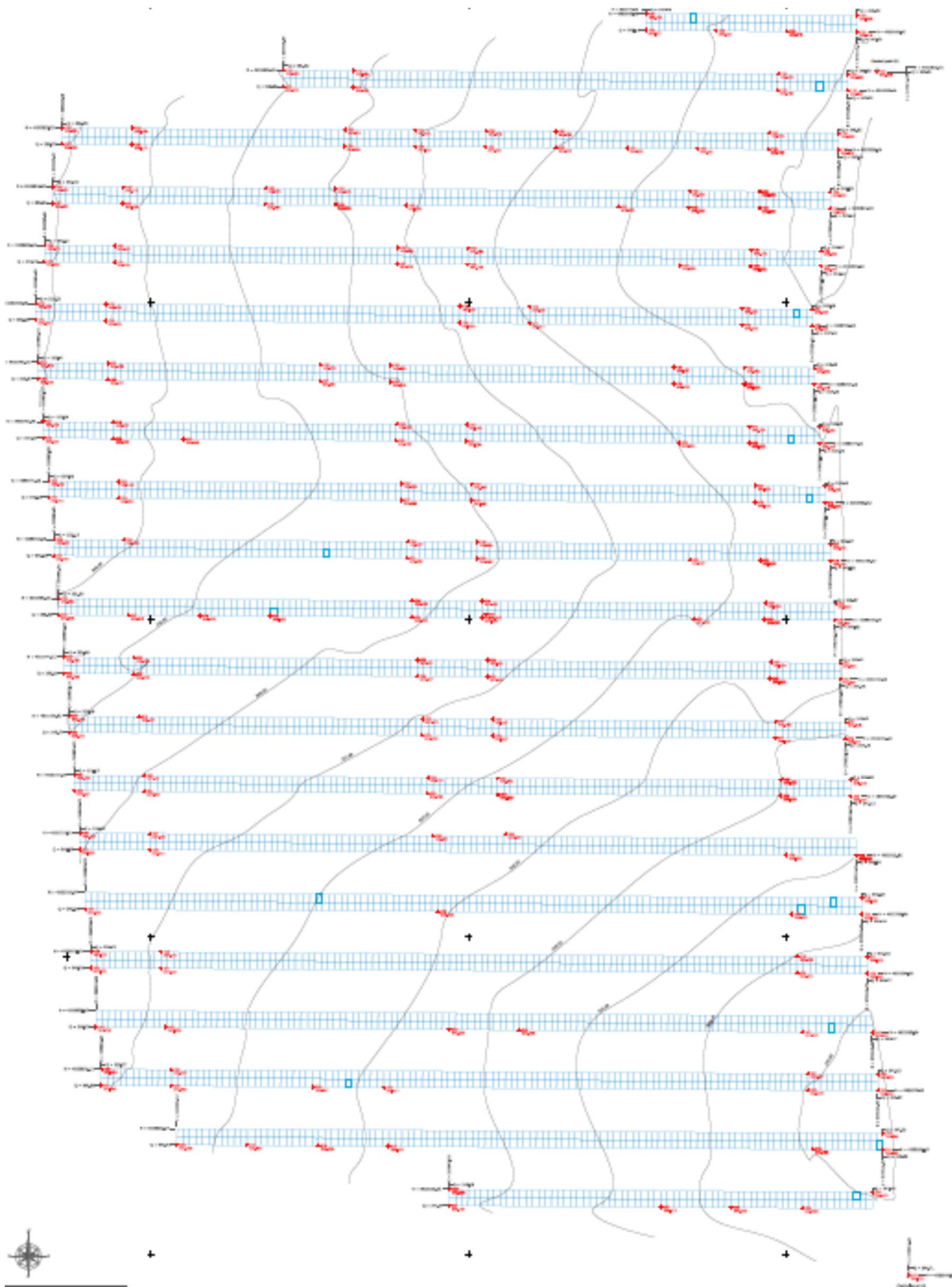


Figure 3-18 PVT2. Geometrical layout with indication of GNSS points surveyed (in red colour)



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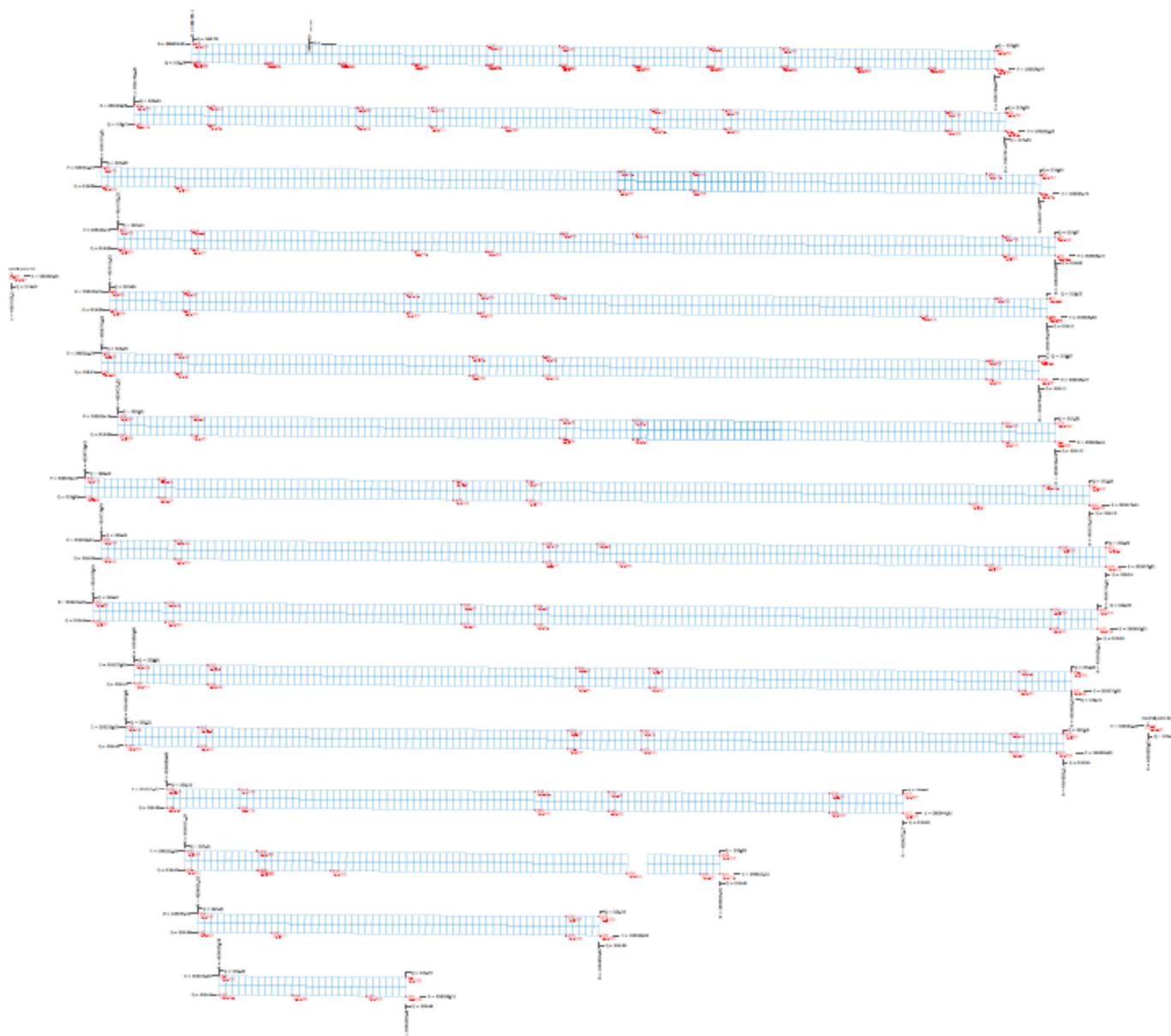


Figure 3-19 PVT3. Geometrical layout with indication of GNSS points surveyed (in red colour)

3.3 EXECUTION OF IR SURVEYS ON THE PVT. IR STANDARD METHODOLOGY (IRSM) PROCEDURE

The three PVT have been surveyed by qualified technicians of ENTEC Spa Company. IR surveys have been performed according to the standard methodologies (IRSM) widely described in RD 4. Hereafter, the main activities of IRMS are summarized:

- IR survey planning. The operator checks the meteorological forecast in the PV plant area, and defines a time window for the survey operation. Furthermore, he checks preliminary the layout of the PV plant (if available), the accessibility, and the potential constraints (barriers, shadows, etc.). Finally, he controls the IR camera conditions (battery load, storage memory availability).
- IR survey, preliminary operations. The operators (usually two qualified technicians) go to the plant. They check the environmental conditions, by means of visual analysis and measure of temperature and solar radiation. The environmental conditions should be near to the standard parameters (clear sky, not cloudy, solar radiation greater than 700 W/m²).



Figure 3-20 IRSM survey, preliminary operation on PV plant on the ground. Temperature and solar radiation measure

- IR survey, image acquisition. The operators start the IR survey, by means of an image acquisition for each module inspected with thermal camera. The IR operator, for each image, checks preliminary the quality of the image acquired and the presence of anomalies. The acquisition is usually performed by setting in the IR camera a range of visualization temperature in the display. This operation is conducted manually by the IR operator, who defines the range of visualization according to his experience. If an anomaly has been detected, the IR operator take an IR image and save it on the IR camera memory, the other operator takes note on a notebook



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of the PV module serial number and position in the plant. Furthermore, if the plant is on the ground he writes with a marker pen the number of IR image and the date of acquisition in the back side of the module. On PV roof plant, the signalization is usually done on the PV module frame.



Figure 3-21 IRSM survey, on PV plant on the ground. Image acquisition



Figure 3-22 IRSM survey, on PV plant on the ground. Signalization of IR image number and date of acquisition in the behind of damaged module.



- Data processing. In the office, operator downloads images acquired in the field and process them in a dedicated software, usually provided by the IR camera manufacturer. First of all, he analyses every IR image and detects potential anomalies through a software tool that lets to visualize the temperature distribution on the panel and to measure differences of temperature. If the PV panel represented in the image is affected by anomalies, it is classified as defected module with the association of anomaly typology reported in the table below. On the other hand, the module is categorized as efficient module.

Name	Pattern visible	Pattern IR	Description	Possible causes	Dimension	Frequency	Environment sensibility
MODULES DESPLACEMENT			PV modules out of their position	Poor fixation system, improper installation	100x60 cm	Rarely	None
GLASS BREAKAGE			PV modules with the cover glass cracked	Transport and improper handling, inappropriate clamping, stones shots or inexperience of the maintenance	20x30 cm	Relatively frequent	Low sensibility
SOILING			PV modules decrease their production because the top surface is soiled	Dust, pollen, airborne pollutants, sand, mould, bird dropping	Along the frame or in corners	Much frequent	Moderate sensibility
FRAMES DEFORMATION			PV modules frame damaged or deformed	Great amount of snow on the frame of PV modules	Profile	Rarely	None
MOISTURE INGRESS			Delamination of PV module layers, glass transparency reduction, active parts corrosion	Bad seal and encapsulation of PV modules	Along the frame	Rarely	None
CELLS HOT SPOT			PV cell clearly warmer than the others	Overshadow of a series of cells or modules, cells faults due to several causes.	15x15 cm	Relatively frequent	High sensibility
HOT RIBBON WELDING			PV rod connectors in over temperature	Bad welding	2x2 cm to 10x10 cm	Relatively frequent	Moderate sensibility
HOT STRIP			PV cells over temperature	Bypass diode short circuited or damaged, series of cells damaged	≈150x30 cm	Relatively frequent	Moderate sensibility



Name	Pattern visible	Pattern IR	Description	Possible causes	Dimension	Frequency	Environment sensibility
SNAIL TRACK			Optical effect with typical aspect of snail trail and thermal effect with light overtemperature of the interested cells.	Construction process with micro cracking of the cells and consecutive exposure to heat and UV.	Some cells	Relatively frequent	Moderate sensibility
PID			A leakage current is created from the frame to the ground. This phenomenon has a thermal effect on the interested modules and decreases the PV production	Massive shunts caused by potential induced degradation or polarization	Some cells	Rarely	Moderate sensibility
STRING DISCONNECTED			One array is warmer than the others	Open circuit by a wire interruption or burnt fuse.	One or some arrays	Relatively frequent	Moderate sensibility
SHADOWS			A section of a PV module is in shadow	Trees, chimneys, others panels	Variable	Relatively frequent	Moderate sensibility

Table 3-4 Anomalies on PV modules.

The most common fault detected on a PV module is the hot spot. It usually appears on modules in various ways, with different entities, related to the cell overheating. During IRSM, operator marks this type of anomaly through the evaluation of the cell temperature, compared to the rest of the module (Δt). In extreme cases, it gets to have a Δt of 50 or 60°C where burning signs are visible in warm point. These anomalies are very dangerous for the PV plant safety and can induce fires.

Usually, modules whose difference of temperature is greater or equal to 25°C are classified as “hot spot”. This value is defined by the manufacturer of PV modules as a threshold for the substitution in guarantee. It is possible to survey hot spot with very small Δt . In fact, "minor hot spot" term was adopted, to mark the modules that show the anomaly, but with a Δt smaller than 25°C. In this case, it is very important to carry out a visual inspection of the module to evaluate if substitution is necessary or it will be rechecked in following inspections. Even if Δt is low, in fact, it is probable that the module shows back-sheet with cracks or burned area (Figure 3-23). Usually, “minor hot spots”, which do not have the problems just mentioned are not marked by the operator. Therefore, they are not considered as anomalies.

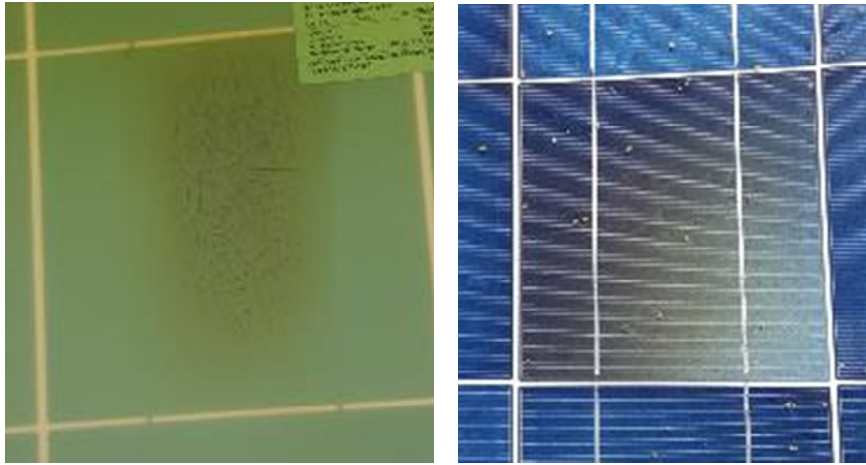


Figure 3-23 Back-sheet with crack due to hot spot (left picture) - Hot spot cell with burned

- Output data. At the end of analysis, a report with the statistics of PV plant problems is performed (SR). Usually, a layout of PV plant with the indication of PV modules damaged is produced and attached to the SR. All data processing operations are carried out manually.

In the next paragraphs, the IRSM approach performed on the three PVT will be described.

3.3.1 IRSM – PVT1 “PERLA”

IR survey planning.

IR survey was planned the 21/09/2017. Two qualified operators were designated by ENTEC spa for the survey operations: Ing. Mattia Bussi (OP 1 - qualified as non-destructive tests operator of second level, according to “UNI EN 16714”) and Christian Vismara (OP 2 – qualified operator with driving licence for aerial platform).

PVT1 is a roof plant with no access, furthermore a homologated aerial platform was rent for a day. The instrument used for the IR survey is a thermal camera model FLIR T440. Technical features are summarized in the following:

- Range of temperature: $-20^{\circ}\text{C} + 1200^{\circ}\text{C}$
- Type of sensor: FPA (Focal Plane Array), microbolometer without cooling
- Spectral interval: $7.5 - 13 \mu\text{m}$
- Thermal sensitivity / NETD: $< 45 \text{ mK @ } 30^{\circ}\text{C}$
- Space resolution: 1.36 mrad
- Optical field (FOV)/minimum distance of focus: $25^{\circ}\times 19^{\circ} / 0.4 \text{ m}$

IR survey

IR survey operations started at 10:30 am. The access of roofs was carried out with the aerial platform, requiring security device wear for the two operators, such as helmets and harness; and six platform movements inside the plant (Figure 3-24). The IR operations were performed in this way:

- OP 2 operated the aerial platform in order allows the access to the roofs.



- OP 1 carried out IR thermal camera survey. He collected pictures of modules affected by anomalies and performed a first classification of damage, through “real – time” image analysis.
 - OP 2 accomplished the annotation of images captured and typology of anomaly on a layout sheet.
- Furthermore, he performed a visual control of anomalies not recognizable by IR images.

The operations lasted 4:55 hours (effective survey time). The time spent for IR image acquisition was 2:25 hours. Consequently, about 50% of total time was dedicated to logistic operations. In Table 3-5, a summary of IR survey operations is reported.

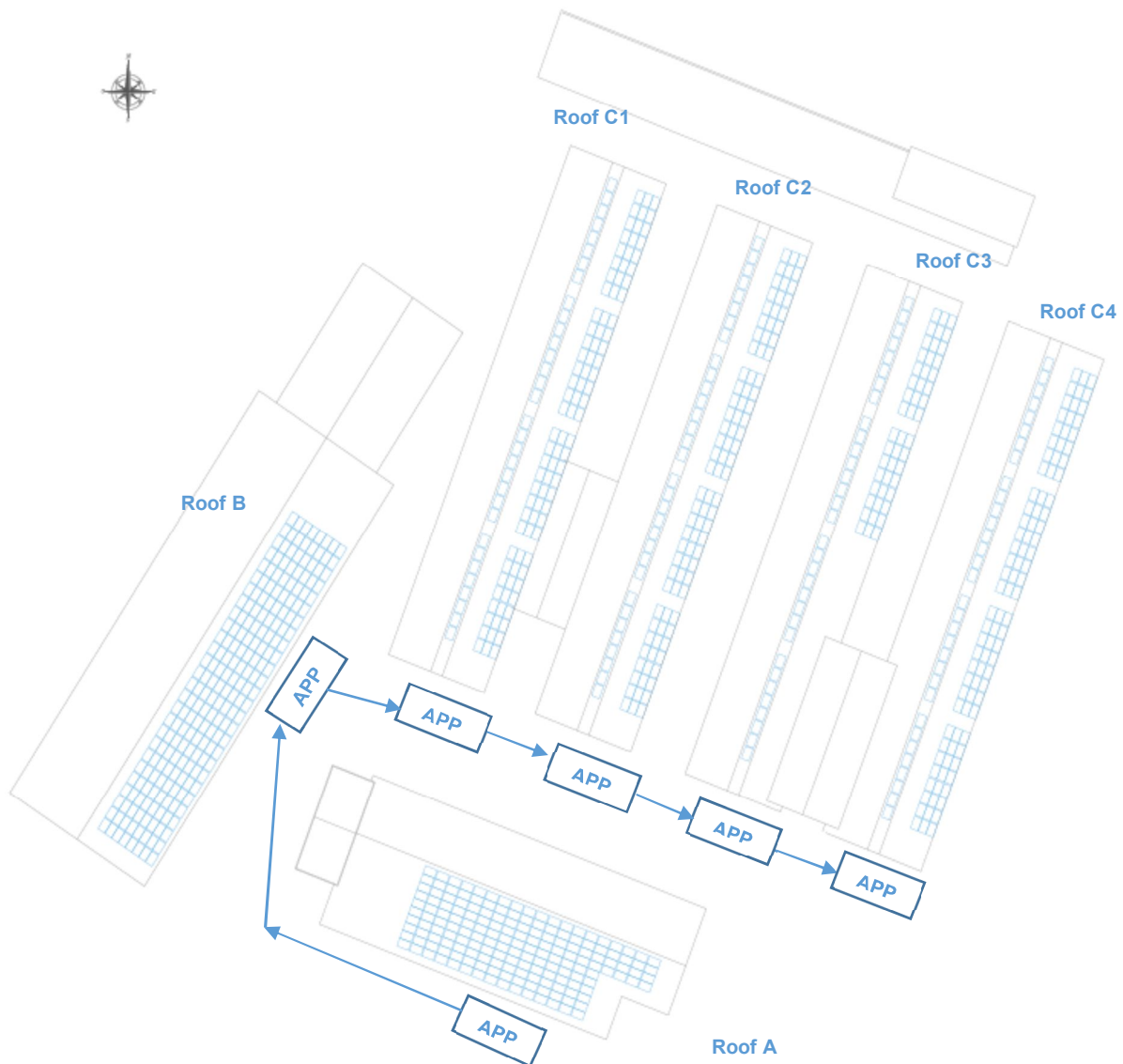


Figure 3-24-Aerial Platform Positions (APP) during the PVT1 IR survey

PV Plant	PVT1 “Perla”		
Date	21/09/2017	IR SURVEY	IRSM
TIME (hour:min)		ACTION	



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absolute	relative	partial	IR acquisition	Logistics
10:30	0:00	0:10		Temperature and IR measurement
10:40	0:10	0:10		IR camera starting, camera parameters control, security devices preparation (harness, helmet)
10:50	0:20	0:10		Access to roof A. Lift track operations
11:00	0:30	0:30	IR acquisition of PV plant - roof A	
11:30	1:00	0:25		Come down from the roof A to the ground – approach to roof B with lift track – ascent to roof B
11:55	1:25	0:35	IR acquisition of PV plant - roof B	
12:30	2:00	0:15		Come down from the roof B
12:45	2:15			Lunch break
14:05	2:15	0:15		Access to roof C1. Lift track operations
14:20	2:30	0:25	IR acquisition of PV plant - roof C1	
14:45	2:55	0:10		Come down from the roof C1 to the ground – approach to roof C2 with lift track – ascent to roof C2, temperature and IR measurement
14:55	3:05	0:20	IR acquisition of PV plant - roof C2	
15:15	3:25	0:15		Come down from the roof C2 to the ground – approach to roof C3 with lift track – ascent to roof C3
15:30	3:40	0:20	IR acquisition of PV plant - roof C3	
15:50	4:10	0:15		Come down from the roof C3 to the ground – approach to roof C4 with lift track – ascent to roof C4
16:05	4:25	0:15	IR acquisition of PV plant - roof C3	
16:20	4:40	0:15		Come down from roof C4. Place of thermal camera and security devices
16:35	4:55		END OF SURVEY	

Table 3-5 Timetable of IR survey operations PVT1 “Perla”



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Next Figures show some pictures taken during the IR survey are showed and copies of data sheets acquisition of the operations.



Figure 3-25- PVT1 - Position of aerial platform



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Figure 3-26- PVT1 - aerial platform operations for roof access

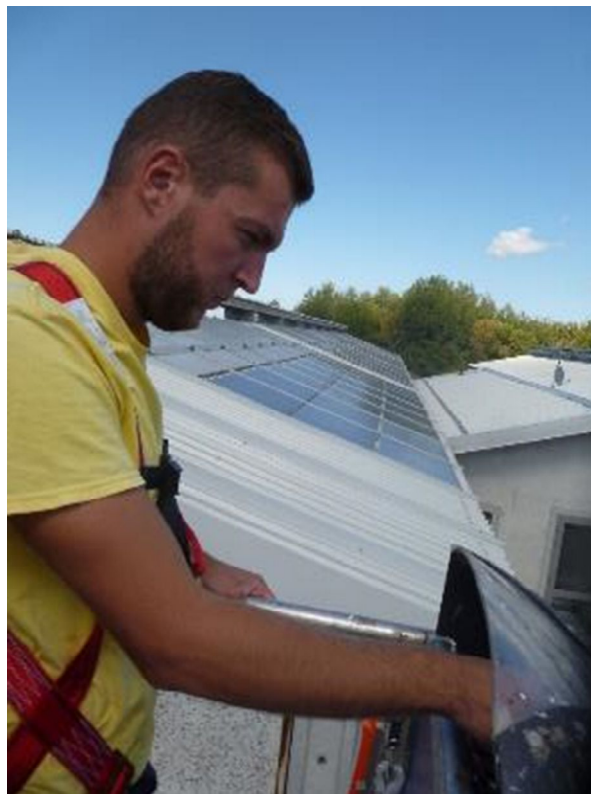


Figure 3-27- PVT1 - aerial platform operations for roof access. Particular of approach to the roof



Figure 3-28- PVT1 - IR survey operation on “Roof A”



Figure 3-29- PVT1 - Manual annotation of PV modules affected by anomalies

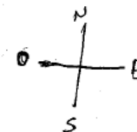


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21-09-17 VISMARA - LIMPIDO - ORA INIZIO = 11:00
 MODULO SPORCHI, BAVA DI LUMACA ORA FINE = 11:30

[9440-9572]

10min = preparazione centrale e
 salita



Impianto PV Perla - Falda A

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
A					9450			9451				9463		9466	9469				
C	9441	9442		9447			9453					9464							9470
E			9448								9462	9465							
G				9446		9451					9461								
				9445	9449					9457	9460								
						9452			9455										
									9456					9467					
			9444							9459									
	X		9443							9458						9468			

1-2 = 9440 = PAR
 ✓ 9441 = PAR
 9442 = Δ 6°C
 9443 = PAR
 9444 = PAR

9445 = PAR
 9446 = PAR
 9447 = Δ 4°C
 9448 = PAR
 9449 = PUNTO CALDO
 9450 = Δ 10°C
 9451 = HOT SPOT LIEVE DIFFUSI

9452 = Δ 40 CELLA BRUCIATA
 9453 = PAR
 9454 = PUNTO CALDO
 9455 = HOT SPOT LIEVE
 9456 = HOT SPOT LIEVE + PAR
 9457 = PAR
 9458 = PAR
 9459 = PAR
 9460 = Δ 7

9461 = PAR
 9462 = PAR
 9463 = PAR
 9464 = PAR
 9465 = Δ 10°C
 9466 = Δ 6°C
 9467 = PAR
 9468 = PUNTO CALDO
 9469 = PAR

9470 = PAR
TOT: 30

Figure 3-30- PVT1 - Manual report "Roof A"

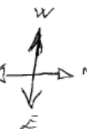
21/09/2017 - VISMARA - LIMPIDO - INIZIO: 12:55
 FINE: 12:30

STAFFE STORTE, BAVA DI LUMACA
 DA 12:00 IN SU

FOTO STAFFE: DATA: 115602 / DATA: 115539 / DATA: 115531

FOTO BAVA DI LUMACA: DATA: 122629 / DATA: 122637

(SALITA + DISCESA)
 20 MINUTI
 INIZIO MISURA 12:45
 FINE 14:05
 - 70 MINUTI RILIEVO GPS (PAL TOTALIS TERMO)
 - 20min RILIEVO + SCENDERE



Impianto PV Perla - Falda B

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
A		9472	9473									9482	9483										9513				
C				9477	9478							9488	9489		9500						9507		9508				
E								9482			9481			9499	9504						9506		9510	9512		9514	
G				9474		9476	9479		9484				9495	9496	9497								9511		X		
					9475			9481		9486		9490	9496			9502	9509							X		X	

9471 = Δ 15°C
 9472 = PAR
 9473 = PAR
 9474 = Δ 10°C
 9475 = PAR
 9476 = PAR
 9477 = PAR
 9478 = Δ 10°C
 9479 = PUNTO CALDO
 9480 = PAR
 9481 = PAR

9482 = Δ 15°C
 9483 = Δ 15°C
 9484 = PAR
 9485 = PAR
 9486 = PAR
 9487 = Δ 15°C
 9488 = Δ 35°C CELLA BRUCIATA
 9489 = Δ 8°C
 9490 = PAR
 9491 = PUNTO CALDO
 9492 = PAR

9493 = PAR
 9494 = PAR
 9495 = Δ 30°C
 9496 = PAR
 9497 = PAR
 9498 = PAR
 9499 = PUNTO CALDO
 9500 = PAR
 9501 = PAR + HOT SPOT
 9502 = PAR
 9503 = PAR

9504 = PAR
 9505 = PAR
 9506 = PUNTO CALDO
 9507 = Δ 50°C CELLA BRUCIATA
 9508 = PUNTO CALDO
 9509 = PAR
 9510 = Δ 10°C
 9511 = PAR
 9512 = PAR
 9513 = PAR

9514 = Δ 15°C
 X: CELLE SCALDATE
 FOTO: DATA: 122634
 DATA: 122636
 DATA: 122606
 DATA: 122623
TOT: 43

Figure 3-31- PVT1 - Manual report "Roof B"



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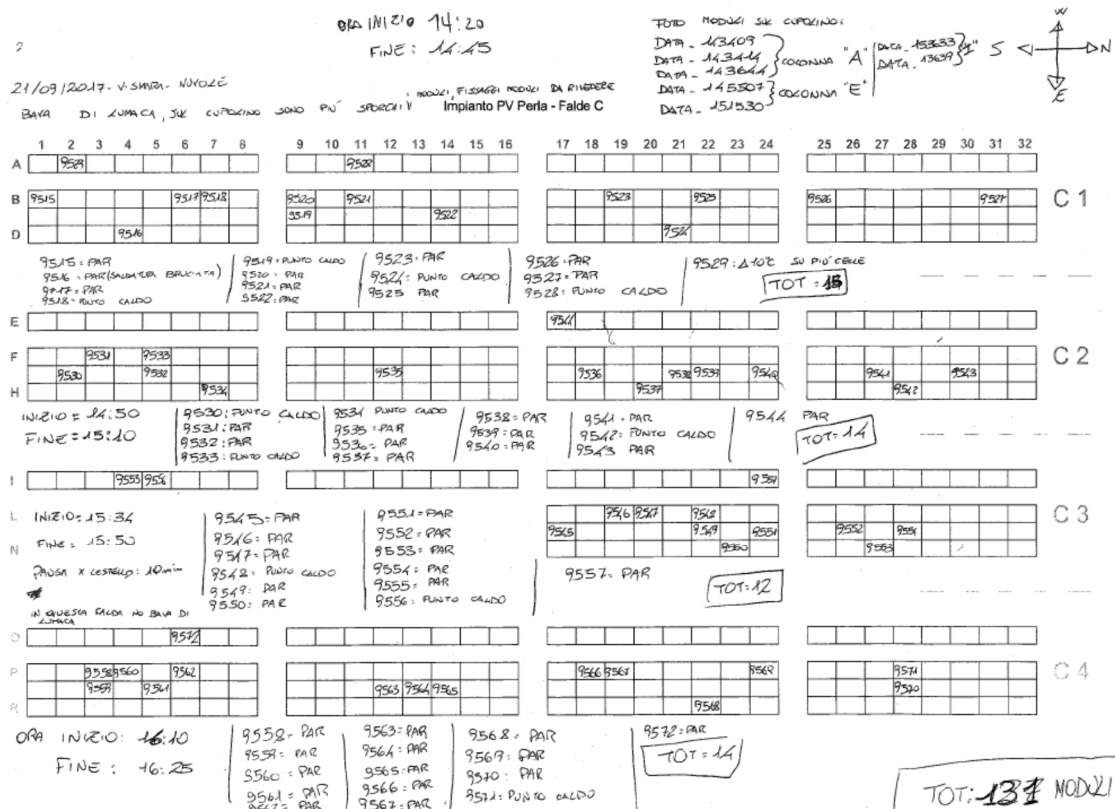


Figure 3-32 PVT1 - Manual report "Roof C1 - C4"

Data processing. Data processing was carried out in the Entec office. The OP1 downloaded the images acquired in the field and processed them using a dedicated software (Flir Tools+), provided by the IR camera manufacturer. He started to analyse every IR image trying to detect potential anomalies. Thanks to a software tool, the operator, visualized the temperature distribution on different areas of the module and measured possible differences. The operator highlighted, on the layout used during the survey, PV panels affected by anomalies.

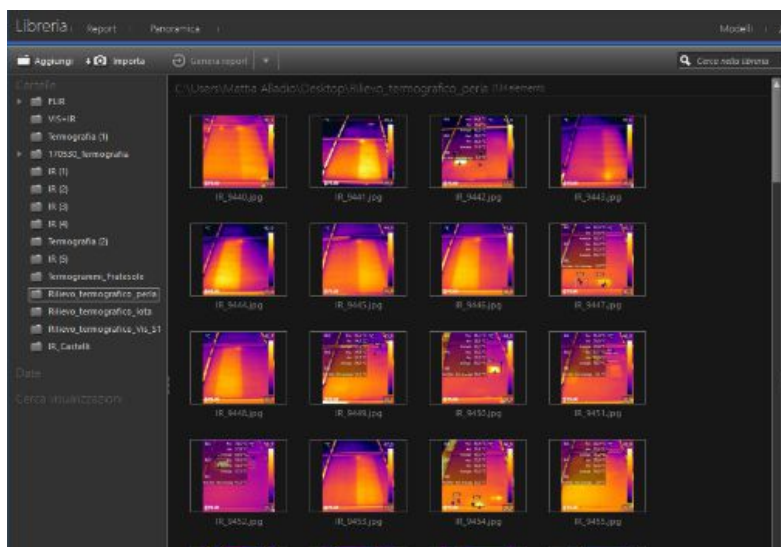


Figure 3-33- PVT1 - upload of IR images inside the analysis software

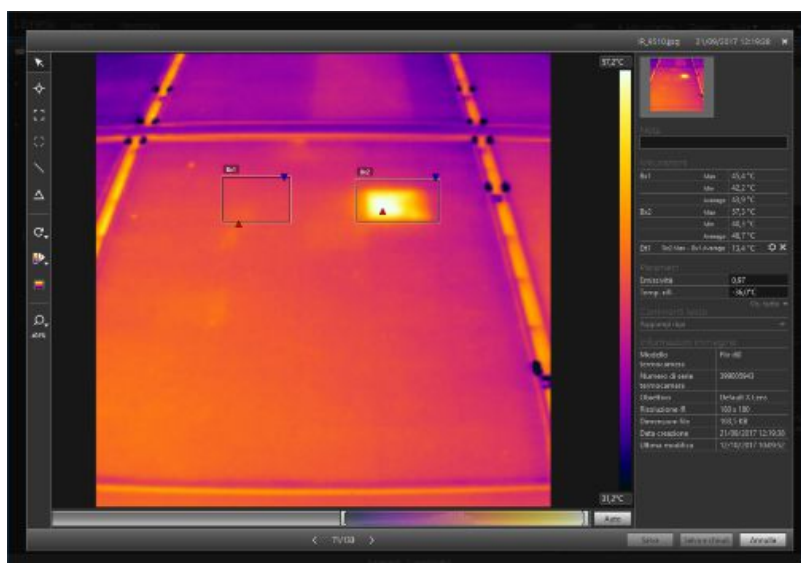


Figure 3-34- PVT1 - manual identification of “Hot spot”

As a result of the analysis, the operator produced a report with the thermal images of highlighted PV modules and a short description of the anomalies (see attachment 1.1). Finally, the operator reported in a layout of PV plant the position of defected modules with the relative IR image number (see attachment 1.2).

In the next table, a timetable of data processing activities is resumed.

PV Plant	PVT1 “Perla”		
Date	26/09/2017	DATA PROCESSING	IRSM
TIME (hour:min)		ACTION	
relative	Partial	Description of the processing	
0:00	0:10	Download of images in a specific folder created for the inspection	
0:10	0:05	Start Flir Tools+ and import IR images	
0:15	1:30	Edit IR images, integration of points or areas to define eventual differences of temperature	
1:45	0:30	Production of the introduction of the IR survey report. Insertion of PV plant and IR survey information. Creation of a table with the number of anomalies located on the PV plant	
2:15	2:00	Production of the IR survey report. Insertion of IR images and a description of anomalies	
4:15	0:30	Edit of the layout of PV plant with the integration of position of damaged module and number of IR image	
4:45		END OF PROCESSING	

Table 3-6 Timetable of data processing operation of PVT1 “Perla”



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Summary of IR operations.

In the following table, the summary of anomalies detected by IRSM is showed.

Anomaly	ΔT	Recommended action	n° of damaged modules	% of damaged modules
Hot ribbon welding	$\Delta T \geq 2$ °C	Module replacement	18	2,13%
Minor hot spot	$\Delta T < 25$ °C	Control during next thermography/ Module replacement	17	2,01%
Hot spot	$\Delta T \geq 25$ °C	Module replacement	5	0,59%
Hot strip	$\Delta T \geq 1$ °C	Reparation / module replacement	93	10,99%
TOTAL	/		133	15,72%

Table 3-7 Statistic of anomalies on PVTI "Perla"

In the following figure, an extract of layout of PV plant with the indication of modules damaged is represented.

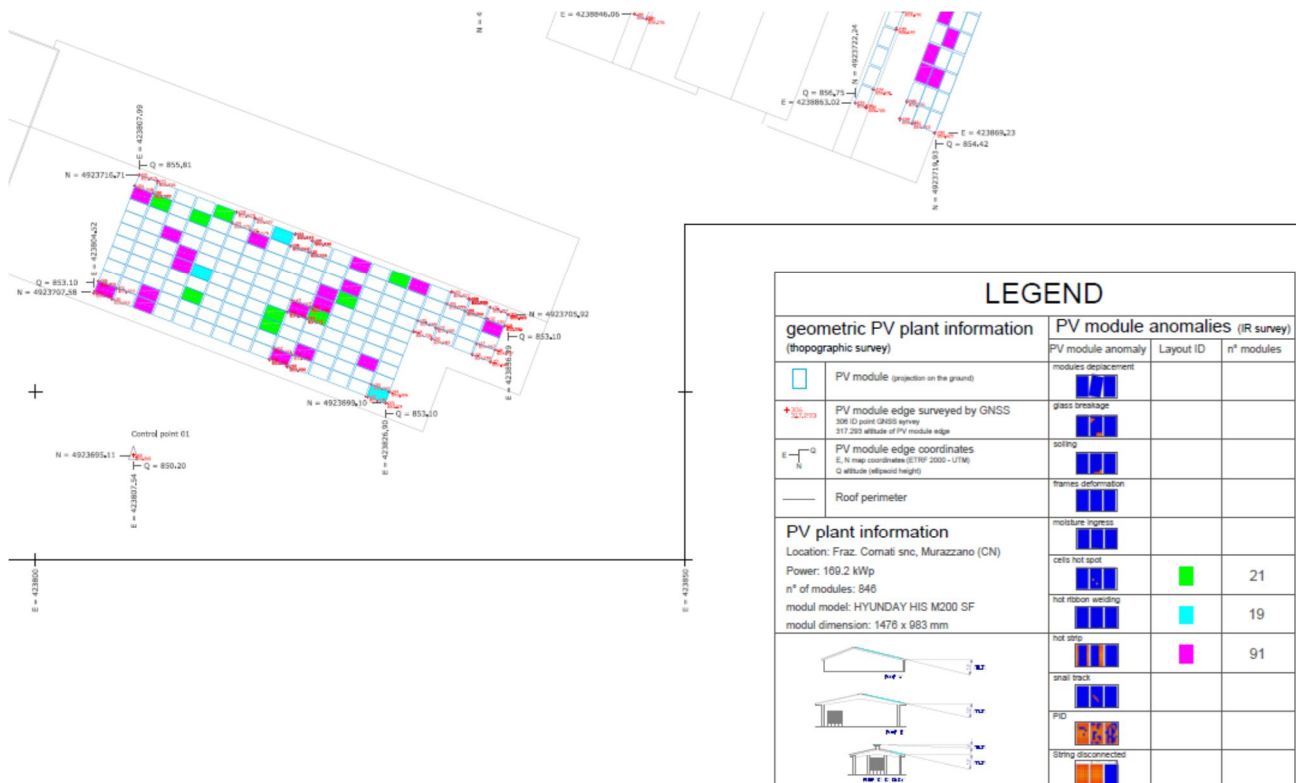


Figure 3-35 extract of PVTI plant layout with anomalies indication



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In the following table, the summary of resources and time spent for the IR acquisition and data processing of PVT1 plant is showed:

PV Plant	PVT1 “Perla”		
Date	September 2017	IR acquisition	IRSM
		ACTION	
TIME (men hour)		Description of the processing	
3:00		Rent of aerial platform (collect and delivery)	
9:30		IR acquisition	
4:45		Data processing and output data production	
TOTAL 17:15			

Table 3-8 Summary of time spent on PVT1 “Perla” acquisition and processing



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3.3.2 IRSM – PVT2 “VIS SOLIS 1”

IR survey planning.

IR survey was planned the 20/09/2017. Two qualified operators were designated by ENTEC spa for the survey operations: Ing. Mattia Bussi and Christian Vismara. PVT2 is a ground plant, therefore the survey was carried out walking on foot row by row. The instrument used for the IR survey is a thermal camera model FLIR T440.

IR survey

IR survey operations started at 9:55 am. The IR operations were performed in this way:

- Operator 1. IR thermal camera survey. Picture shooting of modules affected by anomalies and first classification of damage, through “real – time” image analysis ;
- Operator 2. Annotation of images captured and typology of anomaly on a layout sheet. Visual control of anomalies not recognizable by IR images. Signalization of module damaged through writing of number of IR image and date of acquisition in the back side of the module.

The operations lasted 5:50 hours (effective survey time). The time spent for IR image acquisition was 4:45 hours. Consequently, about 25% of total time was dedicated to logistic operations. In Table 3-5, a summary of IR survey operations is reported:

PV Plant		PVT3 “Vis Solis 1”		
Date		20/09/2017	IR SURVEY	IRSM
TIME (hour:min)			ACTION	
absolute	relative	partial	IR acquisition	Logistics
9:55	0:00	0:05		Temperature and IR measurement
10:00	0:05	0:10		IR camera starting, camera parameters control
10:10	0:15	1:30	IR acquisition of PV plant rows 21-16	
11:40	1:45	0:05		Temperature and IR measurement
11:45	1:50	1:20	IR acquisition of PV plant rows 15-12	
13:00	3:10			Lunch break
13:35	3:10	0:20	IR acquisition of PV plant rows 11-10	
13:55	3:30	0:05		Temperature and IR measurement
14:00	3:35	1:10	IR acquisition of PV plant rows 9-6	
15:10	4:45	0:05		Temperature and IR measurement
15:15	4:50	0:50	IR acquisition of PV plant rows 5-2	



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16:05	5:40	0:05		Temperature and IR measurement
16:10	5:45	0:05	IR acquisition of PV plant rows 1	
16:15	5:50		END OF SURVEY	

Table 3-9 Timetable of IR survey operations PVT2 “Vis Solis I”

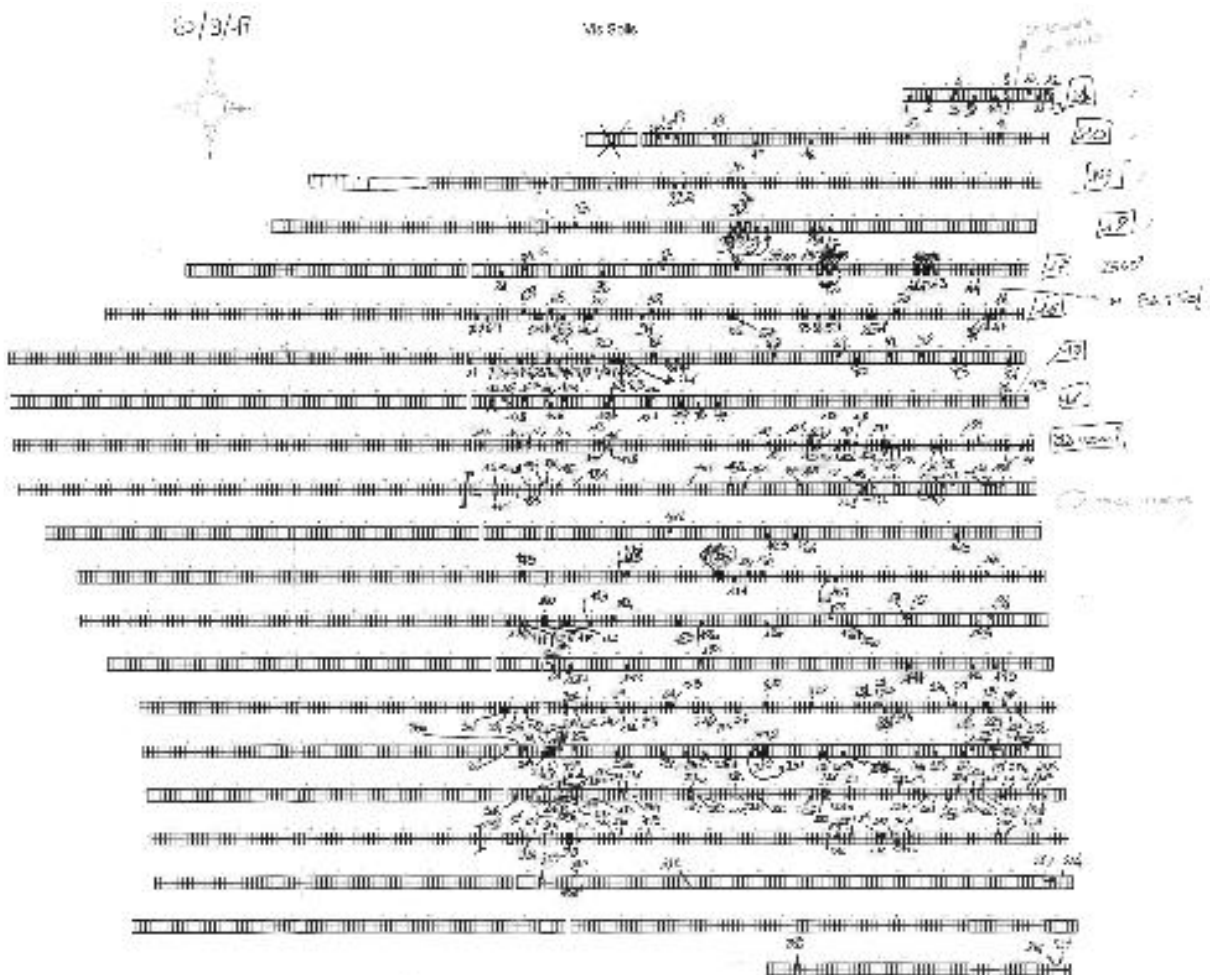


Figure 3-36- Manual report survey



Figure 3-37- Manual report survey

Data processing. The data processing procedure was performed in the same way of operations carried out for PVT1. Hereafter, a timetable is showed.

PV Plant		PVT3 “Vis Solis 1”		
Date		20/09/2017	DATA PROCESSING	IRSM
TIME (hour:min)		ACTION		
relative	Partial	Description of the processing		
0:00	0:10	Download of images in a specific folder created for the inspection		
0:10	0:05	Start Flir Tools+ and import IR images		
0:15	3:30	Edit IR images, integration of points or areas to determine eventual differences of temperature		
3:45	0:30	Production IR survey report introduction. Insertion of PV plant and IR survey information. Creation of a table with the number of anomalies located on the PV plant		
4:15	6:00	Production of the IR survey report. Insertion of IR images and a description of anomalies		
10:15	0:30	Edit of the layout of PV plant with the integration of damaged module position and number of IR image		
10:45		END OF PROCESSING		

Table 3-10- Timetable of data processing operations PVT2 “Vis Solis 1”

Summary of IR operations.



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In the following table, the summary of anomalies detected by IRSM is showed.

Anomaly	ΔT	Recommended action	n° of damaged modules	% of damaged modules
Hot ribbon welding	/	Module replacement	42	0,89%
Glass breakage	/	Module replacement	1	0,02%
Minor hot spot	$\Delta T < 25\text{ }^{\circ}\text{C}$	Control during next thermography/ Module replacement	2	0,04%
Hot spot	$\Delta T \geq 25\text{ }^{\circ}\text{C}$	Module replacement	1	0,02%
Hot strip	/	Reparation / module replacement	287	6,10%
TOTAL	/		333	7.07%

Table 3-11 Statistic of anomalies on PVT3 “Vis Solis 1”

Summary of IR operations.

In the following table, the summary of resources and time spent for the IR acquisition and data processing of PVT2 plant is showed:

PV Plant	PVT2 “Vis Solis 1”		
Date	September 2017	IR acquisition	IRSM
		ACTION	
TIME (men hour)		Description of the processing	
11:40		IR acquisition	
10:45		Data processing and output data production	
TOTAL: 22:25			

Table 3-12 Summary of time spent on PVT2 “Vis Solis 1” acquisition and processing



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3.3.3 IRSM – PVT3 “FRATESOLE”

IR survey planning IR survey was planned the 19/09/2017. Two qualified operators were designated by ENTEC spa for the survey operations: Ing. Mattia Bussi and Christian Vismara. PVT3 is a ground plant, therefore the survey was carried out walking on foot row by row. The instrument used for the IR survey is a thermal camera model FLIR T440.

IR survey

IR survey operations started at 10:15 am. The IR operations were performed in the same way of PVT2 ones. The operations lasted 3:40 hours (effective survey time, see Table 3-5). The time spent for IR image acquisition was 3:20 hours. Consequently, about 10% of total time was dedicated to logistic operations. In Table 3-5, a summary of IR survey operations is reported:

PV Plant	PVT3 “Fratesole”			
Date	19/09/2017		IR SURVEY	IRSM
TIME (hour:min)			ACTION	
absolute	relative	partial	IR acquisition	Logistics
10:15	0:00	0:05		Temperature and IR measurement
10:20	0:05	0:10		IR camera starting, camera parameters control
10:30	0:15	3:00	IR acquisition of PV plant	
13:30	3:15			Lunch break
14:00	3:15	0:05		Temperature and IR measurement
14:05	3:20	1:20	IR acquisition of PV plant	
15:25	4:40		END OF SURVEY	

Table 3-13- Timetable of IR survey operations PVT3 “Fratesole”

Next Figure shows copies of data sheets acquisition of the operations.

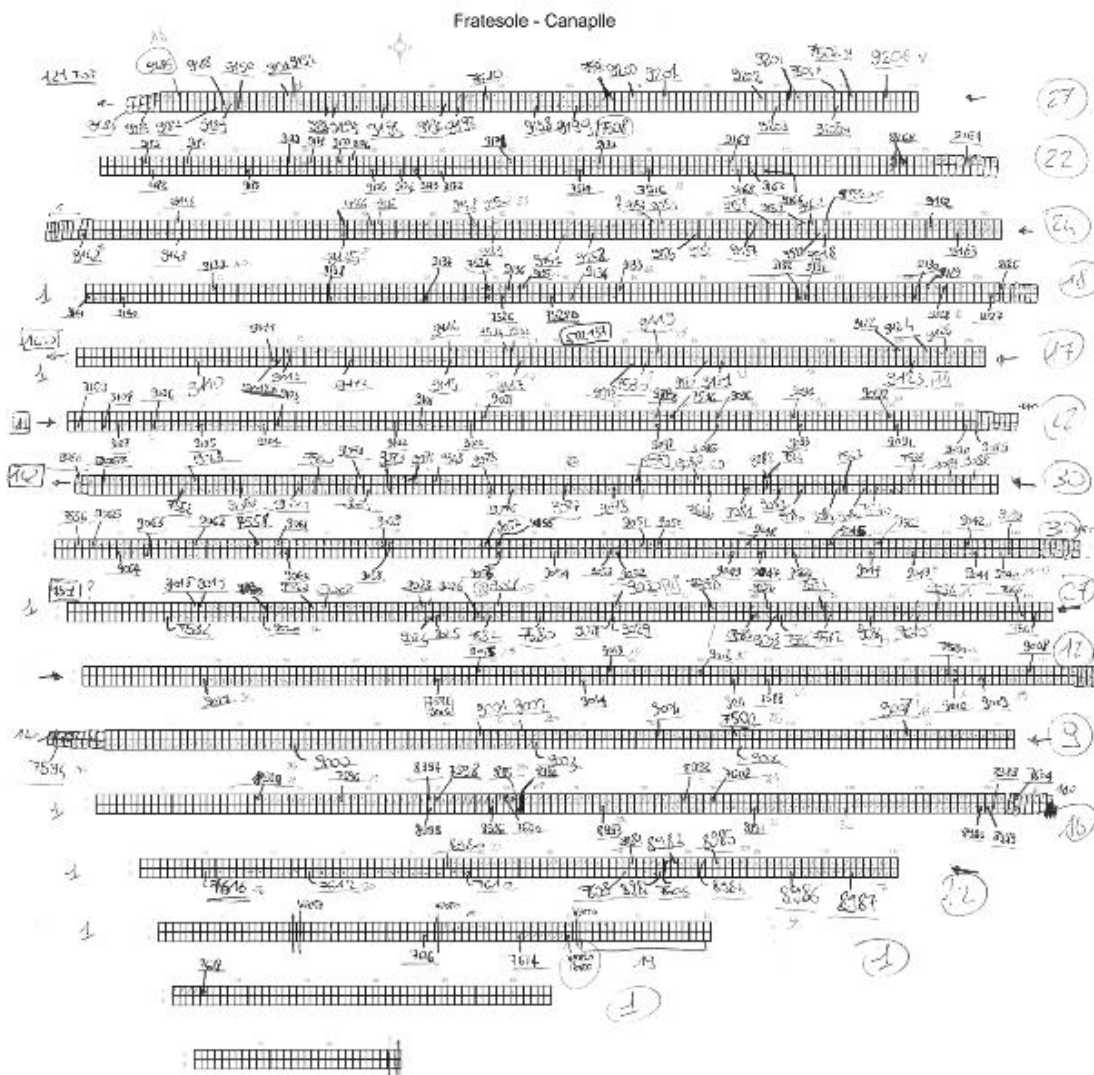


Figure 3-38 Manual report survey

Data processing. The data processing procedure was performed in the same way of operations carried out for PVT1. Hereafter, a timetable is showed.

PV Plant	PVT3 "Fratesole"		
Date	19/09/2017	DATA PROCESSING	IRSM
TIME (hour:min)		ACTION	
relative	Partial	Description of the processing	
0:00	0:10	Download of images in a specific folder created for the inspection	
0:10	0:05	Start Flir Tools+ and import IR images	
0:15	4:00	Edit IR images, integration of points or areas to define eventual differences of temperature	



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4:15	0:30	Production of the introduction of the IR survey report. Insertion of PV plant and IR survey information. Creation of a table with the number of anomalies located on the PV plant
4:45	5:00	Production of the IR survey report. Insertion of IR images and a description of anomalies
9:45	0:30	Edit of the layout of PV plant with the integration of position of damaged module and number of IR image
10:15		END OF PROCESSING

Table 3-14 Timetable of data processing operation of PVT3 “Fratesole”

Summary of IR operations.

In the following table, the summary of anomalies detected by IRSM is showed-

Anomaly	ΔT	Recommended action	n° of damaged modules	% of damaged modules
Glass breakage	/	Module replacement	1	0,03%
Minor hot spot	$\Delta T < 25$ °C	Control during next thermography/ Module replacement	18	0,46%
Hot spot	$\Delta T \geq 25$ °C	Module replacement	250	6,39%
Hot strip	$\Delta T \geq 1$ °C	Reparation / module replacement	6	0,15
TOTAL	/		275	7,03%

Table 3-15 Statistic of anomalies on PVT3 “Fratesole”

Attached files 2.1 and 2.2 include a report with the thermal images of highlighted PV modules and a layout of PV plant with the position of defected modules.

Summary of IR operations.

In the following table, the summary of resources and time spent for the IR acquisition and data processing of PVT3 plant is showed:

PV Plant	PVT3 “Fratesole”		
Date	September 2017	IR acquisition	IRSM
		ACTION	
TIME (men hour)		Description of the processing	
9:20		IR acquisition	
10:15		Data processing and output data production	
TOTAL: 19:35			

Table 3-16 Summary of time spent on PVT3 “Fratesole” acquisition and processing



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3.4 EXECUTION OF IR SURVEYS ON THE PVT. EASY PV SYSTEM (EPV)

Easy PV system has been tested on the three PVT. The acquisitions have been performed by two operators of Top View company, with the assistance of two technicians of Entec spa. The goals of these operations were:

- to test the operational survey procedures (acquisition time, flight trajectories, IR acquisition) and locate potential problems;
- to acquire data (IR images, GNSS observation) in order to process them by the SC.

Hereafter, the EPV acquisition process is summarized:

- pre – flight operations, that include:
 - check of environmental conditions (measure of solar radiation and temperature);
 - inspection of PV plant by pilot;
 - flight planning;
 - position of Ground Station GNSS antenna on a known point (GP);
 - RPAS – payload assembly.
- flight operations, that include:
 - RPAS Take – off;
 - flight over the PV plant and IR image acquisition;
 - RPAS landing for battery change (possible, if the battery autonomy does not allow a complete survey of PV plant);
 - RPAS take – off after battery change (possible);
 - RPAS landing at the end of flight over the plant.
- data analysis, through upload the surveyed data on SC platform
- output data publication on VTE platform.

In the next paragraphs, a description of EPV operations on the three PVT will be showed.

3.4.1 EPV – PVT1 “PERLA”

Pre – flight operations

The IR survey with EPV was carried out the 03/10/2017. Two qualified technicians performed survey operations: Ing. Alberto Mennella (OP 1, RPAS co – pilot, responsible security flight. Top View company) and Graziano Gagliarde (OP 2, RPAS pilot. Top View Company). Two operators from ENTEC spa (Ing. Davide Marenchino, Ing. Mattia Bussi) attended to the survey operations.

At 12.45, the weather was cloudy and partially fog. The temperature on the ground was 21° C and the solar radiation was about 200 W/m². These measurements were acquired just before the survey operations start; therefore, they could be changed during the operations. Nevertheless, weather conditions lasted stationary during

the day and then solar radiation could be considered quite constant. The ground station antenna was positioned on a Ground Point (GP) of the PV plant, surveyed with Topcon HyperPro GNSS instrument.



Figure 3-39 Location of ground station antenna on GCP

After a short inspection, the two operators planned the flight and started to assembly the RPAS.



Figure 3-40 Pre – flight operations. Assembly of RPAS platform

Flight operations IR survey



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Flight operations started at 13:05. The IR operations were performed in this way:

- OP 2 piloted manually the RPAS over the plant checking in real time the data collecting by the IR sensor installed on the RPAS platform, through a monitor located near the RPAS radio-control.
- OP 1 performed a visual control of flight operations.

Four flights were performed in order to survey the six roofs. Next Figure, shows a layout of flight operations.

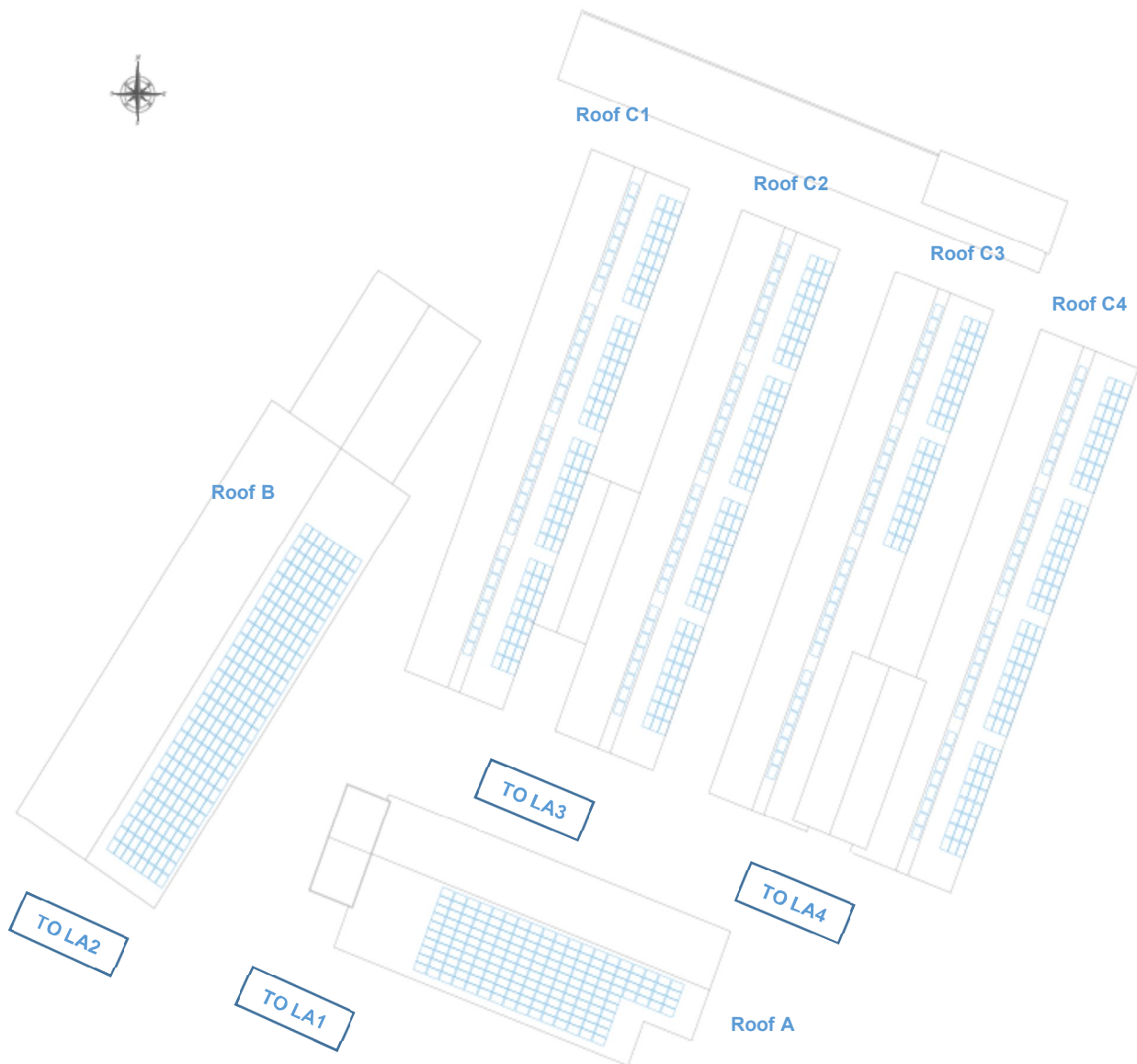


Figure 3-41 Easy PV flights, take – off and land, (TO-LA) during the PVT1 IR survey

The operations lasted 1:25 hours. The time spent for IR image acquisition (flight operations) was 0:35 hours. Consequently, about 60% of total time was dedicated to logistic operations. In Table 3-17, a summary of IR survey operations is reported.



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PV Plant	PVT1 “Perla”			
Date	03/10/2017		IR SURVEY	EPV
TIME (hour:min)			ACTION	
absolute	relative	partial	IR acquisition	Logistics
12:45	0:00	0:20		Temperature and IR measurements, ground station antenna location, RPAS assembly.
13:05	0:20	0:07	Take-off. Flight 1 over roof A	
13:12	0:27	0:05		Landing flight 1 – setting RPAS
13:17	0:32	0:05	Take-off. Flight 2 over roof B	
13:22	0:37	0:05		Landing flight 2 – setting RPAS
13:27	0:42	0:04	Take-off. Flight 3 over roof C1	
13:31	0:46	0:08		Landing flight 3 – change battery
13:39	0:54	0:16	Take-off. Flight 4 over roofs C2 - C3 – C4	
13:55	1:10	0:15		Landing flight 4. Place of RPAS, ground station antenna
14:10	1:25		END OF SURVEY	

Table 3-17 Timetable of EPV survey operations - PVT1 “Perla”

Flight operations required four take – off, due to the set of RPAS parameters. In normal conditions, just two flights could be carried out.

Data analysis

At the end of survey, operator sent data collected by the RPAS payload to the SC. This operation was completely automatic and required about 30 minutes. SC processed the data in a complete automatic way and supplied the output data to the VTE for the visualization. The human effort for the raw data management was assessed in 1:00 hour

EPV survey summary

Next table resumes the human time effort in the EPV survey.

PV Plant	PVT1 “Perla”		
Date	October 2017	IR acquisition	EPV
		ACTION	
TIME (men hour)		Description of the processing	
2:50		IR acquisition	



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0:30	Upload data to SC
1:00	Raw data management
TOTAL: 4:20	

Table 3-18 Timetable of EPV survey operations - PVT1 “Perla”

3.4.2 EPV – PVT2 “VIS SOLIS 1”

Pre – flight operations

The IR survey with EPV was carried out the 04/10/2017. The IR survey was performed in the same way of operations carried out for PVT1. At 10:00 am, the weather was cloudy and partially fog. The temperature on the ground was 18° C and the solar radiation was about 370 W/m². These measurements were acquired just before the survey operations beginning; therefore, they could be changed during the operations. Operators signaled an improvement of weather about one hour after the beginning of survey, whit partially sunny conditions. Then, just after few time, weather was cloudy again.

The ground station antenna was positioned on a Ground Point (GP) of the PV plant, surveyed with Topcon HyperPro GNSS instrument.

Flight operations IR survey

Flight operations started at 11:01. The IR operations were performed in this way:

- OP 2 piloted manually the RPAS over the plant checking in real time the data collecting by the IR sensor installed on the RPAS platform, through a monitor located near the RPAS radio-control.
- OP 1 performed a visual control of flight operations.

Four flights were performed in order to survey the whole plant. Figure 3-42 shows a layout of flight operations. The operations lasted 2:19 hours. The time spent for IR image acquisition (flight operations) was 1:51 hours. Consequently, about 40% of total time was dedicated to logistic operations. In Table 3-17, a summary of IR survey operations is reported.

PV Plant	PVT3 “Vis Solis 1”			
Date	04/10/2017		IR SURVEY	EPV
TIME (hour:min)			ACTION	
absolute	relative	partial	IR acquisition	Logistics
10:30	0:00	0:31		Temperature and IR measurements, ground station antenna location, RPAS assembly.
11:01	0:08	0:18	Take-off. Flight 1 over rows 1-4	
11:19	0:26	0:04		Landing flight 1 – change battery



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11:33	0:30	0:13	Take-off. Flight 2 over rows 5-7	
11:46	0:43	0:06		Landing flight 2 – setting RPAS
11:52	0:49	0:11	Take-off. Flight 3 over rows 8-9	
12:03	1:00	0:04		Landing flight 3 – change battery
12:07	1:04	0:02		Temperature and IR measurements.
12:09	1:06	0:05	Take-off. Flight 4 over rows 10-11	
12:14	1:11	0:05		Landing flight 4. Place of RPAS, ground station antenna.
12:19	1:16	0:14	Take-off. Flight 5 over rows 12-15	
12:23	1:30	0:07		Landing flight 5 – change battery
12:30	1:37	0:07	Take-off. Flight 6 over rows 16-17	
12:37	1:44	0:12		Landing flight 6. Place of RPAS, ground station antenna.
12:49	1:56	0:13	Take-off. Flight 7 over rows 18-19	
13:02	2:09	0:10		Landing flight 7
13:12	2:19		END OF SURVEY	

Table 3-19 Timetable of EPV survey operations – PVT3 “Vis Solis 1”

Flights operations required seven take – off, due to the set of RPAS parameters. In normal conditions, about four or five flights could be carried out.



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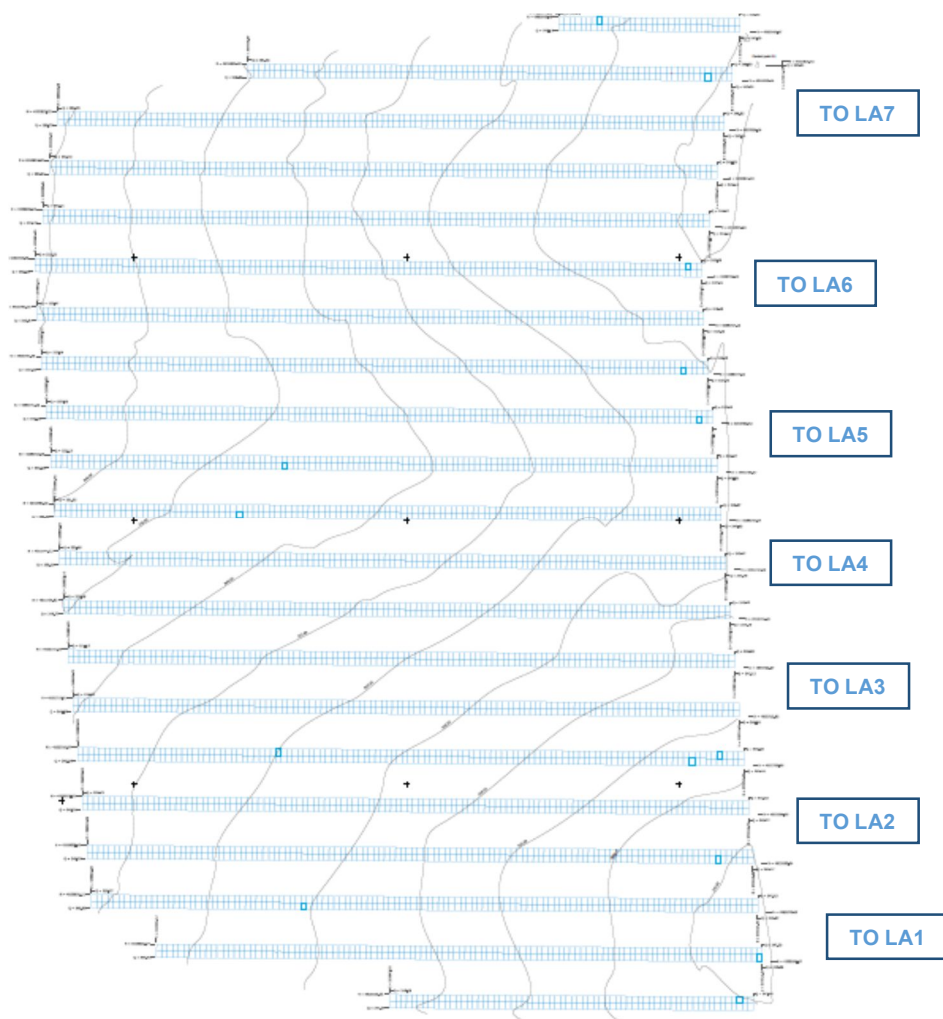


Figure 3-42-Easy OV flights, take – off and land, (TO-LA) during the PVT1 IR survey

Data analysis

Data analysis was performed at the same way of PVT1 one. Effort spent by human operators was 0:30 hours for the data upload and 1:30 hours for data management.

EPV survey summary

Next table resumes the human time effort in the EPV survey.

PV Plant	PVT2 “Vis Solis 1”		
Date	October 2017	IR acquisition	EPV
		ACTION	
TIME (men hour)		Description of the processing	
4:40		IR acquisition	
0:30		Upload data to SC	
1:30		Raw data management	
TOTAL: 6:40			

Table 3-20 Timetable of EPV survey operations – PVT2 “Vis Solis 1”



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3.4.3 EPV – PVT3 “FRATESOLE”

Pre – flight operations

The IR survey with EPV was carried out the 05/10/2017. The IR survey was performed in the same way of operations carried out for PVT1. At 08:57, the weather was cloudy and partially fog. The temperature on the ground was 17° C and the solar radiation was about 91 W/m². These measurements were acquired just before the survey operations start; therefore, they could be changed during the operations. Nevertheless, weather conditions lasted stationary during the day and then solar radiation could be considered quite constant.

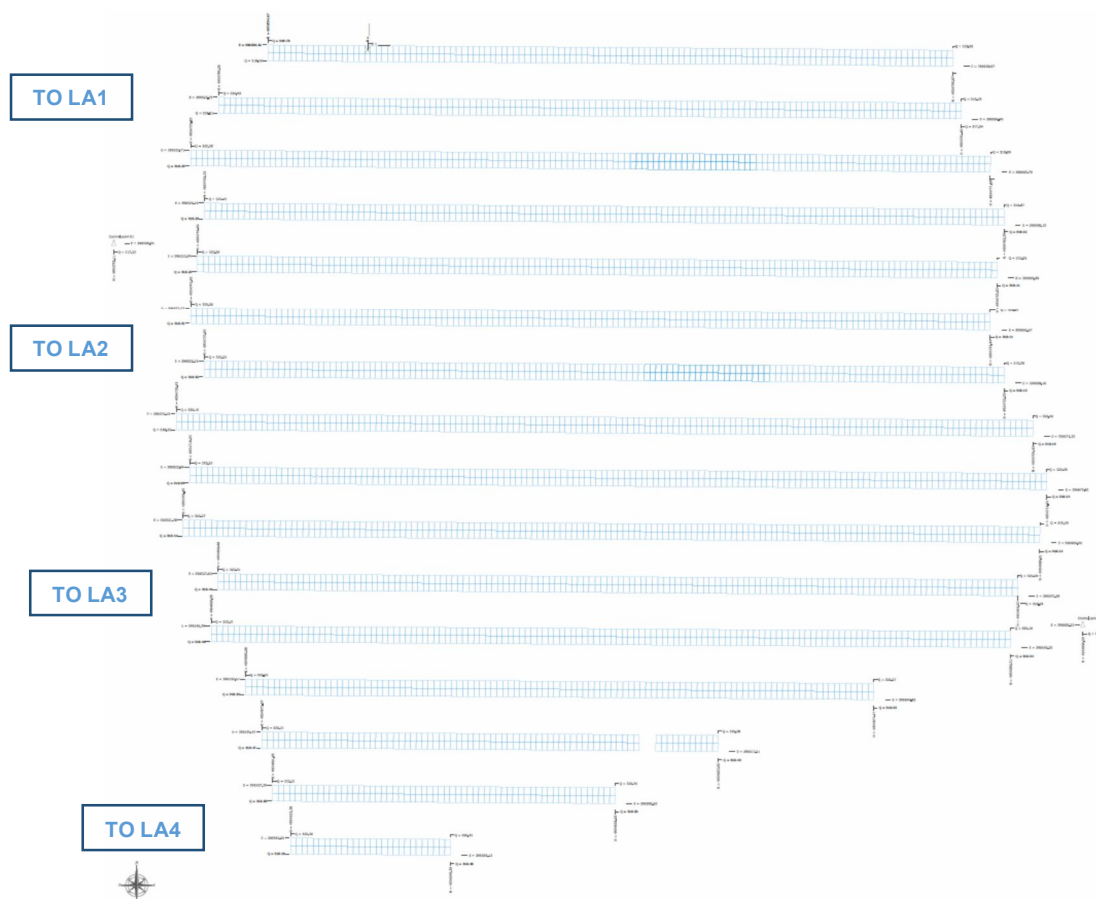
The ground station antenna was positioned on a Ground Point (GP) of the PV plant, surveyed with Topcon HyperPro GNSS instrument.

Flight operations IR survey

Flight operations started at 9:14. The IR operations were performed in this way:

- OP 2 piloted manually the RPAS over the plant checking in real time the data collecting by the IR sensor installed on the RPAS platform, through a monitor located near the RPAS radio-control.
- OP 1 performed a visual control of flight operations.

Four flights were performed in order to survey the whole plant. In the next Figure, a layout of flight operation is showed.





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Figure 3-43-Easy OV flights, take – off and land, (TO-LA) during the PVT3 IR survey

The operations lasted 1:45 hours. The time spent for IR image acquisition (flight operations) was 0:57 hours. Consequently, about 55% of total time was dedicated to logistic operations. In Table 3-17, a summary of IR survey operations is reported.

PV Plant	PVT3 “Fratesole”			
Date	05/10/2017		IR SURVEY	EPV
TIME (hour:min)			ACTION	
absolute	relative	partial	IR acquisition	Logistics
9:05	0:00	0:09		Temperature and IR measurements, ground station antenna location, RPAS assembly.
9:14	0:09	0:15	Take-off. Flight 1 over rows 16-13	
9:29	0:24	0:03		Landing flight 1 – change battery
9:32	0:27	0:16	Take-off. Flight 2 over rows 12-9	
9:48	0:43	0:12		Landing flight 2 – Place of RPAS, ground station antenna.
10:00	0:55	0:05		Temperature and IR measurements.
10:05	1:00	0:16	Take-off. Flight 3 over rows 8-5	
10:21	1:16	0:09		Landing flight 3 – change battery
10:30	1:25	0:10	Take-off. Flight 4 over rows 4-1	
10:40	1:35	0:10		Landing flight 4. Place of RPAS, ground station antenna.
10:50	1:45		END OF SURVEY	

Table 3-21 Timetable of EPV survey operations – PVT3

Data analysis

Data analysis was performed at the same way of PVT1 one. Effort spent by human operators was 0:30 hours for the data upload and 1:30 hours for data management.

EPV survey summary

Next table resumes the human time effort in the EPV survey.

PV Plant	PVT3 “Fratesole”		
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Date	October 2017	IR acquisition	EPV
		ACTION	
TIME (men hour)		Description of the processing	
3:30		IR acquisition	
0:30		Upload data to SC	
1:30		Raw data management	
TOTAL: 5:30			

Table 3-22 Timetable of EPV survey operations – PVT3 “Fratesole”



3.5 EXECUTION OF IRSM SURVEYS ON THE PVT IN THE SAME ENVIRONMENTAL CONDITION OF EPV SURVEY (IRSM-EPV)

In order to collect IR data with standard methodology in the same environmental conditions of EPV ones, three thermographic surveys have been carried out. For safety reasons, during the EPV survey, it was not possible to access on the plant PVT1 "Perla". Therefore, this section only refers to PVT2 "Vis Solis 1" and PVT3 "Fratesole" IR surveys.

3.5.1 IRSM –EPV PVT2 “VIS SOLIS 1”

IR survey planning.

IR survey was planned the 04/10/2017. Two qualified operators were designated by ENTEC spa for the survey operations: Ing. Mattia Bussi and Christian Vismara. The instrument used for the IR survey is a thermal camera model FLIR T440.

IR survey

One row of the plant was inspected by the operators: row number 13. IR survey operations started at 11:30 am, where IR measured was 683 W/m².

Summary of IR operations.

In the following table, the summary of anomalies detected by IRSM for row 13, composed of 244 modules that will be compared with EPV survey is showed

Anomaly	ΔT	Recommended action	n° of damaged modules	% of damaged modules
Hot strip	/	Reparation / module replacement	21	8,6%
Hot spot	$\Delta T \geq 25\text{ }^{\circ}\text{C}$	Module replacement	6	2,5%
TOTAL			27	11.1%

Table 3-23 Statistic of anomalies on PVT2 “Vis Solis 1”

3.5.2 IRSM – EPV PVT3 “FRATESOLE”

IR survey planning.

IR survey was planned the 05/10/2017. Two qualified operators were designated by ENTEC spa for the survey operations: Ing. Mattia Bussi and Christian Vismara. The instrument used for the IR survey is a thermal camera model FLIR T440.

IR survey



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Row number 5 was inspected the operators. Survey operations started at 9:00 am, where radiation measured was 91 W/m².

Summary of IR operations.

In the following table, the summary of anomalies detected by IRSM for row 5, composed by 272 modules, that will be compared with EPV survey, is showed

Anomaly	ΔT	Recommended action	n° of damaged modules	% of damaged modules
Hot strip	/	Reparation / module replacement	1	0,4%
Hot spot	$\Delta T \geq 25\text{ }^{\circ}\text{C}$	Module replacement	21	7,1%
TOTAL	/		22	8.1%

Table 3-24 Statistic of anomalies on PVT3 "Fratesole"



3.6 PERFORMANCE ANALYSIS OF EPV OUTPUT DATA

Performance analysis of EPV is carried out through the verification of output data provided by the system for the PVT, with the user requirements. Finally, for each data, a performance indicator is produced.

3.6.1 EPV OUTPUT DATA

The output data of EPV can be classified as:

- data collected in the SC platform;
- technical report.

3.6.2 EPV OUTPUT DATA. CRITERIA OF EVALUATION

In the next sections, output data provided by EPV for PVT will be analysed, in order to evaluate these criteria of evaluation:

- Usability. EPV output data have to be usable. Final user of EPV (PV plant owner, maintainer) can access to the data through the informatics platform (VTE), furthermore he can consult a technical report.
- Fullness. EPV has to provide full data of PV plant surveyed. The whole PV plant has to be detected by the system and represented on a graphical layout. The anomalies surveyed through IR acquisitions has to be detected, classified and represented in the output data, as graphical symbol on a layout; furthermore they has to be illustrated on a technical report.
- Reliability. EPV data have to be reliable. The geometric position of PV modules has to be accurate according to the tolerance required (50 cm). The detection and classification of anomalies has to be complete and the reliability of this procedure has to be comparable with the standard procedure one.

3.6.3 PERFORMANCE INDICATOR

For each output data and criteria just illustrated, a performance indicator is defined as score:

- 1. No performance;
- 2. Poor performance;
- 3. Enough performance;
- 4. Good performance;
- 5. Excellent performance.

Performance indicator is attributed by the ENTEC spa team after a deep analysis of the SC platform data concerning the three PVT. Two thermographic operators performed a critical analysis of data delivered on SC platform and report. Furthermore, according to the criteria of evaluation and the performance indicators just mentioned, they delivered a judgment, which can be considered as a qualitative opinion expressed by a qualified and expert operator that represents the “mean user” of the EASY PV system.



3.6.4 PERFORMANCE ANALYSIS – SC PLATFORM DATA

SC platform data are composed by:

- Geometric entities concerning:
 - o Point entity: module centre;
 - o Polygon entity: module edge;
- Metadata associated to geometric entities, composed by thermal images, identification and classification of anomalies.

Performance analysis of SC platform data has been carried out on a sample of modules for each PVT plant. In particular:

- PVT1 “Perla”

The performance analysis has been computed on roof A, composed by 166 modules.

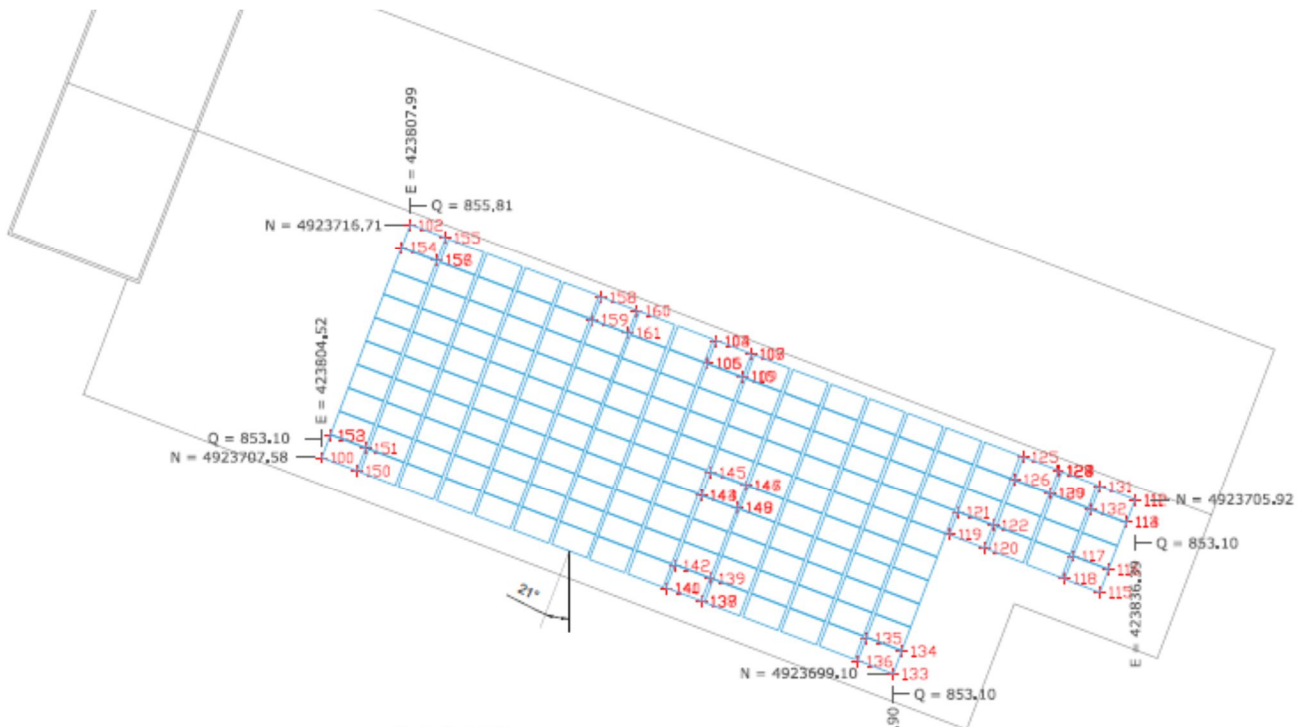


Figure 3-44 PVT1. Performance test area

- PVT2 “Vis Solis”

The performance analysis has been computed on row 13, composed by 244 modules.



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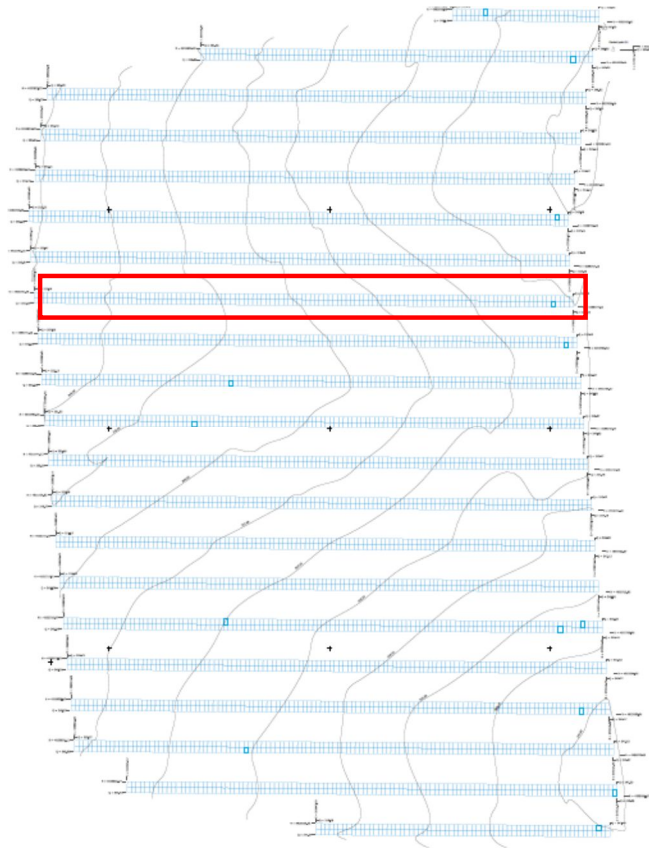


Figure 3-45 PVT2. Performance test area

- PVT3 “Fratesole”

The performance analysis has been computed on row 5, composed by 272 modules.

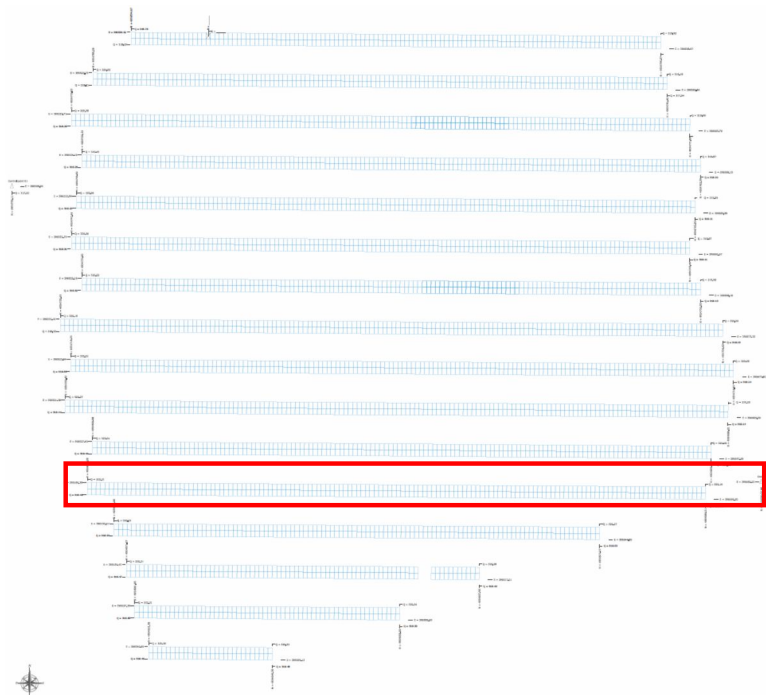


Figure 3-46 PVT3. Performance test area



3.6.4.1 SC data usability

SC output data are organised in a user-friendly interface that allows to save different missions and to assign to each one information about the survey operations and environmental conditions. For each mission it is possible to visualize the PV plant on a “map” layer (google map). Each PV module is represented by a polygon with an associated ID. Modules affected by anomalies are represented in red colour, in order to supply a first graphical indication of damaged modules. Modules are also recorded in a list. Module list and graphical layout are linked to pictures, which include the identification and classification of anomalies. This tool is an added value for the final user, who can visualize and manage data in a user-friendly way. Then, this informatics approach to the data management is an important improvement as to the operation procedures of IRSM, which can optimize time effort in the O&M PV plant management.

These features allow to attribute a performance score and to advise some improvements:

PERFORMANCE LEVEL: 4

TO IMPROVE:

- tool of image visualization. In the current version, the images associated to an anomaly are “static” images. It could be better to manage the image visualization (zoom, pan) and to perform queries (computation of temperature for a single point on the image, computation of mean temperature for a selected image area);
- map tool. In the current version, the geometric entities extracted by EPV are represented on SC platform, but they cannot be exported. It could be better to insert an “import – export tool”, in order to allow a management of geometric data (overlap between geometric entities from VTE and vector or raster data of “as built” PV plant).

3.6.4.2 SC data fullness

3.6.4.2.1 Geometric entities

Performance analysis of raw geometric entities fullness has been carried out on some sample modules for each PVT, in order to produce a synthetic statistical analysis. The parameter (F_G) used to assess the fullness is:

$$F_G = \frac{N_{M-EPS}}{N_M}$$

Where:

N_{M-EPS} = modules number identified by EPV in the sample data.

N_M = modules number of PV plant sample data.

The F_G value range is:

$F_G < 1$. This value means that the extraction of module geometry is not complete and some modules are not detected.

$F_G = 1$. This value means that the extraction of module geometry is complete.



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$F_G > 1$. In this case, EPV detects a number of modules greater than the real one. This means that some modules are wrongly detected (dubious identification) or that some shapes which do not represent a PV module (shadows) are computed.

- PVT1 – geometric entities fullness

Geometric entities fullness analysis of PVT 1 has been computed on roof A, composed by 166 modules. Next table shows the computation of F value.

Performance analysis	Geometric entities fullness	
PV Plant	PV1 “Perla” – Roof A	
Modules Number N_M	EPV Modules Number N_{M-EPV}	Geometric Fullness F_G
166	166	1

Table 3-25 Geometric entities fullness of PVT1 “Perla”

Next figure shows the geometric layout automatically extracted by EPV.

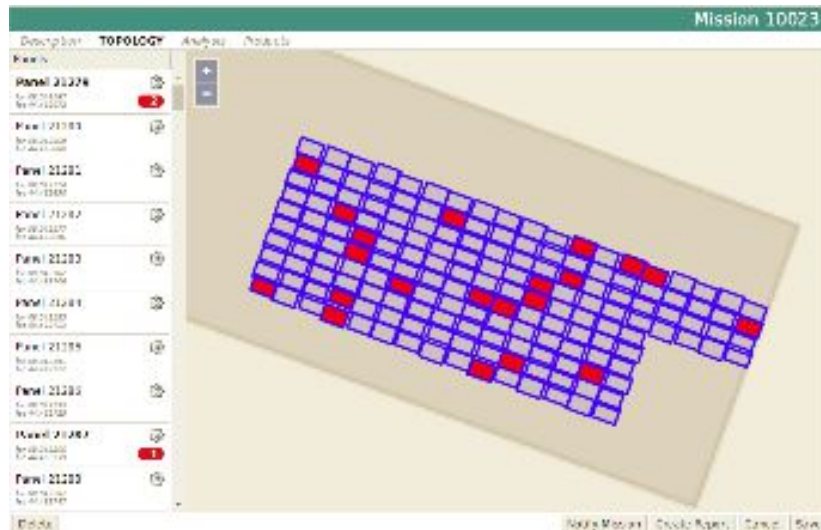


Figure 3-47 PVT1. Graphical layout automatically extracted by EPV

- PVT2 – geometric entities fullness

Geometric entities fullness analysis of PVT 2 has been computed on row 13, composed by 244 modules. In the table is showed the computation of F value.



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Performance analysis	Geometric entities fullness	
PV Plant	PV1 “Perla” – Roof A	
Modules Number N_M	EPV Modules Number N_{M-EPV}	Geometric Fullness F_G
244	244	1

Table 3-26 Geometric entities fullness of PVT2 “Perla”

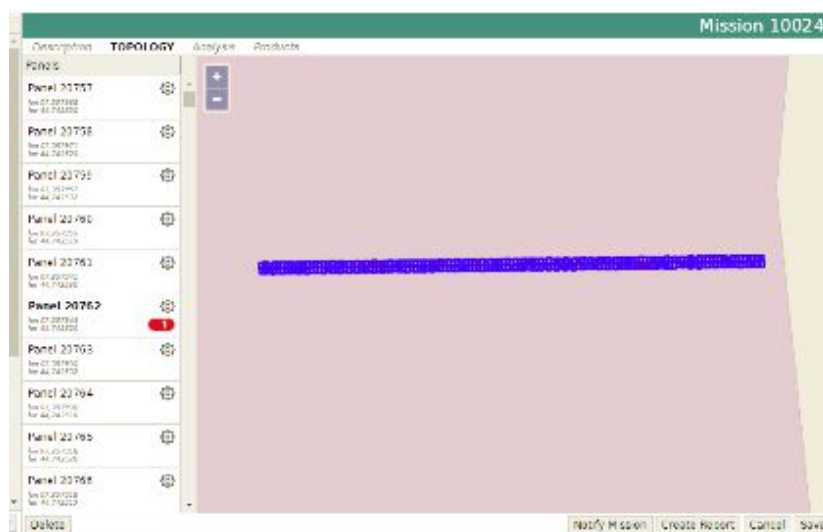


Figure 3-48-PVT2. Graphical layout automatically extracted by EPV

- PVT3 – geometric entities fullness

Geometric entities fullness analysis of PVT 3 has been computed on row 5, composed by 272 modules. In the table is showed the computation of F value.

Performance analysis	Geometric entities fullness	
PV Plant	PV3 “Fratesole” – Row 5	
Modules Number N_M	EPV Modules Number N_{M-EPV}	Geometric Fullness F_G
272	272	1

Table 3-27 Geometric entities fullness of PVT3 “Fratesole”



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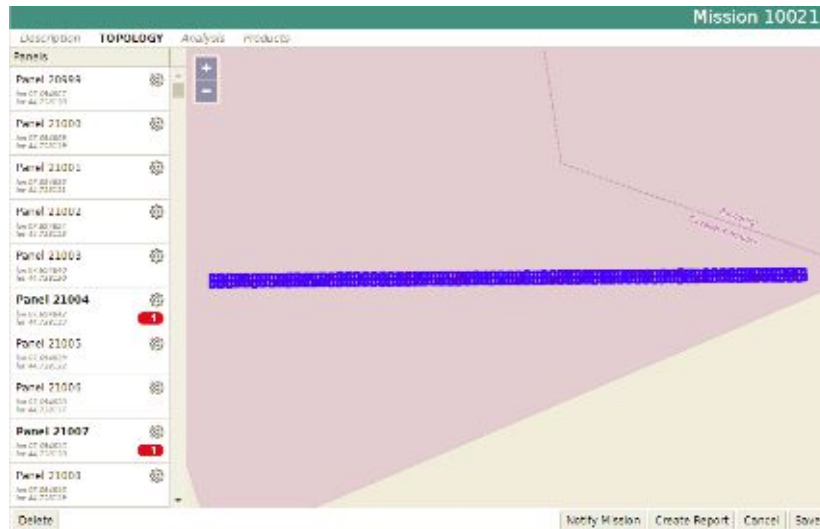


Figure 3-49 PVT3. Graphical layout automatically extracted by EPV

The full automatic extraction of PV module edge is a remarkable improvement in O&M activities. Operators can consult layout on PV plants which are geometrically unknown, or compare “as built” layout with the one surveyed by EASY PV. These features allow attributing the following performance score

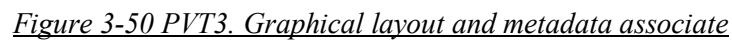
PERFORMANCE LEVEL: 5

TO IMPROVE: nothing

3.6.4.2.2 Metadata

The metadata fullness concerns the availability of metadata associated to each module detected by EPV. The fullness is fulfilled when, for each module, it is possible to associate a set of metadata, which allow to locate the module; to define and classify an anomaly and to perform temperature query.

Metadata are reported in a window of VTE platform. Each panel is associated to an ID number. Furthermore, the geographic coordinates of the PV module centre are reported. Modules with anomalies are signalized with a red warning. The operator can click on the warning and visualize the window metadata associated, composed by an IR image of the PV module damaged and the anomaly classification, reported in a record on the left side of the window.



- Identification of anomaly on the IR image. On the image associated to each ID module is not signalized the position of anomaly (see [Figure 3-50](#)). Consequently, in case of defects located on neighbouring modules, it is not possible to link PV module and anomaly.

- **Position of PV module.** The position of a PV module is referred to geographic coordinates assessed by the EPV algorithms. In some cases, it is useful to have a “relative position” of each PV module in terms of row and column. Therefore, it is recommended to add this metadata on the SC platform.

PERFORMANCE LEVEL: 3

3.6.4.3.1 Geometric entities

$$CE95 = \frac{2.4477}{\sqrt{2}} RMSE_r = 1.7308 \sqrt{\frac{\sum_{i=1}^n (X_{m,i} - X_{r,i})^2 + (Y_{m,i} - Y_{r,i})^2}{n}}$$

X_m, Y_m coordinates of centre module surveyed by EPV;

X_r, Y_r coordinates of Check Pointes (CP) surveyed with GNSS double frequency receiver;



n : number of check points.

CE_{95} must be lower than the system tolerance (50 cm)

Precision assessment has been carried out considering local reference systems for the definition of X_m , X_r , coordinate system.

- PVT1 – geometric entities reliability

The precision analysis has been computed on roof A, composed by 166 modules, which corresponds to 664 edge points and 166 module centre.

On this roof 48 edge points were surveyed with double frequency RTK Topcon receiver. From these points, the geometry of plant has been computed. In order to estimate CE_{95} , 20 centre module points (about 12% of 166 modules) have been used.

First, a Local Cartesian System (X , Y) has been defined to remove bias due to the EASY PV positioning in a global reference system (E_{EPV} , N_{EPV}). The Local System has the origin (X_0 , Y_0) in the centre module 10-1 (row 10 – column 1 of the PV plant panel matrix) surveyed by GNSS technique. X axis is directed along the row 10 of PV plant panel matrix. Y axis is normal to X axis (see [Figure 3-51](#)). Then, a geometrical constraint composed by a rototranslation of EASY PV reference system in the Local System has been forced: the position of panel 10-1 in the EASY PV reference system ($E_{EPV10-1}$, $N_{EPV10-1}$). has been translated to the Local System origin (X_0 , Y_0), then the E_{PV} axis has been rotated to overlap the X axis.

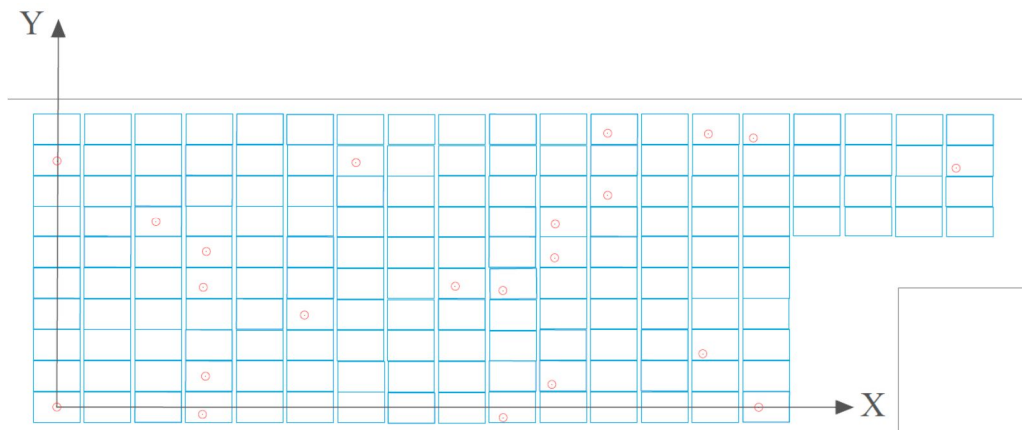


Figure 3-51 PVT1. Definition of local reference system X , Y . In blue PV module edges surveyed by GNSS. Red circles represent PV module centre detected by EASY PV system



ID	n	CP		EPV		$X_m - X_r$	$Y_m - Y_r$	d	$(X_m - X_r)^2$	$(Y_m - Y_r)^2$	Σ
		X_m	Y_m	X_r	Y_r						
1-12	1	17.64	8.82	17.43	8.67	0.21	0.15	0.25	0.04	0.02	0.06
2-1	2	0.00	7.79	-0.01	7.82	0.00	-0.03	0.03	0.00	0.00	0.00
1-14	3	20.85	8.83	20.62	8.65	0.23	0.18	0.29	0.05	0.03	0.09
1-15	4	22.45	8.83	22.04	8.52	0.41	0.31	0.51	0.17	0.10	0.27
2-7	5	9.60	7.82	9.46	7.74	0.14	0.08	0.16	0.02	0.01	0.03
4-3	6	3.21	5.87	3.13	5.84	0.08	0.03	0.08	0.01	0.00	0.01
4-11	7	16.03	5.88	15.77	5.77	0.25	0.11	0.28	0.06	0.01	0.08
3-12	8	17.63	6.86	17.53	6.70	0.10	0.16	0.19	0.01	0.03	0.04
5-4	9	4.81	4.89	4.72	4.90	0.09	-0.01	0.09	0.01	0.00	0.01
5-11	10	16.02	4.91	15.75	4.80	0.28	0.11	0.30	0.08	0.01	0.09
6-4	11	4.82	3.92	4.63	3.77	0.19	0.15	0.24	0.03	0.02	0.06
6-9	12	12.82	3.91	12.61	3.80	0.22	0.11	0.24	0.05	0.01	0.06
6-10	13	14.45	3.90	14.11	3.67	0.34	0.23	0.41	0.11	0.05	0.17
7-6	14	8.03	2.94	7.83	2.89	0.20	0.05	0.20	0.04	0.00	0.04
8-14	15	20.85	1.98	20.44	1.68	0.41	0.31	0.51	0.17	0.09	0.26
9-4	16	4.82	0.98	4.70	0.97	0.12	0.02	0.12	0.01	0.00	0.01
9-11	17	16.03	1.01	15.67	0.71	0.36	0.30	0.47	0.13	0.09	0.22
10-1	18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10-4	19	4.82	0.00	4.60	-0.24	0.22	0.24	0.32	0.05	0.06	0.10
10-10	20	14.43	0.02	14.12	-0.34	0.31	0.35	0.47	0.09	0.13	0.22
										RMSE	0.300
										CE95	0.519

Table 3-28 Statistical analysis of PVT1 “Perla”

Results showed in Table 3-28 allow to conclude that in CE95 error (0.52 m) is higher than the system tolerance. The maximum distance deviation between CP and EPV points (column d in the table) is 0.51 m. This means that sample data are not affected by gross errors. Two points have a distance deviation upper than 0.50 m (0.51 – 0.51 m).

- PVT2 – geometric entities reliability

The precision analysis has been computed on row 13, composed by 244 modules, which corresponds to 976 edge points and 244 modules centre.

On this sample plant 12 edge points were surveyed with double frequency RTK Topcon receiver. From these points, the geometry of plant has been computed. 26 centre module points (about 10% of 244 modules) have been used for the CE95 computation.

The definition of Local Reference System has been performed with the same criteria used for the PVT1 . In this case, local reference system has origin (X_0 , Y_0) in the centre module 1-2 (row 1 – column 2 of the PV plant panel matrix) surveyed by GNSS technique. X axis is directed along the row 1 of PV plant panel matrix. Y axis is normal to X axis. EASY PV reference system (E_{EPV} , N_{EPV}).has been rototraslated in the X, Y system, in order to have the position of module 1-2 (E_{EPV1-2} , N_{EPV1-2}) in the local system origin (X_0 , Y_0) and E_{EPV} axis overlapped to the X axis.



ID	n	CP		EPV		Xm-Xr	Ym-Yr	d	(Xm-Xr) ²	(Ym-Yr) ²	Σ
		Xm	Ym	Xr	Yr						
1-2	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1-27	2	25.33	-0.15	25.19	0.02	0.13	-0.17	0.22	0.02	0.03	0.05
1-28	3	26.48	0.07	26.19	0.02	0.28	0.05	0.29	0.08	0.00	0.08
1-30	4	28.51	-0.05	28.20	0.01	0.31	-0.06	0.32	0.10	0.00	0.10
2-30	5	28.23	-1.50	28.20	-1.26	0.03	-0.24	0.24	0.00	0.06	0.06
2-42	6	40.53	-1.49	40.40	-1.24	0.13	-0.25	0.28	0.02	0.06	0.08
1-44	7	42.73	0.09	42.40	0.04	0.33	0.04	0.33	0.11	0.00	0.11
1-53	8	51.70	-0.16	51.55	0.04	0.15	-0.20	0.25	0.02	0.04	0.06
2-64	9	62.77	-1.36	62.60	-1.24	0.16	-0.13	0.21	0.03	0.02	0.04
1-65	10	63.85	0.00	63.61	0.05	0.24	-0.05	0.25	0.06	0.00	0.06
1-72	11	71.07	0.05	70.76	0.05	0.31	-0.01	0.31	0.10	0.00	0.10
1-75	12	74.00	-0.08	73.74	0.06	0.26	-0.14	0.29	0.07	0.02	0.09
2-76	13	74.99	-1.43	74.74	-1.22	0.24	-0.21	0.32	0.06	0.04	0.10
1-77	14	76.00	-0.05	75.75	0.06	0.25	-0.11	0.28	0.06	0.01	0.08
2-81	15	80.24	-1.17	79.86	-1.21	0.38	0.05	0.38	0.14	0.00	0.15
1-83	16	82.11	-0.01	81.86	0.07	0.24	-0.08	0.26	0.06	0.01	0.07
1-85	17	84.19	-0.09	83.87	0.07	0.32	-0.16	0.36	0.10	0.03	0.13
2-87	18	86.41	-1.22	85.88	-1.21	0.53	-0.01	0.53	0.28	0.00	0.28
2-91	19	90.34	-1.15	89.99	-1.20	0.35	0.05	0.36	0.13	0.00	0.13
2-92	20	91.28	-1.41	90.99	-1.20	0.29	-0.21	0.36	0.08	0.04	0.13
2-93	21	92.46	-1.25	92.00	-1.20	0.46	-0.05	0.46	0.21	0.00	0.21
2-94	22	93.35	-1.36	93.00	-1.20	0.35	-0.16	0.39	0.12	0.03	0.15
2-102	23	101.45	-1.24	101.12	-1.19	0.33	-0.06	0.33	0.11	0.00	0.11
2-103	24	102.58	-1.13	102.12	-1.19	0.45	0.05	0.46	0.21	0.00	0.21
1-113	25	112.64	-0.02	112.25	0.11	0.39	-0.13	0.41	0.15	0.02	0.17
2-119	26	118.80	-1.10	118.27	-1.15	0.53	0.05	0.54	0.29	0.00	0.29
										RMSE	0.34
										CE95	0.59

Table 3-29 Statistical analysis of PVT2 “Vis Solis”

Also in PVT2, CE95 error (0.59 m) is very near to the system tolerance. The maximum distance deviation between CP and EPV points (column *d* in the table) is 0.54 m. Two points have a distance deviation upper than 0.50 m (0.54 – 0.53 m).

- PVT3 – geometric entities reliability

The precision analysis has been computed on row 5, composed by 272 modules, which corresponds to 1088 edge points and 272 module centre.

On this sample plant 10 edge points were surveyed with double frequency RTK Topcon receiver. From these points, the geometry of plant has been computed. 30 centre module points (about 11% of 272 modules) have been used for the CE95 computation.

The definition of Local Reference System has been performed with the same criteria used for the previous PVTs . In this case, local reference system has origin (X₀, Y₀) in the centre module 2-6 (row 2 – column 6 of the PV plant panel matrix) surveyed by GNSS technique. X axis is directed along the row 2 of PV plant panel matrix. Y



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axis is normal to X axis. EASY PV reference system (E_{EPV} , N_{EPV}).has been rototraslated in the X , Y system, in order to have the position of module 2-6 (E_{EPV2-6} , N_{EPV2-6}) in the local system origin (X_0 , Y_0) and E_{EPV} axis overlapped to the X axis.

ID	n	CP		EPS		$X_m - X_r$	$Y_m - Y_r$	d	$(X_m - X_r)^2$	$(Y_m - Y_r)^2$	Σ
		X_m	Y_m	X_r	Y_r						
2-6	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1-7	2	1.04	1.35	1.02	1.42	0.03	-0.08	0.08	0.00	0.01	0.01
2-9	3	3.22	0.09	3.04	0.00	0.17	0.09	0.20	0.03	0.01	0.04
2-15	4	9.44	0.02	9.21	0.00	0.23	0.02	0.23	0.05	0.00	0.05
1-17	5	11.38	1.29	11.23	1.42	0.15	-0.12	0.19	0.02	0.02	0.04
1-23	6	17.45	1.35	17.40	1.42	0.05	-0.07	0.09	0.00	0.01	0.01
2-24	7	18.50	-0.13	18.41	0.00	0.09	-0.13	0.16	0.01	0.02	0.02
1-28	8	22.71	1.41	22.47	1.42	0.25	-0.01	0.25	0.06	0.00	0.06
1-35	9	29.81	1.27	29.64	1.42	0.16	-0.16	0.23	0.03	0.03	0.05
1-46	10	41.34	1.47	40.88	1.43	0.46	0.04	0.46	0.21	0.00	0.21
1-48	11	43.39	1.36	42.91	1.43	0.49	-0.07	0.49	0.24	0.01	0.24
2-48	12	43.13	-0.12	42.91	0.01	0.23	-0.12	0.26	0.05	0.02	0.07
1-49	13	44.18	1.34	43.92	1.43	0.26	-0.09	0.27	0.07	0.01	0.08
2-49	14	43.89	-0.22	43.92	0.01	-0.03	-0.22	0.22	0.00	0.05	0.05
2-53	15	48.40	0.02	47.98	0.01	0.42	0.02	0.42	0.18	0.00	0.18
2-57	16	52.64	-0.02	52.11	0.01	0.53	-0.03	0.53	0.28	0.00	0.28
1-58	17	53.56	1.41	53.13	1.43	0.43	-0.02	0.43	0.18	0.00	0.19
1-59	18	54.48	1.32	54.14	1.43	0.34	-0.11	0.36	0.12	0.01	0.13
1-60	19	55.57	-0.15	55.16	0.00	0.40	-0.15	0.43	0.16	0.02	0.18
2-72	20	67.93	-0.14	67.44	-0.01	0.48	-0.13	0.50	0.24	0.02	0.25
2-81	21	76.04	-0.08	76.65	-0.02	-0.61	-0.06	0.61	0.37	0.00	0.38
2-82	22	77.28	0.04	77.66	-0.02	-0.38	0.06	0.39	0.14	0.00	0.15
1-85	23	80.27	1.44	80.70	1.40	-0.44	0.04	0.44	0.19	0.00	0.19
1-89	24	84.42	1.43	84.84	1.41	-0.42	0.02	0.42	0.18	0.00	0.18
1-93	25	88.60	1.38	88.90	1.41	-0.29	-0.02	0.29	0.08	0.00	0.09
2-95	26	90.44	-0.18	90.92	-0.01	-0.48	-0.17	0.51	0.23	0.03	0.26
1-98	27	93.56	1.25	93.96	1.41	-0.40	-0.16	0.43	0.16	0.03	0.19
1-103	28	98.87	1.37	99.11	1.41	-0.24	-0.04	0.24	0.06	0.00	0.06
1-110	29	105.97	1.17	106.21	1.41	-0.24	-0.25	0.35	0.06	0.06	0.12
1-111	30	107.06	1.37	107.31	1.41	-0.24	-0.04	0.25	0.06	0.00	0.06
										RMSE	0.36
										CE95	0.62

Table 3-30 Statistical analysis of PVT3 "Fratesole"

In PVT3, CE95 error (0.62 m) is near to the system tolerance. The maximum distance deviation between CP and EPV points (column d in the table) is 0.61 m. Three points have a distance deviation upper than 0.50 m (0.53 – 0.51 – 0.61 m).

In conclusion, the statistical analysis of the PVT has supplied CE95 error higher than the tolerance required. This result is not completely negative for these reasons:

- in all the data sets no gross errors have been located;
- although the CE95 is above the tolerance limit, the final users (thermographic experts of Entec spa) have not been problems in the identification of PV module positions on the three PVT;



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- Tests have been performed in not ideal environmental conditions. Cloudy weather affects the IR acquisitions and consequently the performances of automatic feature extraction algorithms.
- Tests have been carried out with EASY PV system equipped with single frequency UBLOX receiver. Now, [RD 3] system is equipped with a double frequency receiver; therefore, it is probable to expect an improvement of precision and a reduction of CE95 below the requested tolerance.

Finally, considering the previous system version (UBLOX), the performance level cannot be adequate to the tolerance requested. Nevertheless, the last important improvements produced (double frequency GNSS onboard) allow to declare that the system can provide enough precision performances. Then, it is possible to deliver the following performance level and to suggest some improvements.

PERFORMANCE LEVEL: 3

TO IMPROVE:

- Graphical output data provides row geometric entities estimated by EPV algorithms. It is recommended to perform a post processing geometric process of the geometric entities, in order to supply a graphical output composed by regular shapes of PV module.

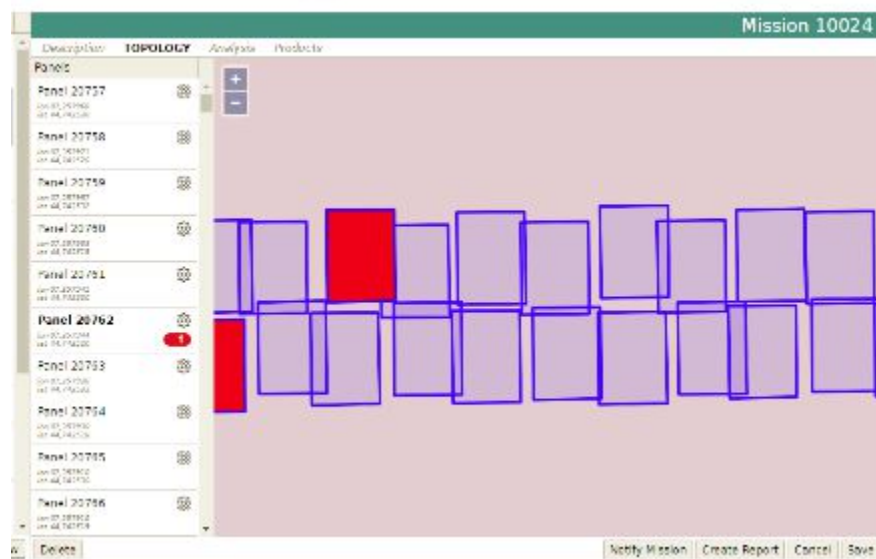


Figure 3-52 Particular of geometric output data

- It is recommended to perform other tests with the last GNSS receiver configuration (RTK double frequency RTKITE receiver) in order to confirm the performance level just provided.

3.6.4.3.2 Metadata.

Reliability of metadata associated to a geometric entity (thermal image of PV module, with anomaly association) is assessed by means of a comparison between results provided by EPV on the three PVT and:



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- results provided by IR acquisitions carried out with IRSM in standard environmental conditions;
- results provided by IR acquisitions carried out with IRSM in the same environmental conditions of EPV acquisitions (IRSM – EPV);
- results provided by the analysis of IR images acquired by EPV and analysed by a thermographic qualified operator (EPV-TO).
- PVT1 – metadata reliability

The analysis of metadata reliability has been performed on the sample data composed by the panels located on roof A. In this case, IRSM – EPV data are not available, due to safety problem during the EPV acquisitions.

In the next table, a summary of the analysis is reported.

		ACQUISITION METHODOLOGY															
ANOMALY	IRSM		IRSM-EPV		EPV-TO		EPV										
	Nr	Nr	%IRSM	Nr	%IRSM-EPV	Nrtot			NrCP			NrWP			NrFP		
						N	%IRSM-EPV	%EPV-TO	N	%IRSM-EPV	%EPV-TO	N	%IRSM-EPV	%EPV-TO	N	%IRSM-EPV	%EPV-TO
HOT STRIP	18	/	/	20	111	20	/	100	20	/	100	0	/	0	0	/	0
HOT SPOT	9	/	/	2	22	1	/	50	1	/	50	0	/	0	0	/	0
HOT RIBBON WELDING	3	/	/	0	0	0	/	/	0	/	0	0	/	/	0	/	/
TOTAL	30	/	/	22	73	21	/	95	21	/	95	0	/	0	0	/	0

Table 3-31 Statistical analysis of anomalies detected on PVT1 “Perla”

In the table cells are reported the number of panels affected by anomalies (described in the first column), with the different survey techniques. About EPV, the number of anomalies detected are classified as:

- N_{rtot} . Total number of faulty modules detected by EPV;
- N_{rCP} . Number of anomalies detected by EPV in a geometric correct position;
- N_{rWP} . Number of anomalies detected by EPV in a geometric wrong position;
- N_{rFP} . Number of false anomalies detected by EPV. These are faults located by EPV, but non-existent.

Test confirm that the anomaly detection through IR analysis depends on the solar radiation conditions and the distance of acquisition. In fact, in EPV-TO only 2 hot-spot are located by the operator (caused by the lower solar radiation), furthermore no hot ribbon weldings are detected (caused both lower solar radiation and distance of acquisition). Nr. 20 hot strips have been located in EPV-TO, 2 defects more than detected by IRSM. This means that, during the period spent between the two acquisitions, 2 new anomalies are raised.

The EPV algorithm has supplied good results. All the hot strips have been correctly detected (rate of 100%, Figure 3-53).

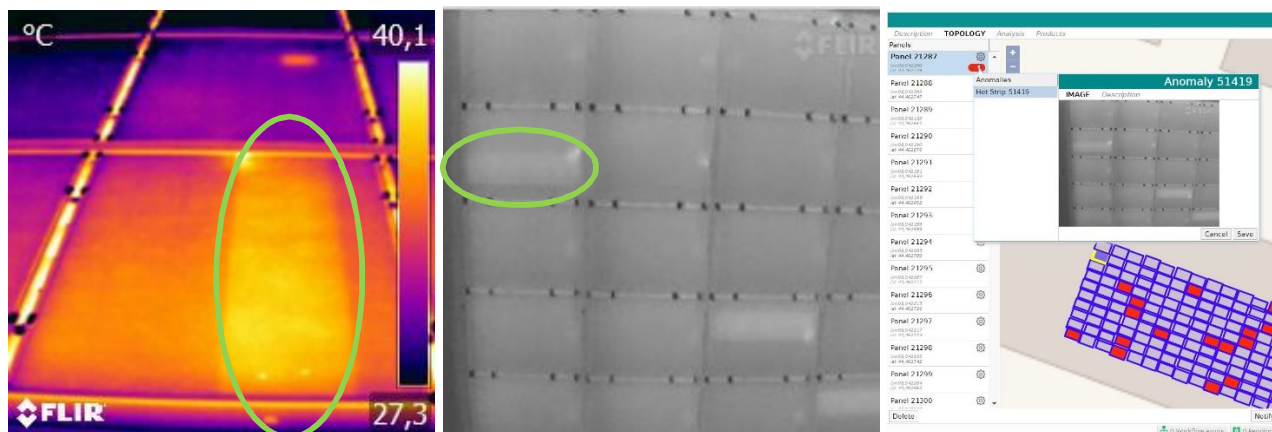


Figure 3-53 Right hot strip detection (IRSM, EPV-TO, EPV)

One hot spot has not been automatically located by EPV, due to the low resolution of IR image acquired by the system (Figure 3-61).

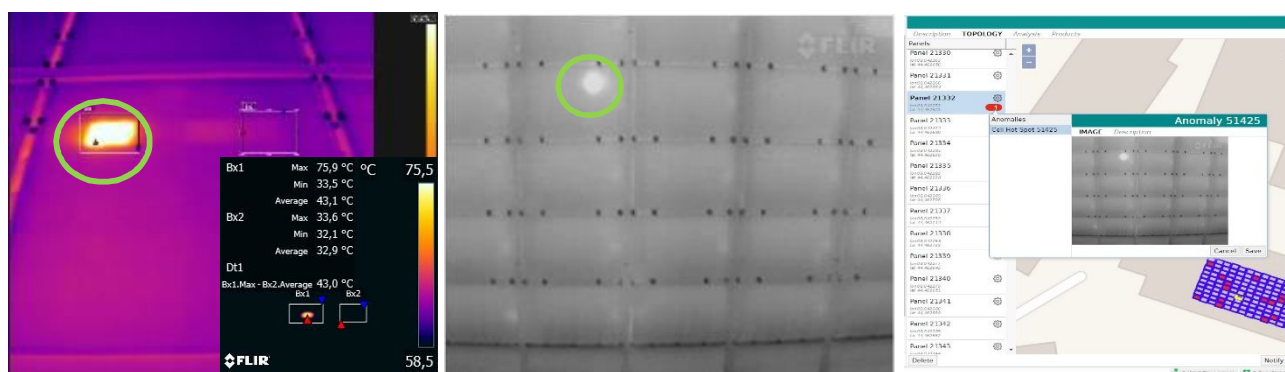


Figure 3-54 Right hot spot detection (IRSM, EPV-TO, EPV)

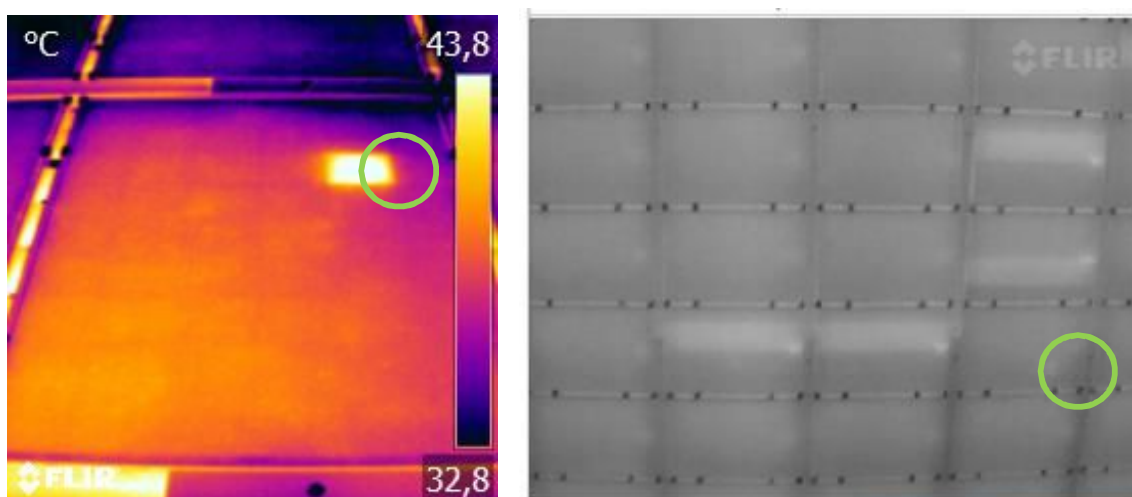


Figure 3-55 Hot spot surveyed by IRSM and EPV-TO, but not identified by the automatic algorithm

No hot ribbon welds have been automatically detected. This problem is due to the poor information collected by the IR sensor installed in the RPAS system.



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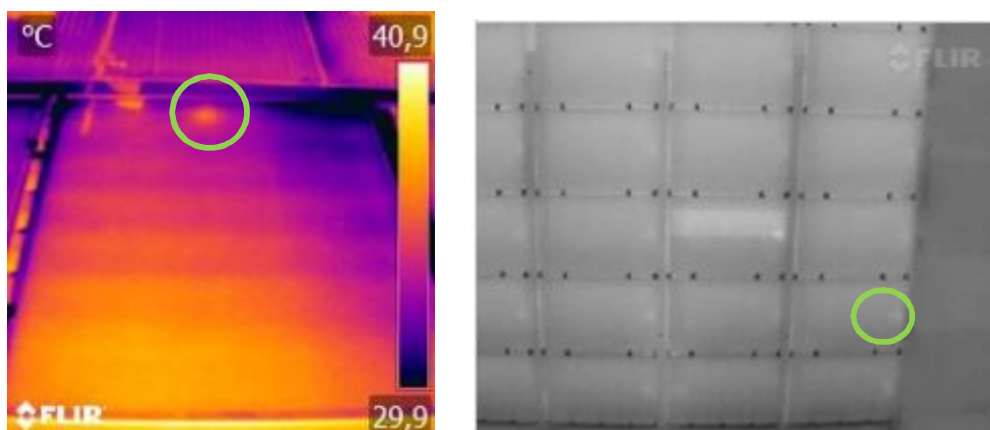


Figure 3-56 Hot ribbon welding surveyed by IRSM and EPV-TO, but not identified by the automatic algorithm

In conclusion, 95% of anomalies have been correctly detected by EPV. No anomalies detected in a geometric wrong position and non-existent faults are computed by the algorithms.

- PVT2 – metadata reliability

The analysis of metadata reliability has been performed on the sample data composed by the panels located on row 13.

In the following table, a summary of the analysis is reported.

	ACQUISITION METHODOLOGY																
ANOMALY	IRSM		IRSM-EPV		EPV-TO		EPV										
	Nr	Nr	%IRSM	Nr	%IRSM-EPV	Nrtot			NrCP			NrWP			NrFP		
						N	%IRSM-EPV	%EPV-TO	N	%IRSM-EPV	%EPV-TO	N	%IRSM-EPV	%EPV-TO	N	%IRSM-EPV	%EPV-TO
HOT STRIP	20	21	105	21	100	22	105	105	21	100	100	0	0	0	1	4.8	4.8
HOT SPOT	1	0	0	6	600	6	/	100	6	/	100	0	/	0	0	/	0
HOT RIBBON WELDING	6	7	117	0	0	0	0	/	0	0	/	0	0	/	0	0	/
TOTAL	27	28	104	27	100	28	/	104	27	/	100	0	/	0	1	/	3.7

Table 3-32 Statistical analysis of anomalies detected on PVT2 “Vis Solis”

This test confirms the good performance of EPV in the automatic detection of hot strip anomalies. In fact, all the faults (20) detected by the operator on EPV images (EPV-TO) are localized in correct way by EPV algorithm. Just a hot strip non-existent is wrongly detected by the system. In this case, the algorithm has classified an anomaly due to soiling problems as hot strip. This problem can be solved through a visual check by the operator on a visible image (Figure 3-58).



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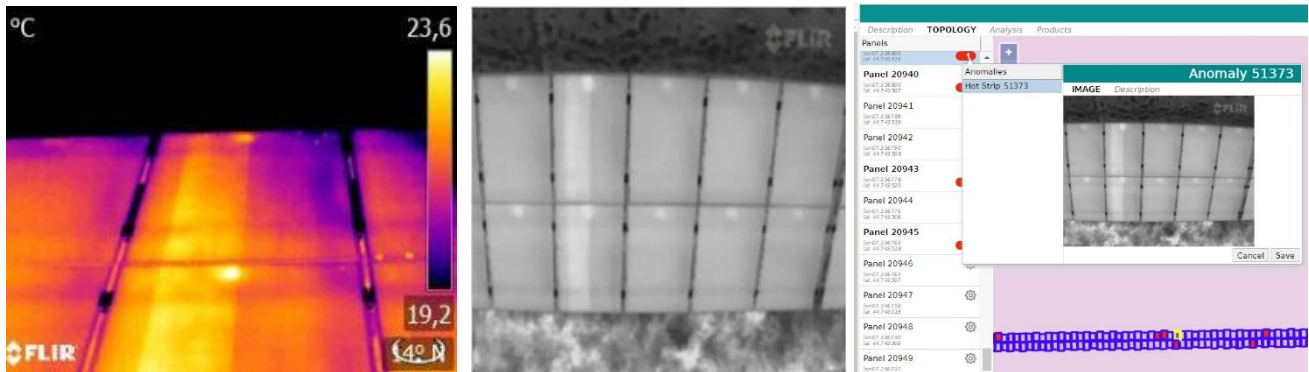


Figure 3-57 Right hot strip detected (IRSM, EPV-TO, EPV)

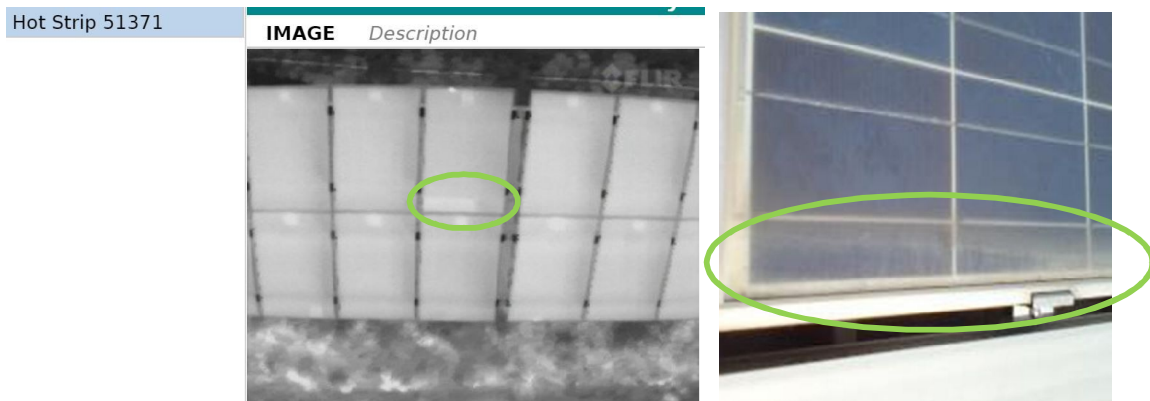


Figure 3-58 Wrong hot strip detected by EPV. Visual image shows soiling anomaly

Hot spots are automatically detected by EPV with high performance: all the defects automatically located by the algorithm (6) are correctly linked to the PV module panels. Otherwise, the number of hot spots identified by EPV is greater than the hot spots computed in IRSM-EPV survey. This difference is due to the classification, computed manually by the thermal operator, of the hot spot in relation to the profile temperature on the cells (see 3.3). This function is not implemented in the EPV platform; therefore all hot spot anomalies are automatically stored in the SC platform. In this way, a conservative estimation of hot spot anomaly is performed.

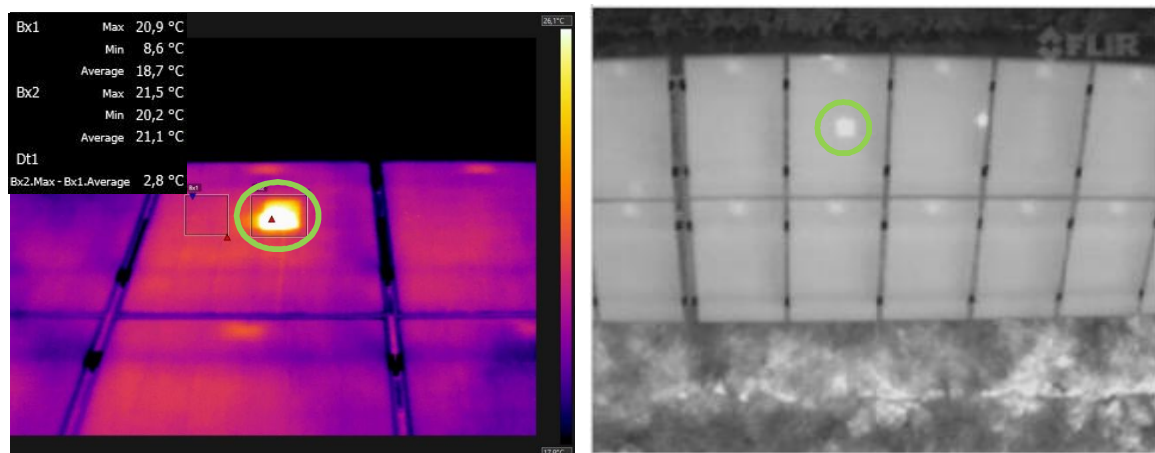


Figure 3-59 Minor hot spot detected with IRSM and EPV



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Hot ribbon welds are not detected by the EPV. As mentioned before, this problem is related to the IR image resolution and consequently to the flight parameters (height altitude) of survey.

In conclusion, the automatic tool of anomalies detection supplies good results. All the anomalies detected by the operator with EPV – TO data are automatically identified and stored in the SC platform. Just one non-existent anomaly is wrongly detected.

- PVT3 – metadata reliability

The analysis of metadata reliability has been performed on the sample data composed by the panels located on row 5.

The following table shows a summary of the analysis.

	ACQUISITION METHODOLOGY																	
ANOMALY	IRSM			IRSM-EPV			EPV-TO		EPV									
	Nr		%IRSM	Nr		%IRSM-EPV	Nrtot			NrCP			NrWP			NrFP		
							N	%IRSM-EPV	%EPV-TO	N	%IRSM-EPV	%EPV-TO	N	%IRSM-EPV	%EPV-TO	N	%IRSM-EPV	%EPV-TO
HOT STRIP	1	1	100	1	100	1	100	100	0	0	0	0	0	0	0	0	0	
HOT SPOT	16	21	131	38	238	38	181	100	32	152	84	6	29	16	0	0	0	
TOTAL	17	22	129	39	229	39	177	100	32	145	82	6	27	15	0	0	0	

Table 3-33 Statistical analysis of anomalies detected on PVT3 “Fratesole”

In this test, the high performance of EPV in the automatic detection of hot strip is confirmed. The one defect is correctly detected by the algorithm.

Hot spots are automatically located with a performance indicator of 82%. 6 anomalies are wrongly detected in the geometric entities. As showed in Figure 3-61 some defected modules are translated of one panel position in direction east compared to the right position. Furthermore, the number of anomalies automatically extracted is greater than the number located with IRSM-EPV. The cause of his problem is the same already found in the previous tests.



Figure 3-60 Right hot spot detection (IRSM, EPV-TO, EPV)



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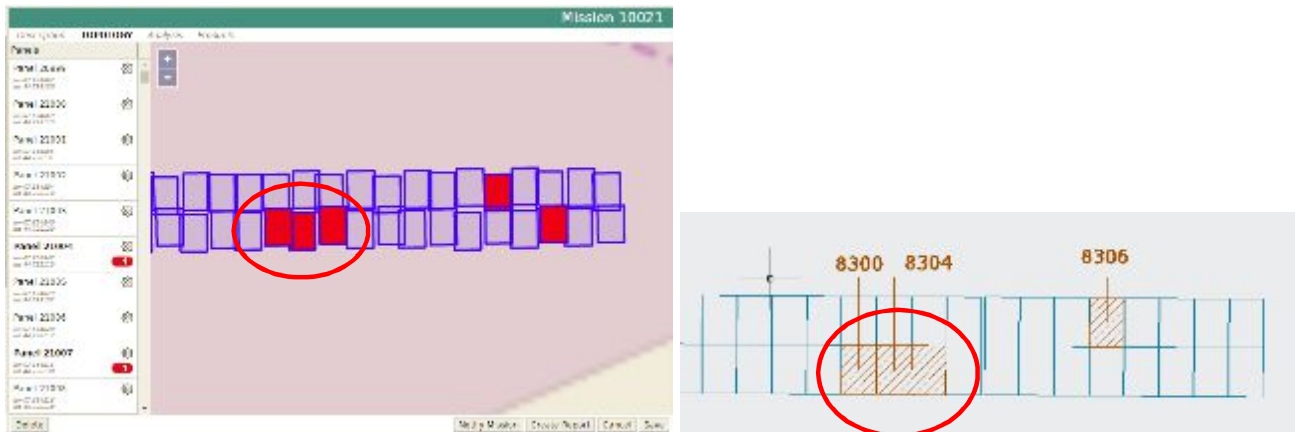


Figure 3-61 Wrong detection of hot spot. (East translation). Geometric layout extracted by EPV (left image). Geometric layout with the indication of modules affected by hot spot (IRSM – EPV, right image)

The rate of anomalies correctly extracted and geo-located are 95%, 100%, 82% ($N_{rCP} - \%_{EPV-TO}$). These results are mainly influenced by the GNSS performance installed on RPAS and the environmental conditions during test flights. Consequently, the bad results provided in the test PVT3 (82%) can be explained by the very low solar radiation conditions (91 W/mq) during the test. On the other hand, results provided in the tests on PVT1 and PVT2 allow to declare that EASY PV system, in environmental conditions quite near to 700 W/mq, provides an high metadata reliability, greater than 95%. Finally, the availability and reliability of metadata associated to each PV module provide an important enhancement in the O&M sector, for quick location and management of modules. However, some improvements of classification tool are recommended, in order to provide an excellent product able to automatically detect PV plant anomalies.

These reasons allow to supply the following performance level and to suggest some improvements.

PERFORMANCE LEVEL: 3

TO IMPROVE:

- Classification of hot spot anomalies. SC platform extracts hot spot without a classification related to the difference of temperature with a working cell. It is recommended to supply more information about the distribution of temperature on the module, in order to allow the differentiation between “hot spot” and “minor hot spot”. Furthermore, it is recommended to link visible images to IR images, in order to allow a visual analysis of the defect.
- Classification of hot ribbon welding. In the tests, SC platform has not detected hot ribbon welding. The main problem is the IR acquisition, and in particular the distance from the IR sensor to the surface modules during the flights. Even through hot ribbon welding is an anomaly with low frequency on PV panels, it is recommended to carry out more investigations about the automatic detection of this defect (which have small dimension), with the evaluation of the best flight altitude.

Finally, in order to perform these improvements, it is recommended to make an updating of the SC platform software and to perform other test analyses.



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3.6.1 PERFORMANCE ANALYSIS – REPORT

3.6.1.1 Report usability

Report is saved in pdf format in a user friendly way. It is enough to click on the “Create report” icon, in order to generate and download the report. This feature increases the productivity of IR data management, with a drastic reduction of time effort concerning the report production, consequently, the performance level attributed is excellent.

PERFORMANCE LEVEL: 5

TO IMPROVE: nothing

3.6.1.2 Report fullness

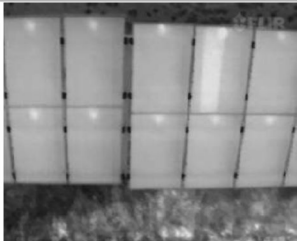
Report includes the most important information about the mission and the output results. After a brief introduction, the information of the PV plant is supplied (localization, number of PV panels, coordinates of PV module centre). In addition, a graphical layout is supplied. Moreover, mission data are summarized (instruments, operators, environmental conditions, flight mission parameters) and a short description of IR technology is showed, with a summary of the most common anomalies which affect PV modules.

Output data are reported as:

- Layout of anomalies, with the indication of modules affected by anomalies;
- Identification of modules affected by anomalies, with short information about module and acquisition data (ID, localization, environmental conditions during the IR acquisition), IR image of module, anomaly classification.
- Summary of modules affected by anomalies, with the total amount of faults.

5.2.2. PANNELLO 20995

ID Pannello	20995
Data Ispezione	30/11/2017
Localizzazione (lat, lon)	44,743517, 7,356444
Emissività	?
Temperatura Ambiente	?°C
Quota relativa di volo	? m

	
File Name	10024_9.jpg
Acquisition Time	04/10/2017 11:03:55
Anomaly	Hot Strip

L'analisi effettuata su 242 pannelli ha permesso di riscontrare la presenza di 27 pannelli affetti da anomalia, con una difettosità pari al 11.16%.

Figure 3-62 Report example



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The report format is complete, consequently a good performance level is attributed. Nevertheless some details could be improved.

PERFORMANCE LEVEL: 4

TO IMPROVE:

- It is recommended to generate the geometric plant layout with anomalies location in a format suitable for paper print.
- The geo-localization of PV modules is expressed in geographical coordinates. It is recommended to geo-locate the PV modules in a local reference system (matrix format, row – column).
- The position of PV fault on the IR images is not underlined. This information lack could create problems in the geo-location of PV modules (see Figure 3-63).

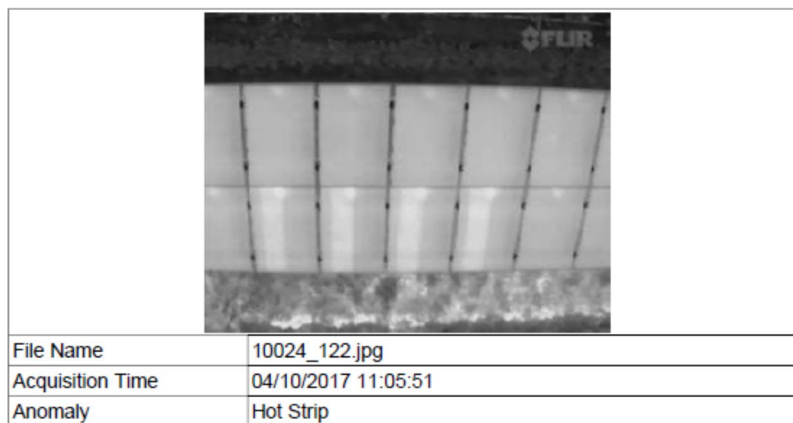


Figure 3-63 IR image associated to a hot strip fault. In the image there are 4 hot strips. Without a graphical indication, it is not possible to locate the damaged module

- It is recommended to add in the report the visible image of PV module, in order to allow a visual interpretation by the operator.

3.6.1.1 Report data reliability

Report collects data obtained from SC platform, consequently the reliability is the same.

PERFORMANCE LEVEL: 3

TO IMPROVE: see paragraph 3.6.4.3



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3.6.2 PERFORMANCE ANALYSIS – FINAL CONSIDERATIONS

In the following table, the summary of EPV performance levels attributed in the validation analysis are resumed.

EPV DATA		CRITERIA		
		USABILITY	FULLNESS	RELIABILITY
SC DATA	Geometric data	4	5	3
	Metadata		3	3
REPORT		5	4	3

Table 3-34. EPV performance level summary

Significance of the three criteria have been evaluated by the thermographic operators, in order to attribute a synthetic performance level to the Easy PV system. In O&M activities, maintainer operates with instruments which have to be:

- usable in order to supply information and solve problems quickly;
- full. Information provided by the instrument has to be complete in order to solve problems with a minimal effort
- reliable. Data quality provided by the instrument has to be suitable for the detection of problems.

Consequently, it is reasonable to consider the criteria with the same weight in the assessment of a synthetic performance level and to assign a mean performance level, in the amount of 3.75. According to these results, it is possible to declare that EPV system is able to geo-locate and automatically detect PV module faults with quite good results. Therefore, the system is suitable for IR inspections on PV module plants. In particular, data extracted by the system are useful for owners and O&M contractors for a cost and time effective thermographic service, which provides an overall diagnosis of a PV module condition.

More details about the use of this system in the PV plant monitoring will be provided in the next document section.



4 EASY PV. INNOVATIONS IN THE IR SURVEY TECHNIQUE OF PV PLANTS

Easy PV system is a product that can improve performance of thermographic monitoring activities concerning PV plants. Therefore, it has a potential market in the O&M PV plant sector. As widely described in this document and in RD 4, there are many difficulties that affect IRSM activities, first of all the time effort for IR survey and data processing, other than safety risks (especially on roof plants). EASY PV is an instrument that can reduce the entity of these problems, providing a semi- automatic acquisition and data processing procedure. This approach allows to reduce human efforts and to increase the IR inspection productivity.

Easy PV supplies improvements in the thermographic inspection process, hereafter described:

IR survey:

- IR acquisitions of PV modules are carried out in a semi – automatic way with a RPAS platform.
- RPAS platform is controlled by a new professional figure in the renewable energy sector: RPAS pilot. Consequently, Easy PV missions can be carried out without the presence in the field of a thermographic operator.
- RPAS pilot check the environmental conditions just before the mission, accomplishes flight operations and finally check the completeness of acquired data. IR image interpretation and PV module anomaly detections are not required in the field.
- RPAS platform acquires more information than IR camera during IRSM (RTK GNSS observations). In particular, the integration between GNSS data and geometric data extracted from IR images allows to geo-locate the PV modules inspected.
- IR acquisitions with Easy PV concern the whole PV plant inspected. This is a very important improvement, because in IRSM inspections, operator saves only images with damaged modules. Finally, with EASY PV, a complete IR survey can be easily performed.
- Risks concerning operator safety are strictly reduced, in particular for IR survey on PV plants roof.
- IR acquisition time with Easy PV system is considerably limited. Table 4-1 shows the IR time acquisition with IRSM and EPV procedures on PVT.

IR TIME ACQUISITION (man hours)	IRSM	EPV	TIME SAVED (man hours)	TIME SAVED (%)
PVT1	9:30	2:50	6:40	70
PVT2	11:40	4:40	7:00	60
PVT3	9:20	3:30	5:50	62.5

Table 4-1. IR acquisition time. IRSM and EPV procedures

The mean time saved during the IR inspection is about 60% for PVT2 – PVT3 (about 1 MW on the ground). This value increases to 70% for PVT1. This means that the system improves time performance



especially on roof plants, where IRSM time is conditioned by safety operations. In conclusion, tests provide good time saved results, which underlines the productivity improvement in the field.

Data processing:

- Easy PV performs an automatic data processing of surveyed data. During this process phase, the human activities are reduced to the management of mission data and to the validation of output data. In this last activity, the Thermographic Expert Operator controls the output data on the VTE and carries out manual adjustments, if algorithm provides error data.
- The automatic data processing allows to reduce the human effort. As showed in Table 4-2, time saved is about 80% on 1 MW ground PV plants. The rate is quite lower (68%) for PTV1.

IR DATA PROCESSING (man hours)	IRSM	EPV	TIME SAVED (man hours)	TIME SAVED (%)
PVT1	4:45	1:30	3:15	68
PVT2	10:45	2:00	8:45	81
PVT3	10:15	2:00	8:15	80

Table 4-2. IR data processing time. IRSM and EPV procedures

Final product:

- EASY PV product is available on an informatics platform (VTE) which allows to manage output data. In particular, it is possible to manage missions, to visualize and edit data on a graphical geo-referenced layout, to make queries on modules, to download an output report. Now, instruments similar to VTE are not present in the market. Consequently, it is possible to declare that Easy PV system it is a complete innovative product in the O&M PV plant sector.
- Tests results have provided an EASY PV system performance level of 3.75. This means that the system offers an overall diagnosis of PV modules in a cost and time effective thermographic service, according to the goal of the project. However, in order to fulfil a complete commercial ripeness, some improvements, widely described in the previous paragraphs, have to be provided.
- The total effort for the IR inspection, process data and output data delivery is very low. Time saved is about 70% for all plants analysed, so it not depends to the kind of plant (roof or ground).

IR PV MONITORING (man hours)	IRSM	EPV	TIME SAVED (man hours)	TIME SAVED (%)
PVT1	17:15	4:20	12:55	75
PVT2	22:25	6:40	15:45	70
PVT3	19:35	5:30	14:05	72

Table 4-3. IR monitoring time. IRSM and EPV procedures



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Finally, EASY PV product fulfils the goals of H2020 project, which concern the development of a time and cost effective system for the detection of anomalies on PV modules and the consequent assessment of production losses caused by PV module faults. Now, the product is suitable for a market entry strategy. However, it is recommended to perform other tests and improve some system features, in order to solve the issues detected during the validation procedure and to get a product market maturity.

4.1 EASY PV APPLICATIONS IN O&M PV PLANT ACTIVITIES

EASY PV system is a product suitable for a market entry in the O&M PV plant providing a time and cost effective diagnostic of PV plant modules.

Maintainers or owners can use this system (as a service or product) in order to perform a fast IR analysis, which allows to carry out a global diagnostic of PV modules in a very fast time. Graphical layout with the indications of damaged panels could be a useful tool for the visualization of the entity of faults on PV plant. Then, the availability of an output report automatically extracted by the system, allows getting an overview of the PV module conditions. Maintainer can use this information to carry out further activities such as the assessment of production losses or the maintenance operation planning, according to the final user. This approach is very profitable in the IR survey of large PV plants, where the inspection time is an important factor, which affects the service costs.

Nowadays, EASY PV system allows to quickly identifying problems like string disconnected or important thermal anomalies, which can be immediately solved through inspection in the field. Thermal anomalies which require particular attention for warranty replacement, (as hot spot), can be easily located in the plant. In order to get a warranty, a rigorous inspection with manual IR camera, performed by thermographic operators has to be performed. . This last manual approach can be easily exceeded through the system implementation of improvements described in the previous section.



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5 CONCLUSIONS

This document (DEL 10.1) outlines the validation activities carried out on the Easy PV product, with a deeply description of tests performed on PV plant test fields whit different IR procedures. Moreover, the document analyses data collected in the tests, with a definition of the system “performance level”, an indicator that resumes the product reliability, in relation to the criteria of evaluation. Finally, the improvements that Easy PV can potentially supply in the IR inspection of PV plants are summarized.

After a brief description of Easy PV system (Section 2), the document (Section 3) analyses the validation procedure of the product. First, three PV plants made available by Entec spa for test, are described. The first plant (PVT1) is on a roof, with a nominal power of 169.2 kWp. The other two plants on are located on the ground (PVT2 “Vis Solis 1”; PVT2 “Fratesole”) and have nominal powers of 941.6 kWp and 904.6 kWp. For each plant, a topographical survey with geodetic GNSS receiver was carried out in order to define the position of each PV module. Then, qualified operators from Entec spa performed IR surveys and data processing on the PVT in standard conditions (IRSM), for the detection of anomalies and the processing time computations.

On the three PVT plants, Easy PV system was tested. Flights were performed in October 2017, with a RPAS platform equipped with a single frequency GNSS receiver (U-blox). Environmental conditions were not near to the standard ones (solar radiation was lower than 700 W/m² during the three surveys); therefore, in order to collect data in the same condition, IR survey with hand camera (IRSM –EPV) were performed on a sample area of PVT during the flight operations. This activity was not performed on PVT1 for safety problems in the roof access.

Validation process consisted in the analysis of Easy PV output data delivered on the VTE platform. In particular, for each criteria (usability, fullness and reliability) and Easy PV data, a performance score was assigned. The final validation result was a “performance - requirement” matrix that resumed the Easy PV features.

The system provides high scores (4 - 5) in the usability requirement. This mean that the final product is delivered in a user –friendly platform with innovative features. Moreover, the system well satisfies the fullness requirement, in particular in the detection of the geometric entities of PV plant (PV modules) and in the completeness of output report. Some problems in the fullness requirement concern the IR images available on the VTE platform. These problems are due to the lack of an associated “query tool” for the assessment of temperature. It is recommended to add this tool in a commercial version of VTE platform.

The system reliability is enough for the required application. Regarding the reliability of the geometric entities automatically detected by the system, it is important to underline that test results (CE95 higher than threshold of 50 cm) were obtained with an “old” GNSS receiver (single frequency U-blox GNSS receiver) and in an environmental conditions quite far from the standard ones. In the last months, the RPAS has been equipped with a GNSS double frequency receiver (RTKITE), which provides better positioning performance than U-blox. This technological upgrade could improve the precision of Easy PV system, with a concrete possibility to get CE95 error lower than the tolerance system limit. The system is able to detect the more frequent PV module faults (hot



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spot and hot strip) with a very high rate. Nevertheless, some improvements should be performed especially in the classification of hot spot and in the location of other anomalies such as “hot ribbon welding” and “soil”. Finally, the mean performance score attributed at the system is 3.75. This result allows declaring that Easy PV system satisfies the requirements of the O&M market, providing a time and cost effective service for the detection of anomalies on PV modules.

Section 4 underlines the improvements that Easy PV system can produce in the PV plant O&M sector. Process automation and time effort reduction are two main advantages that allow to make the system as interesting product in the IR survey of PV plants.

In conclusion, validation tests on Easy PV system have supplied good results. The solution maturity is suitable for a market entry strategy, because it is able to perform IR inspections on PV plants in a fast way in order to produce the complete status of a PV plant. These solution features are particularly requested by O&M operators who manage high power PV plants (more than 500 kW on the ground; more than 100 kW on roof), where the human effort in the inspection is very relevant. Moreover, the document proposes several improvements which are suggested to be implemented as normal maintenance evolution of the solution. Such an approach has to lead the further release of the solution which will be also impacted by requested tailoring by other O&M clients requesting to use I-PV.



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