TRAINING ON PV: FOCUS ON MAINTENANCE, FAULT RESEARCH AND PLANT PERFORMANCE OPTIMIZATION

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ABSTRACT: Although the national PV market stimulation initiative, the "Conto Energia Programme", has been concluded, annual installations are expected not to be stopped, should the Italian Government take into account suitable measures. Nevertheless, the total installed capacity of over 18 GW must be properly managed in order to maximize the benefit of the incentive tariff for a period of 20 years. The training of skills plays an important role, especially for operation and maintenance, faults research and plants performance.
A survey of failure identification occurring in PV Plants was launched among the network of qualified professionals and installers who, in the previous years, attended Mesos courses. The results have been reported in a database and analysed by experts. After the identification of the possible solutions, the most significant faults were included in a training course designed to improve the skills of professionals and installers of PV. Typical faults in PV arrays will be reviewed and reported in guidelines for installers enabling them to operate on PV plant properly and to classify and solve the relative faults towards the optimization of the plant.
Keywords: Education and Training, System Performance, Monitoring

1 INTRODUCTION

Photovoltaic systems installed up to now in Italy are more than 500,000. These installations represents an important market to be managed and maintained in which professionals specialized in operation and maintenance can play a successful role, while diversifying their expertise and professionalism.

Many operators and Italian EPC System Integrators are getting more and more interested in Operation & Maintenance (O&M), of existing plants. The relative training and technical upgrading of professionals is essential to assure to the customer that failures in PV plants are identified and resolved in a short time, that energy production plant is kept at the expected levels of performance while increasing reliability level of the plants, thus ensuring the expected return on investment.

This skill has been often neglected in the past because new plants, if correctly planned and installed doesn't generally bring up any problems during the first years of operation. In order to reduce risk exposure for plant management and performance optimization, third parties are usually appointed to fulfill such activities.

Our task is to review typical faults on the PV array, to provide guidelines allowing installers to operate properly on PV plant and to classify and find the resolution of the defects occurred.

Our aim is to describe the learning methodology and the contents developed in the training courses.

2 THE ITALIAN PV MARKET

2.1 The installed PV capacity

The "Conto Energia" Program is the national market stimulation initiative that has been operated since 2005 [1].

In the framework of its five phases 526.463 plants corresponding to 17.080 MW have been installed and put in operation, while other 4.779 plants corresponding to another 1.136 MW are going to be operational soon. The trend of the installed capacity is reported in Table I.

Table I: Number of plants and installed power

Conto Energia phases	number of plants	Power (MW)
I	5.726	163.431
II	203.767	6.791.240
III	38.608	1.566.636
IV	203.301	7.600.370
V	79.840	2.094.901
total	531.242	18.216.578

2.2 Post incentive market

Even if the "Conto Energia" Program is concluded, PV installations are not expected to stop, should the Italian Government suitable and even lower measures. In fact, it is widely recognized that specific measures at no cost for the public finances, accompanied by the good solar radiation values, especially in southern region of Italy, will be enable the achievement of grid parity.

In particular, AEEG, the Italian Authority for Electricity and Gas has updated the rules for exchanging energy with the grid for plants up to 200 kW, while the Ministry of Finance has officially declared the applicability of 50% tax deductions to the installation of photovoltaic systems up to 20 kW for residential applications.

In these conditions and taking into account both the good values of solar radiation and the high electricity bill as well as the decreased of component cost, the required period for the return of investment is still attractive, even without incentive tariffs (see Table II).

Table II: Pay-back period for different applications

application	*prices per W*	*pay-back time*
3 kW on roof top (30% self consumpion; 50% tax credit)	1.8 – 2.5 €	8 years
500 kW on industrial building (total self consumpion)	1.3 - 2.2 €	9 years
utility scale multi MW on ground (Energy sale)	1 – 1.4 €	10 years

2.3 New professional opportunities

For the Italian PV operators new professional opportunities are emerging in domestic PV market, as a result of the expected reduction [2], to diversify their previous business in design or installation activities.

- The number of Italian companies transferring their activities abroad is higher and higher. It is a positive effect, often underestimated, related to the strong growth which is currently recorded in some countries. They range from companies that have transferred production facilities to the ones offering their skills in obtaining authorization, financial and EPC, primarily in Eastern Europe, but also in Africa and Latin America.
- Operators who historically held EPC activities have started to invest and address their business on O&M services, integrating them in their bids. On the basis of the average values of the current prices for the O&M service and taking into account number of plants installed, a total business volume of 'O & M' in Italy of about 300 million euro per year can be evaluated.
- Asset Management Companies tend to an increasing extent, to directly manage O&M activities, avoiding the outsourcing to subcontractors as in the past.
- Companies operating in collecting and recycling of PV.

3 OPERATION AND MAINTENANCE

3.1 The importance of maintenance

A total capacity of over 18 GW installed in Italy must be properly managed in order to maximize the benefit of the incentive tariff for a period of 20 years. Neglecting, in fact, the maintenance of photovoltaic systems can lead to significant energy production losses, as well as expose them to the risk of further failures. Consequently it is extremely important to keep the plants according to design conditions of functionality and safety, reducing the frequency and duration of failures, minimizing repair time, optimizing the availability of spare parts and at the same time maintaining standards of safety.

In this context training of skills is becoming more and more important, especially for handling operation and maintenance of PV systems, aiming to reduce costs while improving reliability and productivity. In particular technicians are asked to perform preventive maintenance inspection to reduce both the probability of PV system downtime and fire risk as well as to learn how to find and resolve them in the shortest possible time and how to adopt safety measures.

Moreover O&M operators should be able to conduct predictive actions aimed at improve plant performance through measured or extrapolated plant parameters.

The typical model adopted for operation and maintenance of large plants foresees the involvement of internal personnel, the recourse to Engineering, Procurement, and Construction (EPC) contractor that have built the system and who subsequently converted to a O&M company or to a Third Party. Of course, the recourse to EPC or Third Party imply lower risk and greater flexibility but less understanding of the O&M problems.

3.2 Monitoring and plant improvement

The monitoring of plants is aimed at managing and optimizing performance. Generally allow access to data acquired, analysis of the acquired data with the identification of possible improvements as well as resetting remotely in order to minimize losses and maximize availability. In monitored facilities the typically recorded performance ratio of 85% and average plant availability of 99% is reached.

Currently, several techniques for monitoring differentiated according to the level of detail adopted. The higher the level of detail, the better is the ability of fault detection.

Besides, monitoring systems can be distinguished into systems for large systems, for distributed systems, custom solution and monitoring owners.

In order to identify the steps needed to upgrade plant performance it could not be sufficient to verify system parameters through the monitoring systems. In these situation O&M operators should be able to perform tests on site (thermographic analysis), to conduct generally for a limited period a measurement campaign of electrical parameters through dedicated sensors as well as any indoor tests (measurement of modules with solar simulator)..

4 FAULTS IN PV SYSTEMS

4.1 The most common faults

The photovoltaic systems, during their life, are subject to different types of faults due to:

- failed components (typically modules and inverters);
- poor installation;
- poor design;
- external events (as power grid, lightning).

Insulation losses, cells cracking and bypass diodes failure are examples of failures on PV modules. As regards the inverter, often the power section and sometimes the fuses on board fail.

Even a poor installation causes an increasing risk of faults. For example, cables laid without paying attention to their insulation could cause "ground faults" that are very dangerous in large grounded photovoltaic systems because could result in an increase of fire risk.

Cables with a poor tightening into the terminal blocks cause overheating and fire if flowing currents are very high.

Inverter and electrical switchboards exposed to direct solar radiation, instead of being shaded, are other examples of poor installation that in the course of time can cause failures and/or out of service due to high operating temperatures of these components.

Regarding faults due to poor design, we can list:

- incorrect cables sizing;
- inadequate electrical switchboards thermal sizing;
- wrong choice of over current protective devices (fuses or circuit breakers) that does not take into

account device derating when it is applicable;
- the absence of risk management for PV plants due to lightning.

When a fault occurs it is very important to locate and repair it out as soon as possible. This is essential for large photovoltaic systems because fault could cause not only significant economic losses but also dangerous fires.

4.2 Faults detection

In PV plants three approaches are normally used for faults detection:
- visual inspection;
- remote monitoring;
- instrument detection.

Visual inspection is easy to perform and consists in checking whether or not there are visual anomalies in the system components (inverter blocked, modules with burn marks or delamination phenomena, circuit breakers tripped and/or blown fuses, etc.).

The remote monitoring is more detailed and is usually used in large photovoltaic systems. It can detect the fault on the system and / or its components as soon as the fault occurs. It can be used to verify the performance of the PV system too. The modern monitoring systems allow a detailed check of PV module.

The instrumental detection performs specific electrical measurements on the plant. It is very important because, in addition to identifying the fault, this approach is useful to prevent it. A loss of insulation on photovoltaic module that has not yet produced a plant shutdown could be detected in time by specific electrical measurements.

5 SURVEY ON TRAINING NEEDS OF THE O&M MANAGER

5.1 Mesos and ENEA's survey

To improve the skills in O&M of PV plants of professional, Mesos - Innovation and training advice, ENEA's spin off and skilled training provider [3] is working on a training courses mainly focused on the detection and the repair of photovoltaic plant failures.

In order to base the course on valid and meaningful teaching materials corresponding to real cases, ENEA and Mesos have launched a survey of failures [4], occurred involving the network of qualified professionals and installers who previously attended Mesos courses.

The survey results have been reported in a database designed according to a standardized procedure, allowing installers to describe the type of failures occurred and classify them univocally.

The most interesting information included in the survey regard:
- type of fault;
- component involved;
- fault identification method;
- possible cause identification;
- fire involved;
- partial or total shutdown;
- duration of failure detection, repair and component supply.

5.2 Preliminary Survey's results

ENEA experts have analyzed the results of survey, classified the failure and identified the possible solutions.

In particular, statistical evaluations have highlighted the components most prone to failure, the consequences and the possible repair mode. Preliminary results, based on limited set of plants installed in the period 2011 – 2013 has highlighted:
- failure rate of plant components (figure 1);
- the effect of failure on plant operation (figure 2);
- how have been detected faults (figure 3);
- the causes that generate faults (figure 4).

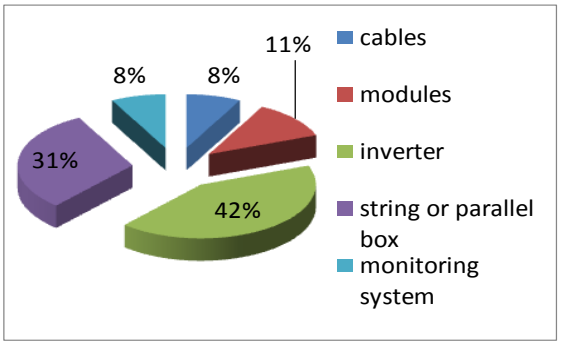


Figure 1: Failure distribution among plant components

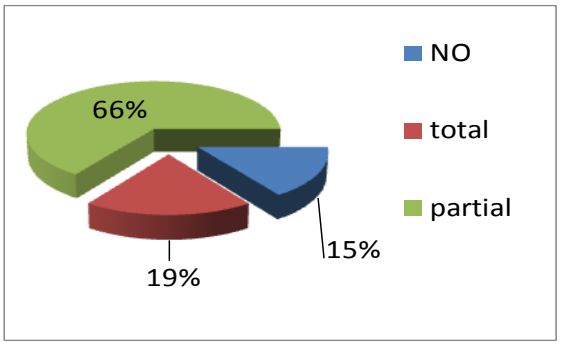


Figure 2: Plant shutdown distribution

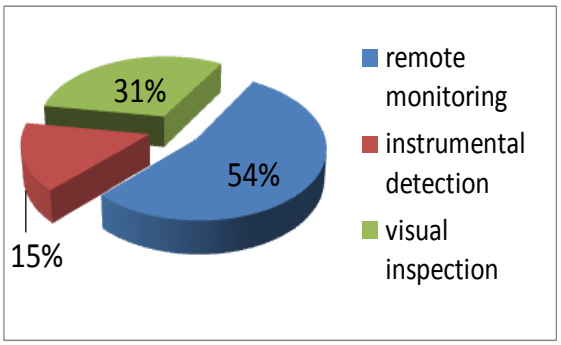


Figure 3: Fault detection approaches

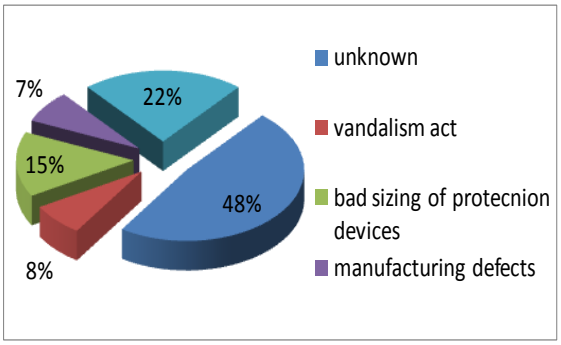


Figure 4: Fault causes

5.3 Implementation and actions

It is worth mentioning that up to now O&M has been performed in some cases empirically (generally requiring more time to plant repair) by plant designer or installer, as only reference of plant owner in most cases.

In this contest is very important to convert those professionals into maintenance operators specialized in the identification of failure causes, often unknown, in their resolution and if necessary in plant performance optimization.

The statistical processing of database information has moreover highlighted that malfunctions or critical situations can reduce performance of the plant such as:

- excessive module pollution;
- early degradation of modules;
- theft or vandalism act of components;
- site careless.

Finally in few cases data evaluation has led to erroneous assessments in reporting preparation due to data acquisition or transmission system failure or malfunctioning or degradation of sensors.

6 ADVANCED TRAINING ON PV OPERATION AND MAINTENANCE

6.1 Requirements

The Legislative Decree 28/2011[5] emended by the Decree Law 63 of 4 June 2013 [6] states that the professional qualification for the installation and maintenance of photovoltaic plants on buildings is achieved with the possession of technical and professional requirements (set out in Decree 37/2008) [7]. They consist in working periods carried out in photovoltaic enterprises, those duration depends on the educational qualifications.

Qualified professionals are obliged to participate in training activities to bring their skills up-to-date. The duration of those training courses is about 16 hours every 3 years.

The same Decree Law foresees that, by October 31, 2013, the Italian Regions will activate a training program for installers of renewable energy systems or will approve training providers. Those Regions may recognize credits equivalent to working periods, to the professionals participating in training,

Since in Italy the legislative competence in the energy sector is of both State and Regions, such situation involves considerable difficulties in terms of legislation harmonisation, and represents a limitation on the homogenous implementation of legislative provisions throughout the country.

6.2 A new competence needed in PV sector

Currently the market of PV plants requires a new professional, the "Manager of Operation and Maintenance".

In this framework three main types of operators can be identified:

- EPC that have started to invest and refocus their business model, providing O&M services through the integration of these services in their bids;
- operators who traditionally operated in the electric and electronic fields, now available to diversify their business model in PV sector;
- asset management companies, which carried out their activities on renewables and now tend to increasingly extent them towards managing O&M activities, usually outsourced by subcontractors in the past.

Professionals on O&M must be able to implement monitoring systems and asses data collected if maintenance and resources are to be optimized. Moreover they should be able to perform corrective maintenance in case of component breakdown and to mitigate unplanned downtime. “Faults Research” on PV plants is therefore a new requirement for professionals and installers.

The courses are suitable for both installers with proven experience in compliance with the Italian law to attend updating training courses and even for installers with a long experience in PV, willing to deal with the management of the system and in particular with faults research..

6.3 Training methodology and course’s contents

In a time of economic crisis, investing in human resources is certainly a successful strategy, because skilled professionals, and virtuous companies are expected to be reward by the market.

The availability of qualified personnel in this field is a guarantee for the consumer and for the growth of photovoltaics.

ENEA, has been developing a qualification scheme for renewable energy installers, including in PV, thanks to its participation in RES working groups and European projects

The training courses developed by Mesos, are based on the results of such European projects, according to training international standards and certification of professionals, both the certification of third parties according to ISO IEC 17024 and the European Qualification Framework (EQF).

In photovoltaic sector ENEA and MESOS have obtained the certification for training courses, issued by, the Italian national Certification Body for Personnel and Training courses (CEPAS) since 2007.

One of the most qualifying aspects of this methodology is the structure of blended courses, combining e-learning and classroom, as well as the possibility to facilitate access to specialist training of learners in the classroom.

The course Mesos "Management of PV systems: management and maintenance of existing facilities" is aimed at providing professionals skills and expertise in faults research, reduce plant malfunction, minimize fire risk, or even increase the productivity of plants poorly designed or poorly installed.

The program of the proposed course includes lectures, hands-on and theoretical work. Moreover particular attention is paid to practical training in the field, with the support of the best experts using the most advanced instrumentation.

The two-day course will teach and evaluate the various opportunities for economic return in the post incentive phase, the new regulations and in particular issues related to fire prevention.

As to plant components, the course will be focused on new technologies and the use of the storage in grid connected systems. They will also be in-depth case studies of the most common failure and their resolution under realistic conditions that implements typical troubleshooting procedures. In this contest measurements will be performed required for testing power and energy through advanced instrumentation (IV meter, thermo room, wattmeters, solarimeters etc). Based on the

outcome of the test, will be analyzed the cases in which it is possible, through appropriate analysis, optimize plant performance.

Finally special focus will be given on some real examples of monitoring systems for large plants and for diffused generation.

6.4 Training on plant optimization

Due to the huge number of systems installed in Italy, improvement of the energy performance of photovoltaic systems is becoming more and more important. The introduction on the market of the so-called "power optimizers" has led to new possibilities for operators. A trained professional must be able to both evaluate each cases and the actual benefits in terms of productivity achievable by the optimization, as well as to make a proper assessment economic investment. To meet this need, Mesos' courses present several case studies of retrofit optimization of PV systems.

One of the most proposed case studies refers to the evaluation of the annual yield improvement of a photovoltaic system already installed.

It is a 6 kWp photovoltaic system, composed of two parallel strings of 12 modules each, with centralized conversion and an object shading. The following figures show some rendering and the increase of yearly energy in case of replacing the centralized conversion with a multi MPPT conversion or a module conversion (use of optimizers).

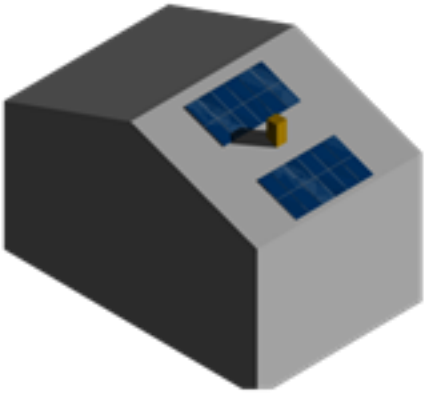
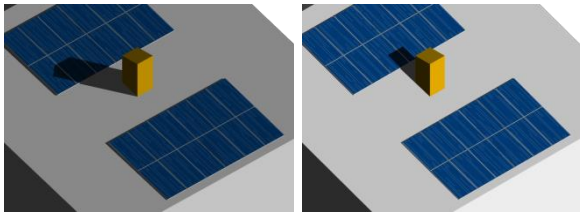


Figure 5: 6 kWp photovoltaic system subject to optimize.



9.00 a.m. 12.00 p.m

Figure 6: Shading analysis on 21th December.

The case study takes into account both the current and the voltage mismatch caused by the presence of shading object. Should the centralized conversion be replaced with a multi MPPT conversion (use of multi MPPT inverter) or with a PV module conversion (use of PV-optimizers), the improvement in annual energy yield would be by 2,50% or by 3,40% respectively (see Table III).

Table III: Annual energy yield improvement in presence of optimization of PV plant.

Type of DC/AC conversion	Annual energy yield improvement
Multi MPPT conversion	2,50%
PV module conversion	3,40%

7 CONCLUSION

Today the Italian photovoltaic market must cope with two new factors. On one hand, plants boosted in the latest years have already exceeded the warranty period (two years), on the other, the absence of incentives has brought down the interest in large systems and moved the market towards small size plants, built and operated in a geographically distributed way. In this situation plant maintenance is entrusted to numerous local professionals, often with short experience and expertise.

A further consideration regards many installers that owing to market reduction have returned to their core business of installers and maintenance of civil and industrial electrical installations, opening new opportunities for professionals intending to start or continue operating in PV.

As a consequence the photovoltaic market will require new profession on operation and maintenance proving new specific skills.

For the achievement of European objectives regarding the dissemination of renewable energy sources a fundamental role is played by the formative process and the continuous technical updating of the operators. In this contest, training processes will have to provide not only the skills necessary for a proper design and installation, but also the competence for both plant maintenance and energy efficiency optimization.

To fulfil the expectations and the interests of photovoltaic investors, the training and the qualification of professionals should be aimed at acquiring the necessary skills, relevant to the management and maintenance of the plants. These skills must comply with high level standards and satisfy functional and economic objectives required.

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