PHOTOVOLTAIC APPLICATIONS IN RAILWAY STATIONS

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ABSTRACT

The photovoltaic (PV) power generation is a potential system to reduce the environmental pollution. In order to reach good level results, PV applications have to be wide adopted. In the future, one important solution could be the application of PV power generator into railway stations.
The present paper analyses the integration of the main power supply of railway stations with PV panels and contact line. In order to reduce the environmental impact and limit the use of the ground, the panels are integrated in the stations' premises (e.g. shelters) using architectonic PV panels.
The study concerns a preliminary technical/economic analysis and evaluation of the PV panel surface necessary to power different station typologies also considering the chance to sell the energy as defined by the Conto Energia Italian document.

INTRODUCTION

The impact of photovoltaic (PV) power generation on the electric public network is still very limited. The Green Book of Energy identifies, as key aspects for the energetic sustainable development, those that are related to the increase of renewable sources of energy (RES), to the competitiveness of the market and to a more secure supply chain thanks to an energetic mix diversification, as also suggested by the European Community. Therefore, it is important to find new solutions where the use of these energy sources can be applied in a profitable way.
The study of hybrid systems, based on the PV technology, to supply railway stations increases the energy efficiency in a strategic market such as the public transportation, improving both the reliability and the aesthetic impact. Furthermore, the implementation of PV systems in railway stations can be easily extended in a systematic way to the large number of stations present in each European country. Of particular importance is the case of stations that are included in geographical protected areas (national parks, special landscape areas) where strong is the need to respect the environment by means of correct architectural choices and energy supplied by renewable sources. The paper goal is to provide a preliminary technical/economic analysis of different configurations for the electrical load supply in relation to the various station typologies.

NETWORK CONFIGURATION

The different network configurations that allows to supply the station loads, integrate the PV panels placed in the stations' premises and, in case, also powered by the railway 3000 Vdc power line as described in fig. 1.

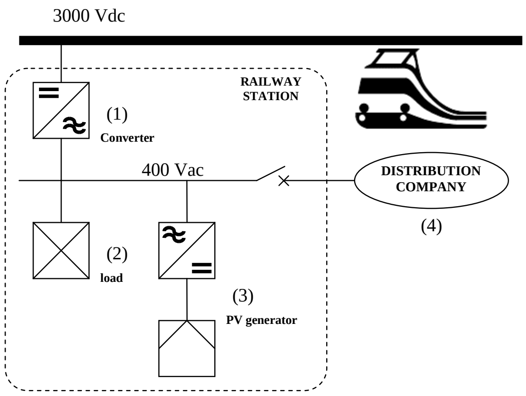

Fig. 1. Modular configuration of the various network analyzed.

It is made up of different modules as follows:
(1) *Converter 3000Vdc – 400Vac*. The conversion system can be realized by two different modules: the first one made up of step-down chopper that converts and stabilizes the 3000Vdc voltage to 650÷800Vdc and the second one made up of an inverter that converts the dc voltage from the output of the chopper in 400V ac voltage to supply the station loads. The conversion device, depending on the reliability of the 3000Vdc network, can be single (with power equal to the 100% of the load), double (each converter is sized equal to the 100% of the supplied load) or triple (each converter is sized equal to the 50% of the supplied load).
Furthermore, depending on the functional typology desired, the converter can be absent or:

- mono-directional: from the 3000Vdc contact line to the 400Vac station power plant;
- bi-directional: as above and also the vice-versa. Such configuration may come to be more expensive than the previous one and has also additional difficulties concerning the design and the control system realization (measurement and operating).

(2) *Load*. To size the PV modules and choosing the network configuration is important to know the value of the electrical load of the railway station. In particular, to evaluate the network configuration the needed data are the load profile absorbed, the contractual power, the energy absorbed in a year and the power profile of the privileged load.
(3) *PV generator*. In order to guarantee a good efficiency of the PV modules integrated in the stations' premises they must have the optimal inclination and exposition. In the best conditions 10m^2 of PV standard modules are required to get 1kWp and produce around 1200kWh/year [3,4].[1] The

1 Such data are referred to the ideal working conditions in the North of Italy. In the following we detail the possible problems

architectonic PV adoptions increase the required surface because the cells are more distant from each other: in this case are required around $12m^2$ to get the same power and production. [2]

(4) *Distribution company*. The connection to the distribution network can be:

- present in order to allow the bi-directional energy exchange with the railway station power plant. In such case the energy supply contract is the traditional one and is chosen depending on the maximum used power and the main profit is related with selling to the public network the energy produced by the PV modules according to the *Conto Energia*[3] program;
- present and used only in emergency conditions to supply the railway station loads. In this case the supplying from the public network does not make any bi-directional exchange of energy. The distribution network represents the reference for the operating frequency and the back-up of the electrical network of the railway station. The supplied energy comes from the 3000Vdc power line that has more advantageous tariffs compared to the ones at 400Vac;
- absent. In such case the 3000Vdc network and the PV modules represent the generators for the station loads. The main benefits are as described above.

Without getting involved in technical details of the modules in fig.1, here follow the possible network configurations.

Network Configuration 1

The energy produced by the PV (3) and, for the major part, supplied by the 3000Vdc contact line through the converter (1) supplies the station loads. Such configuration allows excluding the power supply from the public network and its related costs.

However, in order to have a high reliability in station loads supplying, the 3000Vdc contact line should have a high reliability as well as the conversion devices (1), that should be realized with double/triple converter.

The conversion module can also be bi-directional but, if it is mono-directional the PV modules must be designed in the way that for each instant of time the power generated keeps always lower than the power absorbed from the load.

Network Configuration 2

Beyond the converter (1) and the PV generation (3), we find also the connection to the public network (4). In such case the converter (1) can be mono-directional and the PV modules can be sized depending on the contract power with the distribution company, hence for a higher power than the previous case. The energy produced by the PV modules is completely absorbed during the year by the electrical load of the station and may be paid as defined in the C*onto Energia* by the distribution company. The difference between the energy used for the station loads and the energy produced by the PV modules can be integrated by the 3000Vdc network through the converter (1).

Network Configuration 3

The distributor (4) represents a back-up system and the reference frequency for the electrical network of the station. The load (2) is mainly powered by the 3000Vdc contact line through the conversion system (1) and, in a reduced quantity, by the PV shelters (3) that must be designed as described for the Network Configuration 1 in the case of mono-directional conversion system (1), whereas they may be designed for a higher power if the conversion system (1) is bi-directional.

Network Configuration 4

The converter (1) is absent. In this case the load (2) is powered by the energy produced by the PV shelters and distributor. The PV modules represent the heart of the system and they are sized as described in the Network Configuration 2 with the benefits for the *Conto Energia* tariffs.

PROBLEMS THAT INFLUENCE THE PRODUCTION FROM A PV SYSTEM

In the reality, unfortunately, some of the hypotheses made about the high potential of energy production from PV systems many times come to be wrong. In fact, the PV energy production is based on calculations that, even though are precise, analyze ideal situations and, for this reason, can be encountered in few cases. Some of the factors that can strongly affect the production of a PV system are the following:

- the direct shadows and the horizon profile;
- the installation angle of active surface;
- the temperature of the PV modules and inverters;
- the quality of the energy supplied by the distributor.

Analysing the working installations data it is possible to identify how much the production has been affected and evaluate the number of years needed to reach the break even point for the investment.

The most common case of installation problem are the first two. The first one is the obstacle such as high trees or buildings, that cover a significant part of the solar path. It is very important to avoid that objects may project their shadow onto the PV surface. Indeed a PV module can reduce almost to zero the generated current in case only one of its cells is obscured. Furthermore, higher is the portion of

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that influence the real efficiency of a PV system.

2 Data reported in this paper for the architectural PV has been provided by architectonic PV producer.

3 In the *Conto Energia* financing program the distributor is obliged to buy all the energy produced by PV modules, but, in the best case, pays up only what has been really used by the load. For the energy transferred to the distributor the tariff is 0.445÷0.49€/kWh [5]. Additionally to this price is recognized an extra 10% in case the PV modules have been integrated in brand new buildings or existing building redeveloped. For an exact calculation of the economical return for such a system it must also be taken in account the saving - around 0.15€/kWh – related to the quantity of energy not paid to the distributor.

solar path that the module is able "to see freely" - that is free from obstacles that may cover a part of it - higher is the real production. It is possible to fix, through specific measure instruments, which is the yearly percentage of energy not produced in relation to the covered paths percentage. These instruments use graphs on which are indicated the solar paths and the profile created by the obstacles visible over the horizon (Fig. 2).

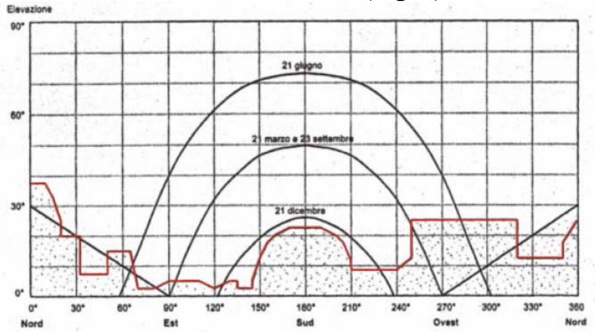

Fig. 2. Solar paths and profile of the shadows (in red) created by the obstacles in the horizon.

The second installation problem is the bad orientation. The way in which the PV modules are oriented may negatively or positively influence the production depending on the period of the year or a particular season. The angles that define the position of the modules are Tilt (represents the elevation of the modules over the horizon) and Azimut (defines the orientation of the modules with respect to the South).These angles may reduce the energy production.

Another typical problem of the PV systems is the overtemperature of the PV modules and PV inverter that increases the energy losses of the system. If the cell temperature gets higher than the nominal (defined in the *Standard Test Conditions* equal to 25°C) is possible to have a decrease in the conversion efficiency of around 5÷8%. This phenomenon happens because the whole potential conversion of the solar radiation in electrical energy by the PV modules is limited to only a part of the total radiation spectrum; the exceeding radiation does not give a contribution to the conversion and it is converted in heat increasing the cell temperature. Often the static converter is installed in particular places. When the temperature of the converter is too high, in order to avoid damages, the device turns itself in stand-by. As a result we have that during the more productive hours of the day the system is in stand-by and the energy production is strongly affected.

The last problem is the quality of the voltage waveform in the connection point. Often it is not taken in account but it is fundamental for the efficient operating of PV system connected to the distribution network. The standards fix that the PV system has to be disconnected automatically from the network (Fig.3) if the voltage waveform is outside from the standard limits. Therefore, the static converter, in presence of distorted loads (such as big motors or inductive loads in general) could continuously disconnect itself affecting the production efficiency.

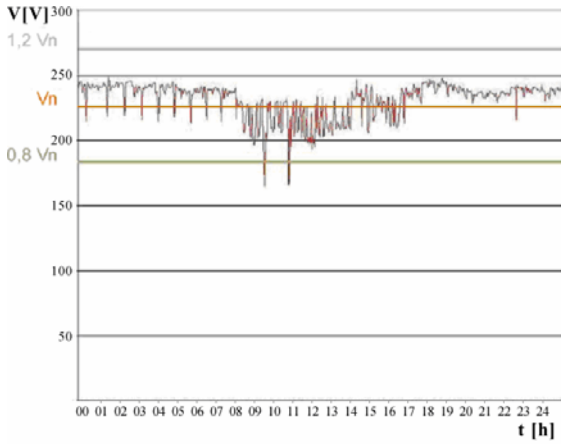

Fig. 3. Trend of the effective value of the network voltage during a day and for a low-power user. $1.2V_n$ and $0.8V_n$ represent the maximum values according to the standard, beyond which is necessary to disconnect from the distribution network

CHOOSING STATION CONFIGURATIONS

Choosing the network configurations for each different installation solution depends on the technical analysis related to the general characteristics of the railway station. First of all it is important to underline that it is almost impossible to abandon the connection to the distribution company because the 3000Vdc contact line does not have the necessary reliability to supply the station loads (it is often interrupted for scheduled maintenance activities). The distributor company supply is also preferred to any back-up systems as batteries, etc.

For what concerns the conversion from 3000Vdc to 400Vac, the solution with single mono-directional converter is preferred because has a lower cost.

The chopper is placed out from the station to prevent from weather problems and it is a controlled chopper with a capacitor between the two converter modules to limit the voltage fluctuations upstream the inverter during the trains' transit. The inverter control logic must be studied depending on the chosen network configuration. In the case of distribution network (4) supply, the inverter must be a current source inverter, whereas in the other case can be adopted a voltage source inverter.

The inverter of the converter (1) and the one used for the energy produced by the PV modules have different control logics and, for this reason, it is better to adopt two different devices so it is quite easy to find them in the market.

Based on the previous considerations we get the following results reported in the following.

In the ***network configuration 1*** the load is supplied only by the 3000Vdc network and the PV shelters. This solution must be rejected because it is not possible to abandon the public network.

In the ***network configuration 2*** the load is supplied by the 3000Vdc network, the PV shelters and the distribution company. The station loads (2) are mainly powered by the PV modules (3). These are designed or basing on the maximum contract power or considering the energy station loads absorption. If the PV modules are sized in the first way, the converter (1) represents an integration system of PV produced energy. It is important underline that the converter (1) works for few hours because it has to integrate a small portion of energy absorbed by the load. If the PV modules are sized instead in the second way the converter (1) is not necessary. Based on the previous considerations this solution appears not to be convenient.

In the ***network configuration 3*** the load is supplied by the 3000Vdc network, the PV shelters and the public network. The PV modules must be sized in order to generate always less power than the load power absorbed at the same time. The load is mainly powered by the 3000Vdc power line trough the inverter of the converter (1) that works as current source because the distribution company supply the voltage reference. Such configuration seems to be the ideal solutions for medium/large passengers building.

In the ***network configuration 4*** the heart of the system is represented by the PV modules; it is the typical configuration for a PV grid-connected system. This configuration seem to be suitable for stations having small electrical loads and ideal for stations without passengers buildings, such as stops, and for stations located in protected areas where the green energy represents a choice for the environment politics.

In conclusion the possible network configurations are the 3 and the 4. It is important to underline that in these configurations, without mains power supply from the distributor network, the PV modules and the converter (1), if present, are disconnected from the load.

LOADS CHARACTERISTICS AND SIZING OF THE PV SHELTERS

In the table 1 the data related to the available contract power and the yearly and daily consumption of a typical stop and medium/large size station are reported.

The PV modules may be sized based either on the peak power or on the yearly used energy. Anyway the absorbed power from the distributor cannot be higher than the contract one. In the table 2 the necessary surfaces for the PV modules are reported. They are calculated with reference to the architectonic PV for two different station typologies.

Table 1. Available power and active energy used in a typical stop and a typical station

	Stop Station	Medium/Large Station
Available contract power	16.5 kW	50 kW
Average daily energy	87.87 kWh	698.14 kWh
Energy used in a year	31632 kWh	251330 kWh

Table 2. Sizing of the architectonic PV modules

	Based on contract power		Based on absorbed energy in a year	
	PV modules surface (m^2)	yearly production (kWh)	PV modules surface (m^2)	Power (kWp)
Stop Station	198	19800	317	26.4
Medium/ Large Station	600	60000	1760	147

CONCLUSIONS

From the table 2 is possible to deceive that for the stop are necessary around 198m^2 of architectonic PV modules to produce the peak contract power. In this case the yearly produced energy is lower than the estimated used energy. Such solution, taking into account also the last two years energy production increase of PV, seems to be ideal for the financing incentives of *Conto Energia* document. To produce instead the whole quantity of energy are necessary 317m^2 of architectonic PV modules. In this case the PV peak power is higher than the contract one. This solution may be applied only increasing the power supply contract with the distribution company. Exceding produced energy would not be financed by the *Conto Energia*. For such stations would be better to use the network configuration 4 sizing the PV modules considering the contract power.

For what concerns the medium size stations, are necessary 600m^2 of architectonic PV modules to produce the peak contract power, and are necessary 1760m^2 to produce the whole quantity of energy (this strategy appears not feasible). For such stations would be better to use the network configuration 3.

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