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ENERGETIC SUSTAINABLE APPLICATIONS IN RAILWAY STATIONS

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The present paper analyses the possible integration of the railway station power supply with photovoltaic panels and the contact line. In order to reduce the environmental impact and limit the use of the ground, the panels are integrated in the shelters using architectonic photovoltaic panels.

The objective of this paper preliminary technical/economic analysis and the calculation of the surface of the photovoltaic panels necessary for the electrical load supply in relation to the various typologies of railway station as well as considering the possibility or not to sell the energy as defined in the Conto Energia *Italian financing scheme.*

Keywords: Photovoltaic system, Hybrid System, Renewable, Railway Station.

1. Introduction

The impact of photovoltaic power generation on the electric public network is still very limited. The Green Book of Energy identifies [1], [2], 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 a diversification of the energy mix, 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 photovoltaic (PV) technology is applicable to a wide range of system sizes, from milliwatts to multi-megawatts, although the most attractive short-medium term applications are for the distributed generation of electricity on the kilowatt scale, both grid connected and autonomous. The Small-scale PV applications (lower then 20kW peak) are considered the cost-effective solutions [3].

The Strategic Research Agenda for Photovoltaic Solar Energy Conversion Technology [4], developed by the main stakeholders in the field, reflects the aim of transferring the economies due to scale observed for large PV systems to the market of many thousands of small systems, by encouraging harmonization and standardization of the approach. This allows establishing the annual rate of growth

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of cumulative installed PV capacity in EU countries with the aim to reach the target set in the white paper and avoid or reduce CO_2 emissions.

The study of mix energy system, based on the PV, 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.

Moreover, particularly important is the case of stations that are included in geographical protected areas (national parks, special landscape areas) where is strong the need to respect the environment by means of correct architectural choices and energy supplied by renewable sources.

The objective of this paper is to provide a preliminary technical/economic analysis of the different configurations for the electrical load supply in relation to the various station typologies.

2. Network Configuration

The possible different network configurations that allow supplying the loads present in the railway station, integrating the PV panels placed in the shelters and, in case, the railway 3000 Vdc power line and the utility are shown in Fig.1.

Concerning the PV shelters, in order to guarantee a good efficiency of the PV modules integrated in the shelters inside the station, they must have the optimal inclination that for North Italy is around 30° respect to the horizon; the exposition must be as much as possible to the South. In the best conditions, as indicated, $10m^2$ of PV standard modules are required to get 1kWp and produce around 1200kWh/year [5], [6].[2] The use of the architectonic PV, that has a higher cost compared to the standard PV, requires a larger surface because the cells are more distant from each other: in this case are required around $12m^2$ to get 1kWp and 1200kWh/year[3]. For the sizing of the PV modules it is necessary to know the station profile load in order to choose the most convenient solution from economic point of view. Table 1 shows the load data related to the available contract power and the yearly consumption of a typical stop and medium/large size station.

[2] Such data are referred to the ideal working conditions. [8] analyses the problems that influence the real efficiency of a PV system.
[3] Data reported in this paper for the architectural PV has been provided by an important company working in the field.

A. Network Configuration 1

In the first configuration, presented in Fig. 1a, the whole energy requested to power the station load (2) is supplied by the PV generator (3) and, for the major part, by the 3000Vdc network through the converter (1). In this configuration the power supply from the utility and its related costs are excluded.

However, in order to have a high reliability in powering the station loads the 3000Vdc network should have a high reliability as well as the conversion devices (1) that should be realized with double/triple converter. It can also be bi-directional but, in case it were mono-directional, the PV shelters must be designed in way that for each instant of time the power generated keeps always lower than the power absorbed from the load.

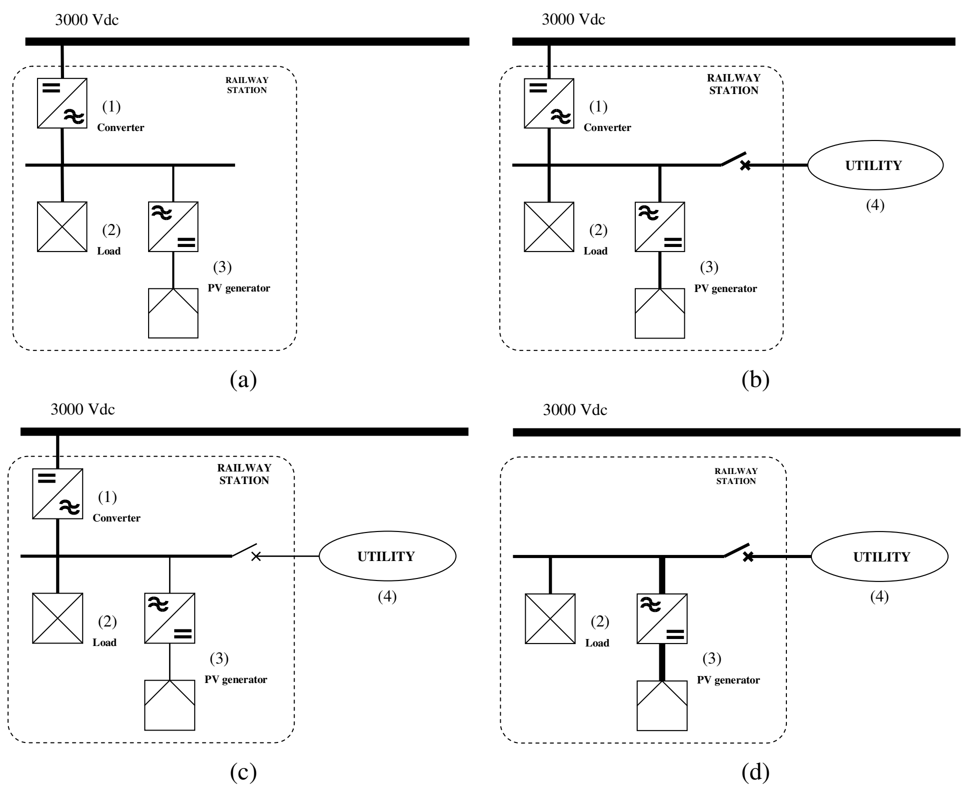

Fig. 1. Network configurations: (a) 1, (b) 2, (c) 3, (d) 4.

B. Network Configuration 2

In the second configuration (Fig. 1b), beyond the converter (1) and the PV generation (3), we find the connection to the utility (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 utility, hence for a higher power than the previous case. The energy produced by the PV shelters is completely absorbed during the year by the electrical load of the railway station and may be paid as defined in the *Conto Energia*[4] financing scheme. The difference between the energy requested by the loads present in station and the energy produced by the PV modules can be integrated by the 3000Vdc network through the converter (1).

C. Network Configuration 3

In the third configuration (Fig. 1c), the utility (4) represents a back-up system and the frequency reference for the electrical network of the station. The load (2) is mainly powered by the 3000Vdc power 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 will be bi-directional.

D. Network Configuration 4

In the last configuration depicted in Fig. 1d, the converter (1) is absent.

In such case the load (2) is powered by the PV shelters and utility. 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* financing scheme.

3. 3000Vdc-400Vac converter

The choice of the network configurations for each different installation solution depends on the technical analysis related to the general characteristics of

[4] In the financing *Conto Energia* Italian program the utility absorbs all the energy produced by PV modules. The Italian state pay this energy with a tariff that depends on the power of the system and the integration level, as follows [9]:

Size[kWp]	No-Integrated [€/kWh]	Partially Integrated [€/kWh]	Integrated [€/kWh]
1<P<3	0.40	0.44	0.49
3<P<20	0.38	0.42	0.46
P>20	0.36	0.40	0.44

For an exact calculation of the economical return it must also be taken in account the saving related to the quantity of energy not paid to the utility. Two types of contract are possible. In the first case, called exchange on site, the energy produced by PV panels is deducted from the Energy absorbed by the load for a maximum corresponding to the total energy absorbed: the saving is around 0.15€/kWh.

In the second contract, called network transfer, the energy produced by the PV panels is paid by the utility 0.0964 €/kWh but the energy absorbed by the load is paid to the utility about 0.15€/kW. In this case the energy produced by the PV panels can overcame the energy absorbed by the load and the PV system is a true electric plant.

the railway station and the economic convenience to have the dc/ac converter in the network configuration.

Concerning the railway station technical constraints, it is important underline that it is almost impossible to abandon the utility because the 3000Vdc power line does not have the necessary reliability to supply the station loads (it is often interrupted for scheduled maintenance activities). The utility is also preferred to the batteries and other back-up systems. Furthermore, for the conversion from 3000Vdc to 400Vac the solution with single mono-directional converter is preferred because its lower cost.

The economic convenience to install the dc/ac converter is analysed considering the two following typologies of connection of the conversion system to the electrical network of the station (Fig.2): connection of the chopper/inverter with a transformer to the electrical network or directly without the transformer.

From the data supplied by the railway company the average price (may 2006) of the energy 3000Vdc including taxes has been 11.27 c€/kWh, VAT excluded. The average price of the energy 400Vac including taxes has been variable between 14.5 and 16.5 c€/kWh, VAT excluded. In this paper has been considered the average price of 15.5 c€/kWh. Therefore, the average money saving in using the 3000Vdc power supply instead of the 400Vac is 4.13 c€/kWh.

The selling price of the converter has been calculated starting from the data of labor and material cost provided by companies in the field.

In the Table 1 the requested years to reach the break-even point for the stop/small and the medium/large stations are reported.

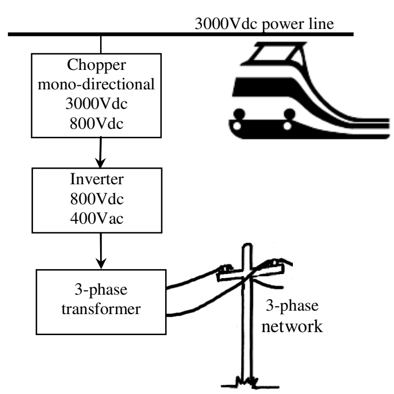

Fig. 2. Connection of converter (1) to the electrical network.

As we can see, the 3000Vdc power supply seems not to be convenient for small or stop stations. More than 65 years are, in fact, necessary to have an economic return supplying the whole station load through the contact line. In case of supply made up of photovoltaic, contact line and utility such years would increase. The power supply through the converter should become profitable only eliminating the utility power supply and its related fixed costs (network configuration 1). In case of medium/large stations, the years requested for the break-even point are 10. This time may even decrease for a high number of purchased converters.

Table 1

Requested years Number to reach the economic convenience for the two typical stations

	Stop/Small Station	Medium/Large Station
Available contract power	16.5 kW	50 kW
Energy used in a year	31632 kWh	251330 kWh
Converter Power	20 kVA	50 kVA
Solution with transformer	70 years	10 years
Solution without transformer	65 years	9 years

4. Loads characteristics and sizing of the PV shelters

The PV modules may be sized based either on the peak power or on the yearly used energy when the absorbed power from the distributor cannot be higher than the contract power.

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. The calculations have been carried out based on both the peak power and the absorbed energy.

Table 2

PV modules Sizing

	Based on the contract power		Based on absorbed energy in a year	
	PV modules Surface (m^2)	Yearly production (kWh)	PV modules Surface (m^2)	kWp
Stop - architectonic PV	198	19800	317	26.4
Station - architectonic PV	600	60000	1760	147

From the Table 2 is possible to deceive that for the stop or small stations are necessary around 198 m^2 of architectonic PV modules to produce the peak contract power. In this case the yearly produced energy is lower than the estimated absorbed energy. Such solution, taking in to account also the last two years energy production increase of PV, seems to be ideal in the optic to use the financing incentives from the *Conto Energia*.

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 supply power contract with the utility and/or to be sure that the load is always absorbing.

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

5. Choosing the network configurations

Basing 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 utility.

In the network configuration 2 the load is supplied by the 3000Vdc network, the PV shelters and the utility. 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. The converter (1) in the first case represents an integration system of PV produced energy if they are sized in the first way. But, in this way, 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 in the second way the converter (1) have to be absent. Basing 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 utility. The PV modules in this case must be sized in order to generate less power then the instantaneous power absorbed by the load. The load is mainly powered by the 3000Vdc power line trough the converter (1) that works as generation current because the utility represents 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 shelters; it is the typical configuration for a PV grid-connected system. This configuration is the classical grid connected system and seems 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.

6. Conclusions

The network analysis for supplying the station loads and the analysis of the two typical stations brings to the following comments.

(a) The network Configuration 3 is suitable for medium/large station. In such case the energy of the loads is supplied by:

- the converter (1) mono-directional with power 50kVA. The isolation transformer with the same power of the converter is better solution in order to realize a metallic separation between the 3000Vdc line and the 400Vac network;
- the PV shelters (3); in this case the generated power must never overcome the load absorbed power. For this reason it is important to make a preliminary evaluation of the load diagram of the station load profile absorptions in order to size the solar system;
- the distributor (4) only in case of emergency and so with a special supply contract.

(b) The network Configuration 4 is instead suitable for small or stops stations. The energy requested by the load of the station is mainly provided by the PV shelters and in a minor part by the distributor, in particular:

- the converter (1) is absent ;
- the PV shelters (3) are designed based on the maximum contract power (16.5 kWp). In the best condition are necessary around 200m^2 of PV modules to reach the limit of the contract power;
- the distributor (4) with a traditional supply contract and the *Conto Energia* financing program

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