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Heiselberg, Per Kvols

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Increase of photovoltaic self-consumption through innovative managing methods of heat pumps and chillers in buildings

Biagio Di Pietra^{#1}, Giovanni Puglisi^{#2}, Danilo Sbordone^{*3}, Giuseppe Emmi^{#4},
Giacchino Morosinotto^{#5}

[#]ENEA, Italian National Agency for New Technologies, Energy and Environment-Rome-Italy

¹biagio.dipietra@enea.it

²giovanni.puglisi@enea.it

^{*}University of Rome - La Sapienza, Department of Electrical Engineering-Rome-Italy

³danilo.sbordone@uniroma1.it

[#]University of Padua, Department of Industrial Engineering-Padua-Italy

⁴giuseppe.emmi@unipd.it

^{*}Studio Franchetti S.r.l.-Vicenza-Italy

⁵giacchino.morosinotto@studiofranchetti.com

Abstract

Solar assisted heat pump system is a technology many discussed in recent years. It represents an important integration in the air-conditioning of buildings due to the following advantages: high renewable energy share, low electricity demand, low primary energy demand, and low CO₂ emission depending on the electricity mix feeding to the heat pump.

The objective of this study is to investigate the benefits obtained from the adoption of innovative methods of managing heat pumps in order to increase the consumption of electricity produced from renewable sources. The logics of management induce to use the thermal units largely in times when sustainability of power generation is high by a photovoltaic plant on the building (or by another renewable source connected to the electric smart grid). The logic of the management plan to maintain internal comfort in any condition and manage the thermal storage to accumulate the energy produced that is not immediately used.

The study confirms the importance of using integrated management methodologies in order to increase the share of renewable sources used for the energy demand of the new buildings and also in energy-efficient retrofit of existing ones. It was possible to evaluate the influence of operating procedures in different case studies by determining the optimal configuration and its energy benefits.

Keywords - Solar energy utilization, sustainable energy for buildings, energy efficient in heating and cooling systems component.

1. Introduction

The European directive EPBD of 2010/31 declare that all new buildings will have to be Near Zero Buildings (NZB) up to 2016. The NZB energy needs very low or almost zero should be covered in a very significant extent by energy from renewable sources, including energy from renewable sources produced on site or nearby.

In the last years, the big attention given to the environmental problems involved in a huge diffusion of the Renewable Energy Resources (RESs) power plants. Among the different technologies (biomass, wind, solar, etc.), the photovoltaic (PV) systems are the most widespread, mainly for economic reasons (national incentives) and simplicity of installation and integration in buildings and other civil structures in urban context.

In particular, as showed below, in Italy most of Dispersed Generation (DG plants connect to low voltage) are PV plants (about 98.5%).

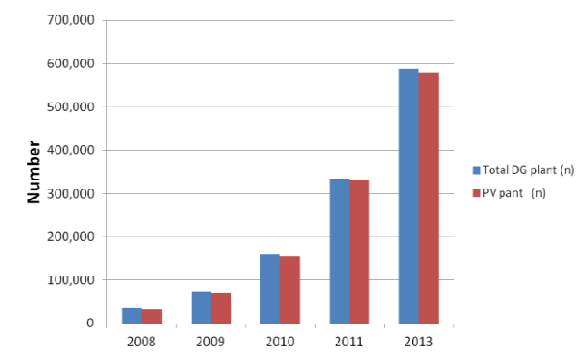


Fig 1: DG and PV plants in Italy: number installed in the last 7 years

Most of these PV systems (90.5 %) are small size plants with a nominal power less than 20 kW, and so they are connected to LV grids owned and managed by final users so called prosumers.

Table 1: PV plants in Italy: number installed for different nominal power in the 2014 [1]

Nominal power	PV plants [n]	%
1-3 kW	213157	32,87
3-20 kW	374474	57,75
20-200 kW	49158	7,58
200-1000 kW	10503	1,62
1000-5000 kW	943	0,15
>5000 kW	183	0,03

The high PV penetration levels may be cause for the many problem in regards to: difficulties when managing the grid, transmission lines congestion, power flow inversion (from LV to HV), hosting capacity problems in critical area (south of italy), overvoltage in many nodes of distribution lines (violation of EN 50160 prescriptions).

So the need of making regulated the interaction between these new widespread users and the main grid has become mandatory. The level of interaction with the electrical grid of prosumers is function of the effective flexibility of the power demand and local production.

The flexibility can be increase thanks to the integration in building of Energy Storage System. Different papers are recently published different models and applications of electrical storage system in order to increase self consumption of energy supplied by PV plants [2,3,4].

Currently in Italy the self-consumption of energy supplied by PV plants amounted to 3000 GWh (only 16% of the total energy produced by installed photovoltaic systems).

The aim of this paper is to investigate the benefits obtained from the adoption of innovative methods of managing heat pumps and thermal storage system, in place of electrical storage system, in order to increase the self-consumption of electricity produced from PV palnts with low investment cost.

2. Simulation numerical model

The model is made of different blocks, each one modelling the physical components of the system; the main ones are:

- building: to simulate heating and electric load in one year [5];
- thermal storage systems;
- heat generator: to simulate the heat pump and other heat supplier;
- PV model: to simulate the effect of a photovoltaic field;
- weather generator: to simulate hourly meteo input.

The model is developed in Matlab-Simulink and is able to simulate the thermal behaviour and the energy performance of building-plant system both in heating and cooling configuration. The tool allows to analyse various scenarios and different control strategies in order to study and to evaluate primary energy saving and performances in each case.

The main heating output variables of the model are:

- average inner temperature both of the building and the tank;
- COP, thermal and electrical power of the heat pump;
- energy parameter for building load and PV production.

Buildings and Thermal storage

In the model each building is defined starting from its opaque and transparent envelope: size and thermal-physics characteristics (e.g. layer stratigraphy, layer conductance etc.). Details about the type of emission system are needed too. Each building is considered as a single thermal zone and the space heating and cooling demands are calculated in order to maintain the indoor air temperature within a certain range around the seasonal temperature set-point. The mathematical model of the indoor air temperature of each building is made with a set of differential equations in time domain, with variables parameters, and is based on knowledge of the physic that governing the processes of heat exchange of all variables that influence the thermal behavior of buildings.

The energy balance equation used to describe the building model takes into account:

- heat input due to solar radiation on glass and opaque surfaces (Q_g)
- presence of people, lighting and electrical appliances (Q_i)
- heat loss through the building envelope (Q_{disp}) and ventilation (Q_v)
- power supplied by heating or cooling systems (Q_{aux})

according to the following relation:

$$CAP * \frac{dT_r}{d\tau} = Q_{aux} + Q_g + Q_i - Q_{disp} - Q_v \quad (1)$$

where CAP is the total thermal capacity of building and T_r is internal temperature of building.

To take into account the time delay and the attenuation of the heat flux between internal and external surfaces due to the fact that while convective part of heat gain become immediately cooling load, radiative part is first absorbed by wall and then, after time delay, transferred by convection to room air, the time series coefficients are introduced (Ashrae, 2009). This coefficients (called conduction time factors, CTFS) are applied to the Q_{disp} component of the energy balance and distribute heat gain over time; they also reflect the share of heat gain of a wall or roof that becomes heat gain.

The heat and cool distribution system of each building is considered as an equivalent thermal storage (which can include also an actual thermal storage, if present), to which the heat is provided or subtracted by a heat exchanger connected to the district thermal network, in heating and cooling mode respectively. The presence of the equivalent thermal storage allows to separate from a thermal point of view the distribution system of each building from the thermal network of the district, allowing each building's distribution system to operate at independent operating temperatures.

In each building the needed heating or cooling flow is provided by the equivalent thermal storage, whose temperature varies between set-point values. The temperature of the equivalent thermal storage is calculated by the same differential equation described in (1). Table 2 shows the figures for the residential building used in the simulations.

Table 2: Dimension of the building and U-values for the different building components used in the simulation

Height	m	10
Length	m	8
Depth	m	6
Total heating surface	m ²	180
Volume	m ³	300
Form factor		0,6
Floors	n°	2
Walls transmittance	W/ m ² K	0,310
Windows transmittance	W/ m ² K	2,616
Intermediate floor transmittance	W/ m ² K	0,362
Ground floor transmittance	W/ m ² K	0,357
Roof transmittance	W/ m ² K	0,326

Heat pump and managing

The model developed provides the performance of the inverter-heat pump from the nominal data for air-water configurations. In particular, we have implemented in accordance with the algorithms provided by the technical regulations (UNI EN 15316, UNI TS 11300 and EN 14825) correction matrices that determine the performance parameters of a heat pump in function of the variation:

- return water temperature
- outdoor air temperature
- percentage of load

Such matrices have been determined from experimental performance data of a sample of commercial heat pumps.

The output parameters provided by the model are: Coefficient of Performance (COP), thermal and electrical power. Table 3 shows the nominal data of operation, the model you have entered all the data to the various regimes of operation of the compressor (in the range 30% -100%) provided and certified by the manufacturer.

Table 3: Technical data about A/W heat pump

Heating		
Heat power	kW	31.5
Electric power	kW	10.70
COP (EN 14511:2011)		2.93
Cooling		
Cooling Power	kW	29.1
Electric power	kW	12.70
EER (EN 14511:2011)		2.29

In the management configuration of unit was inserted a photovoltaic control. This control allows the unit to vary its operating set point in proportion to the availability of electrical energy produced by the photovoltaic plant. It is a very simple and economic control and it can also be implemented in existing plants, in the case of energy retrofitting. In fact, for its operation it is sufficient to know the available electric power, for example through the measuring transformers installed in the building electrical line, and change the set point of operation via the unit software or through communication using a communication protocol (like BMS, BACnet, Konnex).

PV model

The model simulate a grid connected PV plant through parametric curve of commercial mono and polycrystalline module [6]; the output generated is the electric power of each module in Maximum Power Point inverter configuration, which is function of irradiation and outdoor temperature and take in account:

- pv generator losses
- overheating losses
- reflection losses
- losses in CC/CA conversion

Table 4: Technical data photovoltaic modules

Technology		monocrystalline silicon
NOCT	°C	44
Nominal Electric power per module	W	240
Tilt angle of module	°	35
Azimuth angle of module	°	0
Number of modules		25
Dimensions	m	1.58x0.8x0.035

Weather Generator

Temperature and radiation input to the model are produced by a climatic data generator, called Neural Weather Generator (NWG) developed by ENEA. Unlike common models, in which data are given by a database of historical values of several locations, the NWG estimates climatic values through neural evolutive networks. This networks are trained with weather data (mean monthly values) of Italian provinces (UNI 10349) and verified by ENEA's solar radiation atlas. For this work were used climate data refer to the city of Milan for the year 2015, they have been directly measured. The use of real data (instead of the year type) allows to obtain very realistic simulations as shown in another paper [7]. Figure 2-3 show the outside temperature and solar radiation considered.

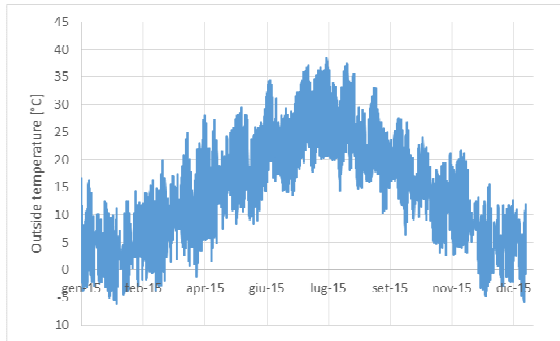


Fig 2: Outside temperature

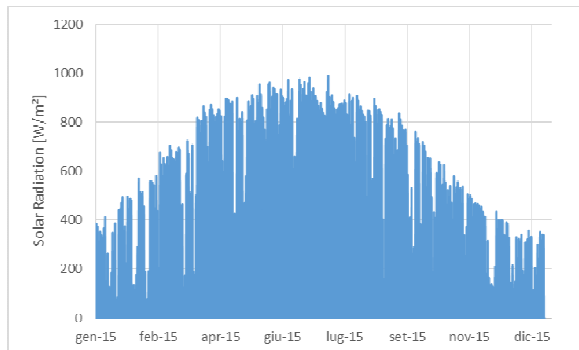


Fig 3: Solar radiation

3. Result

The results obtained show how the simple and cheap monitoring system proposed can lead to good benefits. The following charts are shown for each month: the photovoltaic electricity used by the unit, the amount of photovoltaic electricity get into the grid and the efficiency of the operation of the unit. The basic configuration foresees the use of the two systems independently (no communication between photovoltaic plant and heat pump) as happens in most cases. In other cases it has been implemented the control system to increase the self-consumption and after has been increased the size of the thermal storage to allow greater heat storage. Months of May and September are not showing because in these months there are not heating or cooling demand so the unit doesn't work.

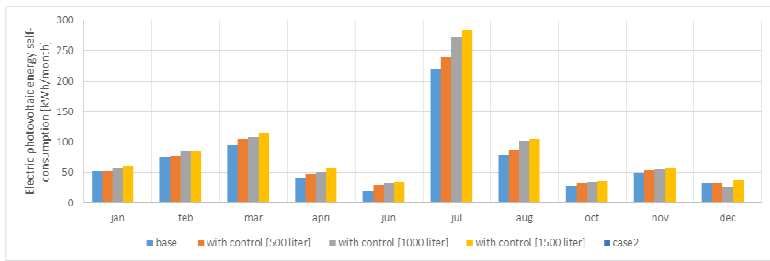


Fig 4: Photovoltaic electricity used by the unit

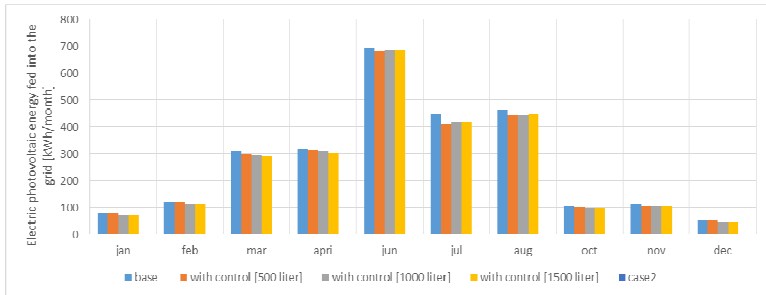


Fig 5: Photovoltaic electricity get into the grid

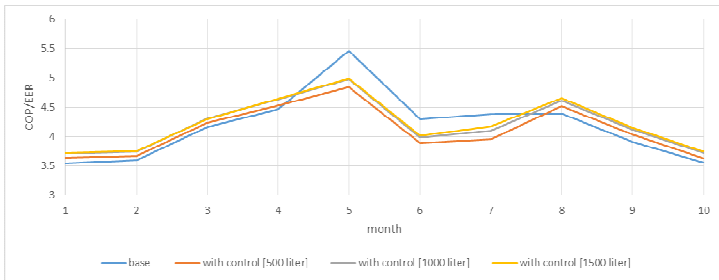


Fig 6: Efficiency of unit (COP or EER)

4. Discussion and conclusion

Dynamic simulations carried out have had as subject a residential building has a photovoltaic system and an inverter air / water heat pump. In most cases it happens that these two systems do not communicate between them and then the photovoltaic energy is get into the grid without own consumption and the heat pump is powered by energy source not totally renewable. To overcome this inefficiency has been implemented an adjustment mechanism which allows the heat pump to work more when it has available energy from renewable sources. In this case renewable energy is that produced directly from the building but in the future may be the one transported by the electric smart grid (smart grid ready heat pumps). The suggested type of control is very simple, inexpensive and can also be implemented in existing systems. Simulations showed that increasing the size of the accumulation heat the self-consumed energy share increases (and consequently decreases the share of photovoltaic energy get into the grid). An indirect consequence very positive is the increase of the COP of the unit during winter operation, in fact the heat pump induced to work more during the day, with a greater outside temperature and therefore with a greater efficiency. The detail and the precision with which it was developed the simulation model will surely deepen the theme and to study new configuration setting in order to obtain results even more satisfying.

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