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An evaluation of distributed solar thermal "net metering" in small-scale district heating systems

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Abstract

In this paper the presence of customers (prosumers), connected to a District Heating Systems (DHS), that not only can consume but also produce district heating by means of small-scale solar collectors, and that can use the DHS as a virtual storage for the thermal energy produced and not immediately used, with the possibility to use it later, is investigated. Three configurations were simulated: (1) absence of solar thermal system, (2) solar thermal system not connected to the DHS, (3) solar thermal system feeding a local heat storage, connected to the DHS by a single bi-directional heat exchanger. The results show that for the connected configuration, the thermal solar system can overcome the limited production of the isolated configuration during summer, producing thermal energy to feed the DHS, and that the thermal energy produced annually is more than 100% the annual energy needs of the single family house for space heating and domestic heat water.

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Keywords: District heating, Solar thermal, Net metering, Distributed generation, Prosumers.

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1. Introduction

The goal of the paper is to identify energetic and economic benefits and to investigate the problems resulting from the grant of the thermal net metering to the users with solar thermal plants connected to district heating networks.

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Gathering the definition used for power grids, thermal net metering can be defined as a mechanism that allows renewable energy producers to use the district heating network to which they are connected as a thermal storage for the energy produced and not self-consumed, in order to use it later.

The Italian Legislative Decree no. 28/11: implementation of Directive 2009/28/EC requires, since May 2012, that thermal energy plants for new buildings or for buildings subjected to a deep renovation, must be designed and built to ensure that at least 20% of the heat demand for domestic hot water, heating and cooling must be met by renewable sources; the limit will be increased to 50% from January 1, 2017. The targets of the decree could be particularly ambitious, especially in areas with high population density, where the installation of technologies to produce the required heat demand from renewable sources might be difficult due to lack of space or for integration problems. These difficulties could drive designers to invoke the presence of technical constraints. The aim of this work is to investigate solutions to solve these technical constraints.

On the other hand the installation of a solar thermal plant for heating and domestic hot water demand, may be oversized during periods of low heat demand (from March to September) in the absence of applications such as solar devices for cooling. In these conditions, the production of thermal energy from a renewable source is likely to be heavily penalized because, in absence of demand, the pumps of the solar circuit are switched off and the collectors covered to avoid the risk of stagnation of the fluid.

The district heating network, through a "net metering" management, could provide a daily and seasonal storage service for users with solar thermal systems, allowing to feed-in extra solar production and to supply all network users (such as domestic heat water in summer or space heating demand in winter), increasing in this way the share of energy demand from renewable sources provided to each building.

2. The bidirectional customer substation

The numerical tool used to simulate a small scale district heating system (DHS) in this paper is described in [1]. The software platform, developed in a Matlab/Simulink environment, is able to perform dynamic simulations of a small scale district heating, where a multi-building system (residential buildings, dwellings, office buildings, shopping centers, etc.), with inhomogeneous electric and heat loads, is served by thermal networks. The developed software takes into account heat generator models (CHP, gas boiler, solar plant), thermal network, building models, utilities substations and a wheather generator in order to analyze various scenarios and different control strategies for small-scale district heating. The main heating output variables, calculated hourly, are: indoor air temperature for each building, average fluid temperature of the network, fluid temperature at each node of the network, thermal power supply for each building and for the whole network, thermal losses along the network.

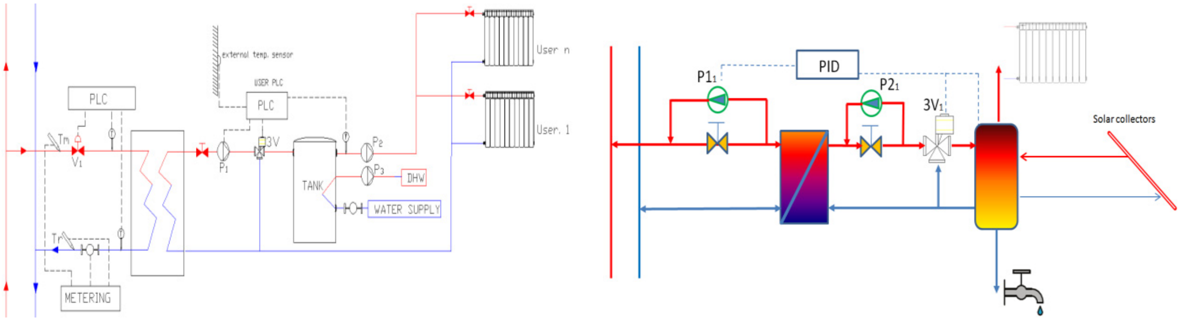
User substations are one of the most important components in a district heating system, because they represent the transfer point of thermal energy from the grid to the users. In this paper, a bidirectional substation is modeled in order to investigate the presence of customers, connected to a DHS, that not only can consume but also produce district heating by means of small-scale solar collectors. In this scenario, the energy and environmental benefit represented by DHS can be further enhanced with the concept of Smart District Heating (SDH). A smart district heating system replies, in the heating sector, the concept of distributed generation and of energy exchange between a prosumer (i.e. a producer and consumer of energy) and the grid, already known for the electrical sector [2] [3].

In the investigated “net metering” connection mode, the prosumer can use the SDH as a virtual storage for the thermal energy produced and not immediately used, with the possibility to use it later.

Figure 1-a shows the scheme of the modeled traditional substation of a building connected to a DHS and Figure 1-b shows the scheme of the modeled bidirectional substation of a prosumer connected to a DHS.

In the traditional substation, the valve V1 (network side) is controlled to keep a constant return temperature and variable mass flow rate. On the user side, a three way valve “3V” is controlled by a PID to keep the operating temperature (T3) set point according to the climatic curve supplied by the Italian National Standard UNI 8364-2:2007.

The proposed scheme for the bidirectional substation (Figure 1-b) is designed to introduce into the distribution network only the excess of thermal energy produced by a local source (solar thermal collector). The operating principle of the bidirectional thermal exchange is "return to supply": it provides no impact on the district heating system return temperature and could be easily integrated with existing customer substations.



(a) (b)

Figure 1. (a) Scheme of a traditional substation; (b) Scheme of the bidirectional substation.

According to the solution of Figure 1-b, the solar system is connected directly to the thermal storage: it preheats the operating temperature during the winter season and it risks to overheat the water during the summer season.

The regulation strategy of the prosumer substation, showed in Figure 2, requires that the heat flux from the solar plant is firstly used to heat the fluid of the thermal storage. If the thermal load for space heating and domestic heat water (DHW) is not completely satisfied by the local production system (e.g. during winter) the PID controller closes the three way valve "3V1" to provide the residual heat by the thermal network (the DHS) leading the temperature of thermal storage to the set point according to the climatic curve. If the local production exceeds the thermal load (typically during summer and spring), the storage temperature exceeds the temperature of the supply network, and the control system activates the pump P2 and opens the three way valve "3V1" to its max position, in order to achieve the introduction of heat into the network. The pressure supplied by the pump P2 must overcome the pressure in the district heating network.

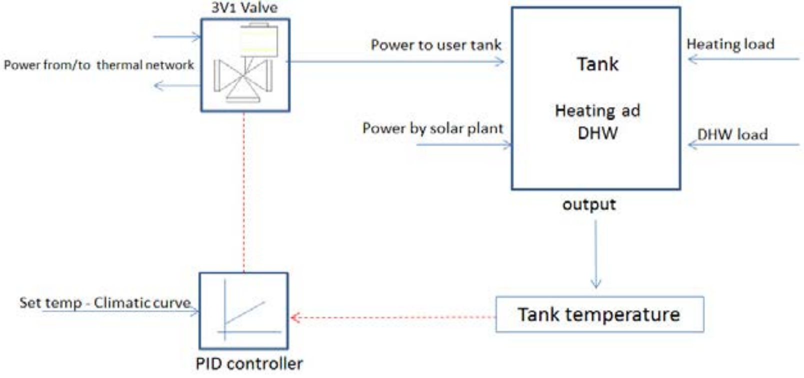


Figure 2. Regulation strategy for the bidirectional substation.

3. The simulated small-scale District Heating System

The presence of prosumers in a small-scale DHS has been investigated by means of the simulation of the small-scale DHS schematically represented in Figure 3. It is a tree type DH scheme, with centralized heat production, hypothetically located in Rome and with the following connected users:

- a single family house, 100 m^2 of heated surface;
- a school, 1000 m^2 of heated surface on two floors;
- an office building, 500 m^2 of heated surface;
- a block of 5 single family dwellings, 100 m^2 of heated surface each.

The centralized heat generator is a natural gas CHP unit, with a nominal thermal power of 250 kWt and nominal electric power of 170 kWe.

The main geometric features of the DHS, with reference to the scheme of Figure 3, are presented in Table 1.

Table 1. Main geometric features of the DHS

Ø of the main pipe [m]	L_1 [m]	L_2 [m]	L_3 [m]	L_4 [m]	L_5 [m]	L_6 [m]	L_7 [m]	L_8 [m]
0.25	300	15	200	15	100	100	100	20

Further characteristics of the DHS are schematically summarized in Table 2

Table 2. Further features of the DHS

U-value of the main pipe [W/mK]	Volume of the centralized heat storage [m^3]	Overall volume of the heating fluid in the DHS [m^3]	Set-point of the working feeding temperature during winter [°C]	Set point of the working return temperature during winter [°C]
0.14	3	10	85±2°C	65±2°C

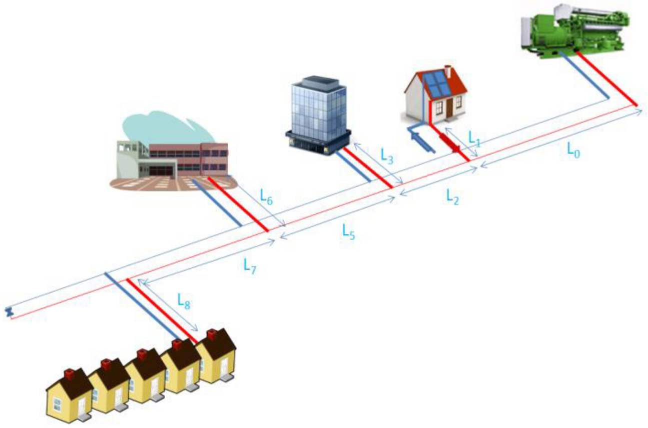


Figure 3. Scheme of the simulated small-scale District Heating System.

3.1. The simulated schemes

The 100 m^2 single family house, connected to the DHS, has been simulated in three different configurations:

- without any solar thermal system;
- with a 50 m^2 solar thermal system and a 3 m^3 daily heat storage, in a stand- alone configuration (no connection of the solar system to the DHS);
- with a 50 m^2 solar thermal system and a 3 m^3 daily heat storage, connected to the DHS as described in §2.

The size of the solar thermal system (50 m^2) was chosen, in the hypothesis of a two slope roof facing North and South, to cover almost completely the Southern slope. A common design practice for solar thermal would suggest to use a heat storage of about 4 m^3 per 100 m^2 of collectors, that would mean about 2 m^3 for the simulated case. An increase to 3 m^3 was chosen to increase the solar fraction from the solar system during summer. With the same purpose, the upper working limit temperature chosen for the pressured thermal storage was 110°C.

In the third configuration the single family house is a “prosumer” for the DHS.

4. Results and discussion

The simulation results show a dynamic behavior of the active user during the year. In Figure 4 the heat flux exchanged between the DHS and the bidirectional substation in case of solar system connected to the DHS is represented with a black line. A clear inversion of the heat flux can be observed on about the first week of April (the 2500th hour of the year). Between the first week of April and the end of September (about the 6900th hour of the year) the substation is feeding the DHS and the single family house is no longer a consumer, but a producer.

The switch from a consumer to a producer behavior is related to a rise of temperature of the heat storage over the working value of the feeding temperature of the DHS; this rise is caused by a heat production by the solar system that exceeds the energy needs of the single family house for space heating and DHW.

Figure 4 shows also the temperature reached by the heat storage in the three different simulated configurations. With the stand-alone configuration (green line) the temperature reaches the upper working limit for the solar system (110°C) during summer, stopping the operation of the solar plant and thus limiting its annual energy production.

Connecting the solar thermal system to the DHS (Figure 4, yellow line), the temperature of the heat storage remains below 90°C, feeding into the thermal net the thermal overproduction.

In the three simulated configurations, during winter, the heat storage temperature follows the reference temperature given by the climatic regulation curve according to the implemented Italian National Standard UNI 9317/89.

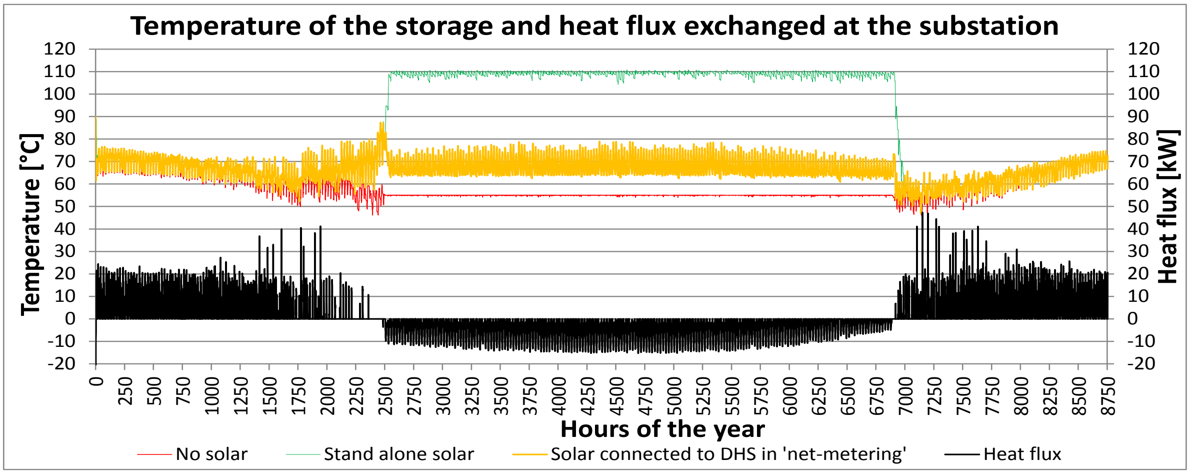
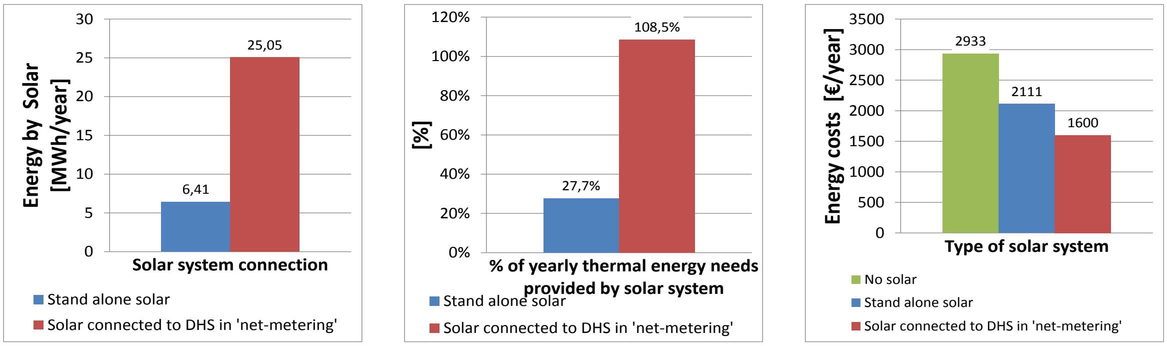


Figure 4. Temperature of the heat storage in the prosumer substation and heat flux exchanged with the DHS.

The effect, on the annual energy performance of the solar system, of the connection to the DHS in comparison to a stand-alone configuration is shown in Figure 5 (a) and (b). When connected, the solar system can use the DHS as a heat storage, and its energy production can continue throughout summer instead of being stopped for operational reasons. The consequence is that the total annual thermal energy production of the connected solution is about 4 times the annual production of the stand-alone configuration (Figure 5-a). Comparing the energy production to the annual energy needs of the single family house for space heating and DHW (Figure 5-b), the stand-alone configuration provides about 28%, whereas the connected solution can cover about 108% of the total needs. If a "thermal net-metering" tariff scheme would be adopted using the same ratio of the already existing electric net-metering, the additional 8% exceeding the annual energy needs of the prosumer, could be used as credit for the following year. The results show also that the considered solar system, when in the stand-alone configuration, can satisfy about 19% of the needs for space heating and 100% of the needs for DHW, and it is therefore oversized considering only the summer heat demands.

A cost analysis has been performed, since the economic sustainability of the thermal net-metering solution depends on the price of both the energy bought from the DHS and sold to the DHS.

In a case of thermal net-metering already existing in Sweden [4], the price of the energy fed into the DHS is about 0.25 the cost of the energy bought from the DHS. Considering 0.09 €/kWh as the average price of the energy sold by the DHS utilities to the consumers in Italy, we used a ratio energy sold/energy bought of about 0.45 considered more suited to the Italian market, and thus we consider 0.04 €/kWh as the reference price of the energy sold by prosumers to the DHS utility.



(a) (b) (c)

Figure 5. (a) Total energy produced by the solar system; (b) Energy needs of the prosumers, provided by the solar system; (c) Annual cost of the energy for space heating and DHW for the three simulated schemes.

With the above hypothesized prices, as shown in Figure 5-c, the net-metering configuration allows a reduction of the heating bill of about 60% with respect to a passive user without solar system, and a reduction of about 44% with respect to the stand-alone solar system configuration.

5. Conclusions

The detailed reference substation model and the new model of bidirectional substation were integrated into the energy networks simulation platform, implementing a new software tool realized to evaluate (in the time domain) heat fluxes exchanged with the network by active users and the effects generated on the management strategy of centralized systems.

In the paper the presence of a prosumer with a 50 m^2 solar field integrated in the roof, in a small-scale DHS is presented. The results of the simulations carried out show that the net-metering integrated solution would guarantee an increase in meeting the annual total heat demand of the building from 27% (for stand-alone solar system) to more than 100%, with a reduction of the heating bill of about 60%, compared to passive management of users.

Furthermore, the high thermal power fed into the grid from the solar field during the summer season allows a reduced use of the centralized systems which, due to the low demand (only for DHW), would work in conditions of low thermal efficiency.

The goal of the analysis was to evaluate the right implementation of the models and their integration in the simulation platform. For this reason it is not possible to generalize the results of the simulations in terms of energy and cost savings to other network configurations. However the value of energy savings obtained, suggests the potential benefit of applying the net-metering configuration for thermal distributed systems connected to DHS.

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