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Smart District Heating: Distributed Generation Systems' Effects on the Network

M. A. Ancona[a]*, L. Branchini[b], A. De Pascale[a], F. Melino[a]

[a]*DIN - Alma Mater Studiorum University of Bologna – Viale del Risorgimento 2 - 40136 Bologna, Italy*
[b]*CIRI EA – Alma Mater Studiorum University of Bologna – Viale del Risorgimento 2 - 40136 Bologna, Italy*

Abstract

The European strategy 20-20-20 – providing for energy efficiency increase, pollutant emissions reduction and fossil fuel consumption reduction – leads to an increasing attention on the concept of smart cities. In this scenario, it is important to consider a possible integration between networks and distributed generation systems – *i.e.* to realize a bidirectional energy flux at the utilities, giving rise to the so-called smart grid – not only for the electrical sector, but also for the thermal energy field. Therefore, the concept of smart grid could be extended to the heat sector in relation to District Heating Networks (DHNs) and considering thermal energy distributed generation systems, such as solar thermal panels or micro-Combined Heat and Power (micro-CHP) generators.

In this study several different layouts for the utilities substations in smart DHNs will be presented and discussed. These layouts have been developed in order to allow the bidirectional exchange of thermal energy at the utilities, optimizing the thermal exchange as function of network design temperatures (for both the supply and the return), of utilities' thermal power requirement and depending on the characteristics of the production system.

Further, in this paper the results obtained from the simulations, carried out with the software Intelligent Heat Energy Network Analysis (I.H.E.N.A.) considering the implementation of the elaborated layouts, will be analyzed.

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Keywords: Smart Grid; District Heating; Utility Substations

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1. Introduction

As a consequence of climate change and urban air quality degradation, in the last year increasing attention has been paid on energy efficiency topic, renewable sources and distributed generation systems. In this scenario, an important goal would be to replicate in the heat sector the concept of smart grid, well-known for what concerns electric energy. With this purpose, the idea of Smart District Heating Networks (SDHNs) – *i.e.* the possibility of a bidirectional energy exchange at the utilities, realized thanks to the

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* Corresponding author. Tel.: +39 051 209 33 20; fax: + 39 051 209 33 13.
E-mail address: maria.ancona2@unibo.it.

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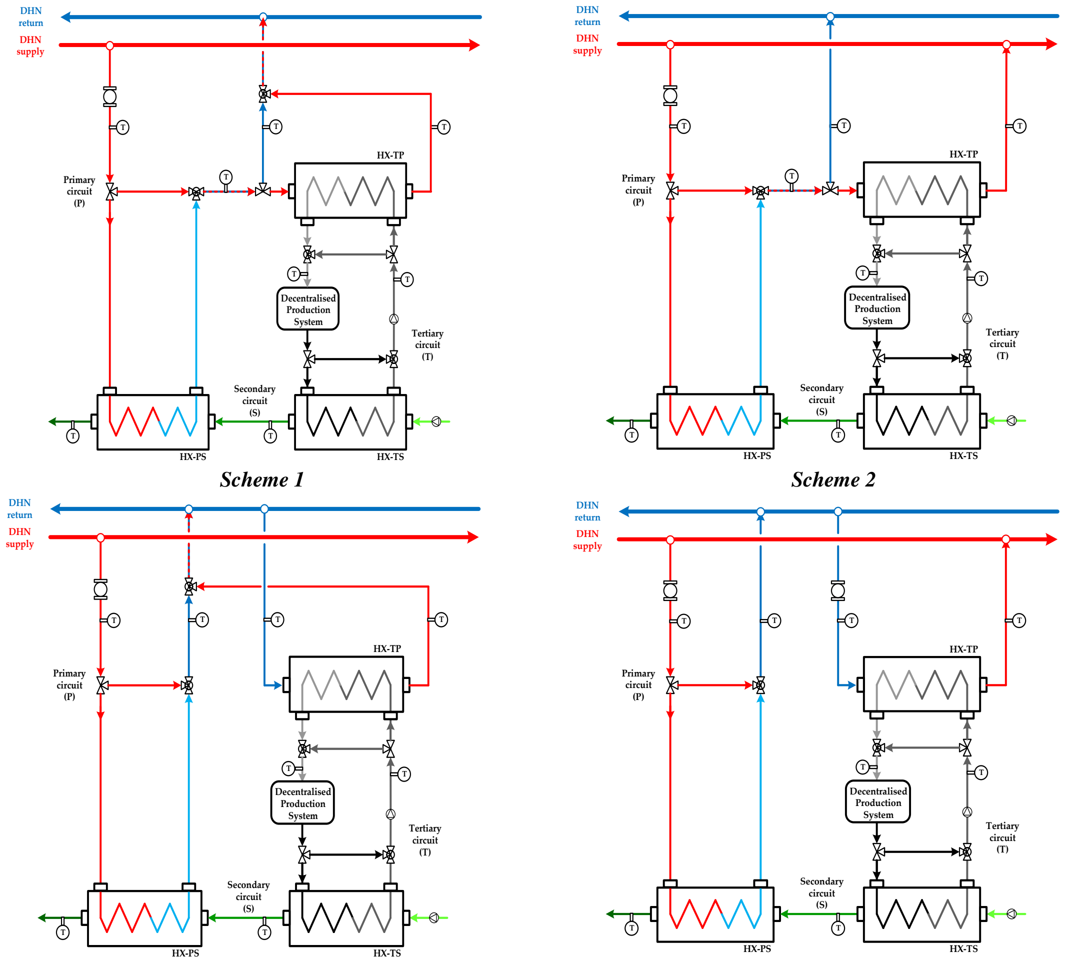
integration between distributed thermal energy generation systems and District Heating Networks (DHNs) – has been developed [1].

Examples of SDHNs can be found in Central and Northern of Europe, such as in Sweden, Denmark and Austria [2]; in particular, the distributed generation systems in these smart networks are often thermal solar generators. Obviously, also the cogeneration units can be used as decentralized thermal production systems in SDHNs with the only constraint of needing suitable temperature levels.

2. Utilities Substations in Smart District Heating Networks

In order to allow a bidirectional energy flux, the utilities substations are one of the most important components in the SDHNs, because they represent the transfer of thermal energy from the grid to the utilities. The four different utility substations layouts are presented in Fig. 1.



Scheme 1

Scheme 2

Scheme 3

Scheme 4

Fig. 1 – Hydraulic integration of decentralized production systems: scheme 1 – supply to return; scheme 2 – supply to supply; scheme 3 – return to return; scheme 4 – return to supply.

From the figure it can be noted that:

- scheme 1 *(supply to return)*: a mass flow rate is extracted from the supply of the network and it is heated by decentralized production system before the reintroduction in the return circuit;
- scheme 2 *(supply to supply)*: the thermal energy transfer from the decentralized production system towards the distribution network concerns only the supply circuit;
- scheme 3 *(return to return)*: the transfer of thermal energy from the utility to the network involves only the return circuit;
- scheme 4 *(return to supply)*: a mass flow rate is taken from the return circuit, heated from the decentralized production system and reintroduced in the supply of the network.

In all of the presented layouts three different circuits can be defined: a primary circuit, which connects the distribution network to the substation; a secondary circuit, which is internal to the utility and, finally, a tertiary circuit, which exchanges the heat produced by the decentralized system.

Moreover a common assumption has been made for all of the proposed schemes, *i.e.* the introduction only of the excess of thermal production into the distribution network. Therefore, the regulation strategy imposes that the produced thermal energy is always firstly used for the utility needs.

The increase of temperature on the return circuit of distribution network is not appreciated for the network management because it implies a change in control and regulation strategy of the whole network (reducing the conversion efficiency of the central production system); for this reason schemes 1 and 3 are rarely adopted. On the other hand, the increase of the supply circuit temperature is reached with the scheme 2; this effect could not be optimal for downstream utilities if they need a constant temperature flow and/or for others decentralized systems which can be excluded from the possibility of thermal energy feed-in. Finally, scheme 4 is the more complex scheme and it is the only one which modifies the current flow of the network, due to the flow from the return to the supply of the network. However, this scheme do not necessary implies the increase of the supply temperature (see Fig. 1), avoiding particular regulation problems related to the temperature profile. For instance, scheme 4 is widely adopted in existing SDHNs.

3. Software I.H.E.N.A.

The software I.H.E.N.A. (Intelligent Heat Energy Network Analysis) has been developed by University of Bologna with the aim of evaluating the performance of a SDHN. This calculation code is based on the Todini-Pilati algorithm [3] generalized by the use of Darcy-Weisbach equation and represents an evolution of the software Ca.R.Di.F. 5.1 [4], in order to take into account the bidirectional exchange of thermal energy with reference to the substation schemes in Fig. 1. The calculation code validation can be found in [5]. This software can be used for the design of new networks or for performance analysis and optimization of existing networks.

In Fig. 2 the flow chart of the software is presented. As it can be seen in the figure, six different sections can be identified:

1. *network implementation*: in this section the geometry layout of the network is defined;
2. *network input*: the main network input (source and utilities characteristics) are introduced;
3. *utilities fitting*: the first attempt solution – in terms of the balance between the decentralized thermal production, the utility needing and the network feeding – is calculated;
4. *network geometry implementation and operational parameters definition*: the network is drawn and the regulation strategy is defined;
5. *network calculation*: temperatures, pressures and mass flow rates are calculated, by applying the Todini-Pilati algorithm;
6. *text and graphical output*: the output in both text and graphical form are written.

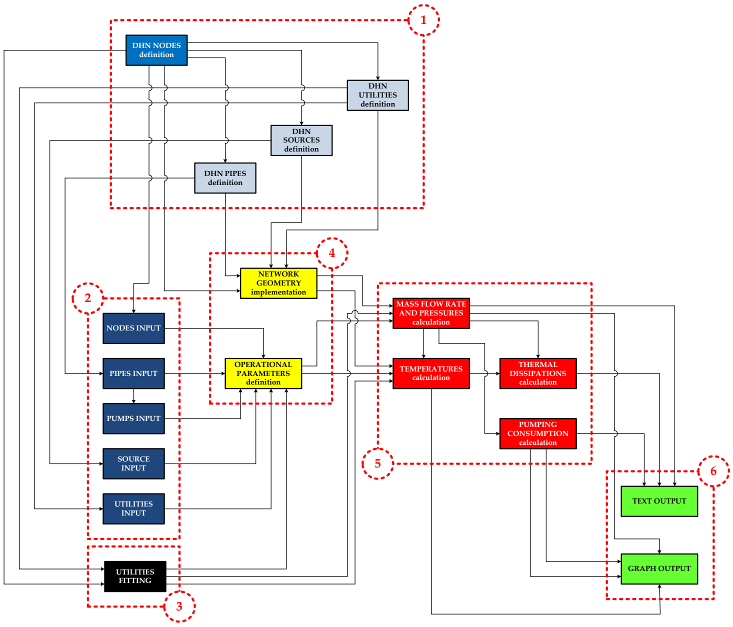


Fig. 2 – IHENA software main flow chart.

A detailed description of the required input and the software output is given in Authors' previous studies [1, 5].

4. Simulations and discussion

The developed software has been applied with the aim of studying the different behaviors of a district heating network when the various smart utilities substation schemes are considered. The network presented in Fig. 3, really designed even if not realized, has been chosen for the simulations. Firstly, with the software I.H.E.N.A., a simulation of the behavior of the chosen network, when no thermal production occurs at any utility, has been carried out. This preliminary analysis enabled to individuate the critical path – *i.e.* the path that, starting from the source, presents the higher pressure losses – highlighted in green color in Fig. 3. The main hypothesis assumed for the simulation are summarized in Table 1.

Subsequently, the utility represented by the node #12 has been selected as the one where a bidirectional thermal exchange with the network can occur. This choice has been made focusing on the critical path and considering that the node #12 is contemporarily mixer and utility, allowing therefore to generalize the developed analysis. The main characteristics of the distributed generation system, supposed to be installed at the utility #12 – are shown in Table 2.

In order to study the effect of the bidirectional thermal exchange on the network, several simulations have been carried out:

- the SDHN behavior has been analyzed by carrying out four set of simulations, each one considering a different smart utility substation scheme (schemes from 1 to 4 in Fig.1) in correspondence of the node #12;
- for fixed smart utilities substation scheme, the behavior of the network – when the ratio between the thermal power required by the utility ($Q_{th,u}$) and the thermal power produced by the distributed generation system ($Q_{th,sp}$) varies from 0 to 1 – has been evaluated.

The same simulations have been carried out considering also two other values for the supply temperature (T_M), equal to 90 °C and 60 °C respectively, but for the sake of simplicity only the case of T_M = 80 °C will be discussed in this paper.

The results of the simulations, in terms of temperature profile along the critical path for the case $Q_{th,u}$ / $Q_{th,sp}$ = 0.0, are presented in Fig. 4.

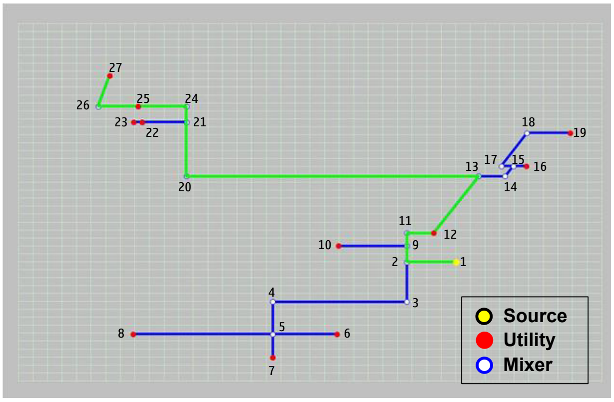


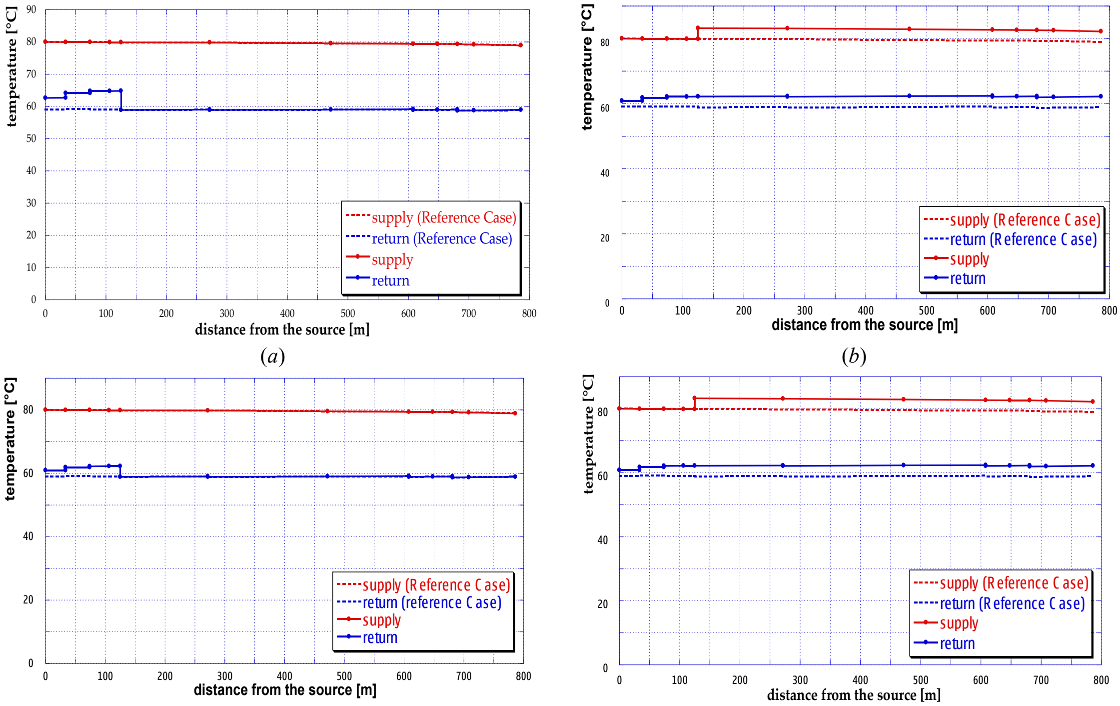
Fig. 3 – Network layout used for the analyses.

Table 1 – Main utilities and source parameters assumed for the analysis

Design thermal need of each utility ($Q_{th,u,\ DES}$)	200 MW
Supply temperature (T_M)	80°C
Supply pressure (p_M)	18 bar
Return pressure (p_R)	4 bar

Table 2 – Distributed generation system parameteres

Design thermal power production ($Q_{th,sp,\ DES}$)	200 MW
Production temperature (T_{SP})	110 °C



(*a*) (*b*)

(*c*) (*d*)

Fig. 4 – Temperature profiles along the critical path of the network – for both the supply and the return – for the case $Q_{th,u}$ / $Q_{th,sp}$ = 0.0 and when the utility substation at the node #12 can be represented with (*a*) scheme 1, (*b*) scheme 2, (*c*) scheme 3 or (*d*) scheme 4. In dotted lines the temperature profiles when no thermal production occurs are presented as comparison.

From Figure 4 it can be noted that:

- the scheme 1 entails the increase of the temperature on the return of the DHN and, as a consequence, also the temperature at the inlet of the centralized source increases. This effect is unpleasant for the management of the network, due to the need of regulating the operation conditions according to the modified temperature, causing consequently a decrease of the centralized production system efficiency;
- with the scheme 2 the temperature increase occurs on the supply of the network and, then, it propagates also on the network return. However, due to the thermal dissipations across the network, the return temperature increase is lower than the one achieved with the scheme 1. On the other hand, with this second configuration, the inlet primary circuit temperature for the utilities located downstream – on the respect of the considered smart utility – is higher than in the case without the smart utility. This effect might be negative if the downstream utilities have particular temperature limits and/or if these utilities are smart utilities too and the energy production occurs contemporarily;
- for what concerns the scheme 3, the same considerations already made for the scheme 1 can be done again. Moreover, the layout of the utility substation is more complex and it is necessary to take a certain mass flow rate from the return of the network with consequently management complication;
- finally, with the scheme 4 the same qualitative effects observed for the scheme 2 occur. Further, in this case even more than in the previous, the management of the network mass flows is critical and extremely delicate. On the other hand, the scheme 4 is the only scheme that – taking a mass flow rate from the return of the network and introducing it to the supply – allows to keep unchanged the temperature levels of both the supply and the return, only varying the mass flow rate.

Obviously, with the increase of the ratio $Q_{th,U}/Q_{th,SP}$ and with the increase of T_M the achievable temperature differences on the respect of the case without smart utilities decrease.

5. Concluding Remarks

With the aim of extending the concept of smart grid to the heat sector, especially in relation to DHNs, four different layouts for the utility substations in SDHNs have been presented in this paper. The effect of the bidirectional thermal exchange on the network temperature profile has been evaluated with the in-house developed software I.H.E.N.A.. The results show that schemes 1 and 3 cause a temperature increase on the return of the network, with a consequent decrease of the centralized production system efficiency. On the other hand, the effect of the schemes 2 and 4 is on the supply of the network; in particular, scheme 4 eventually allows to vary only the mass flow rates while temperature levels might result unchanged.

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