SIXTH FRAMEWORK PROGRAMME

HOME

Multigeneration perspectives

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Gianfranco Chicco graduated in Electrical Engineering (honors) at the Politecnico di Torino (PdT), Torino, Italy, in 1987 and received the Ph.D. degree in electrotechnical engineering from the PdT School in 1992. In 1995 he joined the PdT, where he is currently Associate Professor of Distribution Systems. Since 1998 he participated to the research activities of the National Power System Group (PdT unit), to research activities funded by the Italian Ministry for the University and for Scientific and Technological Research. He is author or coauthor of over 120 publications in national and international journals and Conference Proceedings.

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MULTIGENERATION PERSPECTIVES

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OUTLINE

- Distributed Energy Resources
- From cogeneration to multi-generation
- A look at the literature
- Approaches to multi-generation
- Distributed multi-generation
- Multi-generation schemes and components
- Equipment performance
- Examples of multi-generation schemes
- Energy carriers
- Conclusions

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ENERGY FOR THE NEW MILLENNIUM

- The New Millennium has started with several *innovations* driven by the evolution of the technologies
- Some of these technologies have already reached the *commercial stage*, providing solutions available to the consumers
- A clear example of large-scale diffusion of technologies is provided by *mobile phones* and *telecommunication devices*
- The *energy sector* is evolving very fast as well
- A *strong impulse* towards the diffusion of new solutions comes from:
  - ✓ the evolution of new *energy-efficient* technologies
  - ✓ regulatory *incentives* related to energy production from *renewable sources* and promotion of *environment-friendly* solutions
  - ✓ the evolution of the *electricity markets*
  - ✓ the need for reducing the electric system *vulnerability*

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DISTRIBUTED ENERGY RESOURCES (DER)

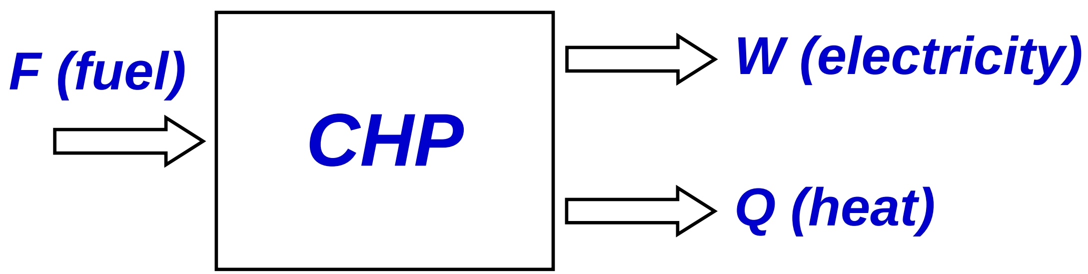
- The acronym DER encompasses *three* main components:
  - ✓ ***DG (Distributed Generation):*** *local energy production from various types of sources*
  - ✓ ***DR (Demand Response):*** *energy saving by customer participation to specific programmes for reducing the consumption*
  - ✓ ***DS (Distributed Storage):*** *local energy storage*
- The concepts of "*dispersed storage and generation*" and "*demand side management*" are not new
- The *theoretical framework* have been set up more than 20 years ago
- Various applications have been developed in the *industrial* sector (*self production* and energy *backup* during emergencies)
- The present technologies and economical systems are enabling the diffusion of DER applications in different energy contexts, up to the individual *non-industrial* users

DIFFUSION OF DER

- The adoption of DER solutions can *defer* huge investments in new large generation plants, substations or infrastructures, whose long return of investment does not fit the current trend towards setting up *rapidly profitable* solutions
- DG has emerged as a key option for promoting energy efficiency and use of *renewable sources* in alternative to the traditional generation
- Availability of local resources may lead to preferring the type of energy with *higher local availability* of the corresponding “fuel”
- The presence of *local* resources requires to take into account the *local emission* problem, not addressed with large and “far” generation plants
- The trend towards *distributed micro-power* could be significant for reducing the *vulnerability* of the electrical system from the effects of service interruptions, blackouts, vandalism or external attacks

FROM COGENERATION …

- The *multi-generation* (or *poly-generation*) concept is emerging as a generalization of the aspects related to the classical cogeneration
- ***Cogeneration*** (or ***CHP***, Combined Heat and Power) refers to the *simultaneous production* of electricity and heat from the fuel source
- The cogeneration effectiveness is due to the possibility of obtaining significant *energy saving* with respect to *separate production* of the energy required to satisfy the user's demand
- Considering a *black-box* model



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… TO MULTI-GENERATION

- The *multi-generation* (or *poly-generation*) concept is emerging as a generalization of the aspects related to the classical cogeneration
- ***Multigeneration*** refers to the simultaneous production of *electricity*, *heat* (at one or more *enthalpy levels*, e.g., including hot water and steam) and *cooling power* from the fuel sources
- Depending on the *number of outputs*, it is possible to set up cases of *tri*-generation, *quad*-generation, and so forth
- Multi-generation *plants* can be considered to be *local* (i.e., connected to a single node of energy networks) or can form a ***DMG*** (Distributed Multi-Generation) system
- *Coordinated control* and possible *optimization* of the plant operation according to specified objective functions are needed within the DMG system

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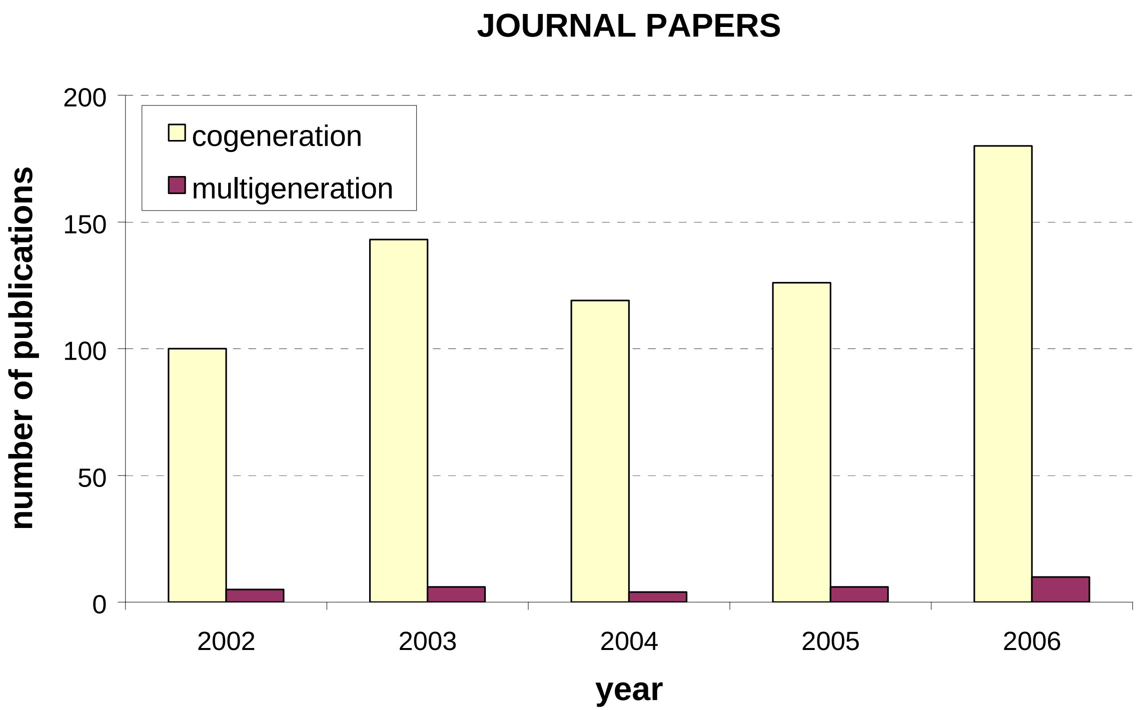
A LOOK AT THE LITERATURE

- The number of publications addressing *multi-generation* issues is still relatively limited
- Most papers refer to *cogeneration* issues, as indicated from the number of *journal papers* appeared on the IEEE Xplore and Elsevier on-line Web sites in the last 5 years



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APPROACHES TO MULTI-GENERATION

- Various *approaches* have been formulated recently for addressing the studies on multi-generation systems, each of which within a specific framework
  - ✓Distributed Multi-Generation (DMG)
  - ✓Micro-grids
  - ✓Energy Hubs
  - ✓Integrated Energy Systems (IES)
  - ✓Virtual Power Plants (VPP)
- Specific reference is made here at first to the DMG approach
- The other approaches are then briefly recalled

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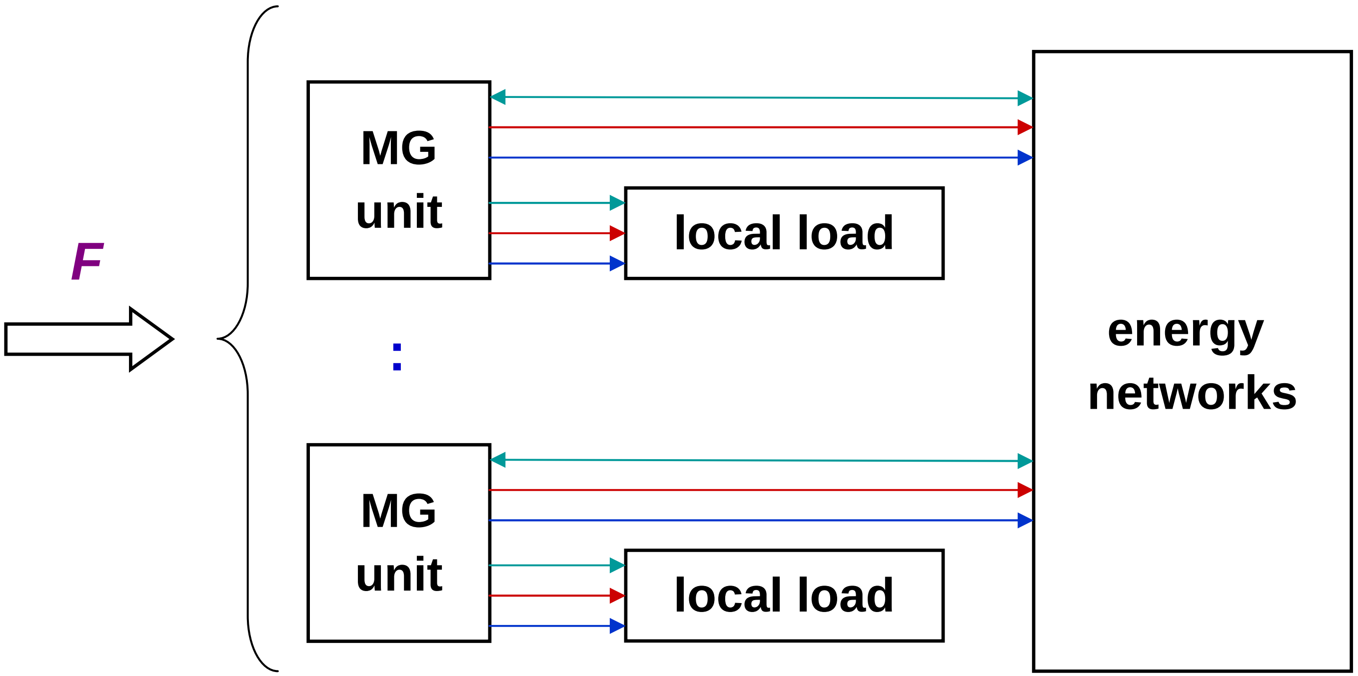
DISTRIBUTED MULTI-GENERATION

- Within the *black-box* model, the DMG system is structured as a set of multi-generation (MG) units supplied by the relevant *fuel* and connected to the *energy networks*



F (fuel) ***W (electricity)*** ***Q (heat)*** ***R (cooling)***

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MULTI-GENERATION APPLICATIONS

- In the *present status* of the energy production:
  - many local resources are *scattered* within the system
  - there is little or no *coordinated control* of these resources
- The distributed generation has an increasing diffusion at the *small-scale* level (below 1 MW_e)
- Some *existing technologies* (e.g., internal combustion engines, microturbines) well fit into co-, tri-, quad-generation (…) applications
- Enhanced *absorption group* and *heat pump* technologies are available at decreasing price
- There is a consequent improvement of the economic *profitability* of setting up the DMG system
- Many potential *multi-generation applications* on a small-scale basis include hospitals, hotels, food industry, schools, department stores, commercial buildings, offices, etc.

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MULTI-GENERATION APPLICATIONS

- The main advantages of the DMG diffusion refer to the *electrical grid* (peak load reduction) and the community (*energy saving*)
- Higher efficiency enables accessing to possible *financial discounts* provided by the national regulation
- *Emission* reductions (for hazardous pollutants and CO_2) give the possibility of accessing new *energy-related markets* (e.g., for white certificates, green certificates, emission allowances)
- The typical *limit* of adopting multi-generation solutions lies in the need for *simultaneous demand* of the different types of energy
- The *variety* of technologies that can be adopted in the multi-generation plant enables exploiting the *different energy vectors inside* the plant and is particularly helpful in finding out *viable* and *effective* solutions for different types of applications

DMG BENEFITS

- *Cogeneration* of heat and electricity, as well as the generation of cooling power with opportune chillers and cooling storage systems, can lead to:
  - ✓ better and longer **exploitation of the prime mover capacity**
  - ✓ higher **primary fuel exploitation**
  - ✓ enhanced **economic profitability**
- The higher overall efficiency production of manifold energy vectors with respect to the separate production, may reduce the investment *Pay-Back Time*, in particular if compared with the case of the electricity-only production
- An investment deemed to be *non-profitable* in terms of electricity-only generation may become *viable* in terms of DMG
- *Dispatching* DMG systems is likely to provide better plant management, obtaining a production cost lower than for electricity-only production (especially in the presence of financial discounts)

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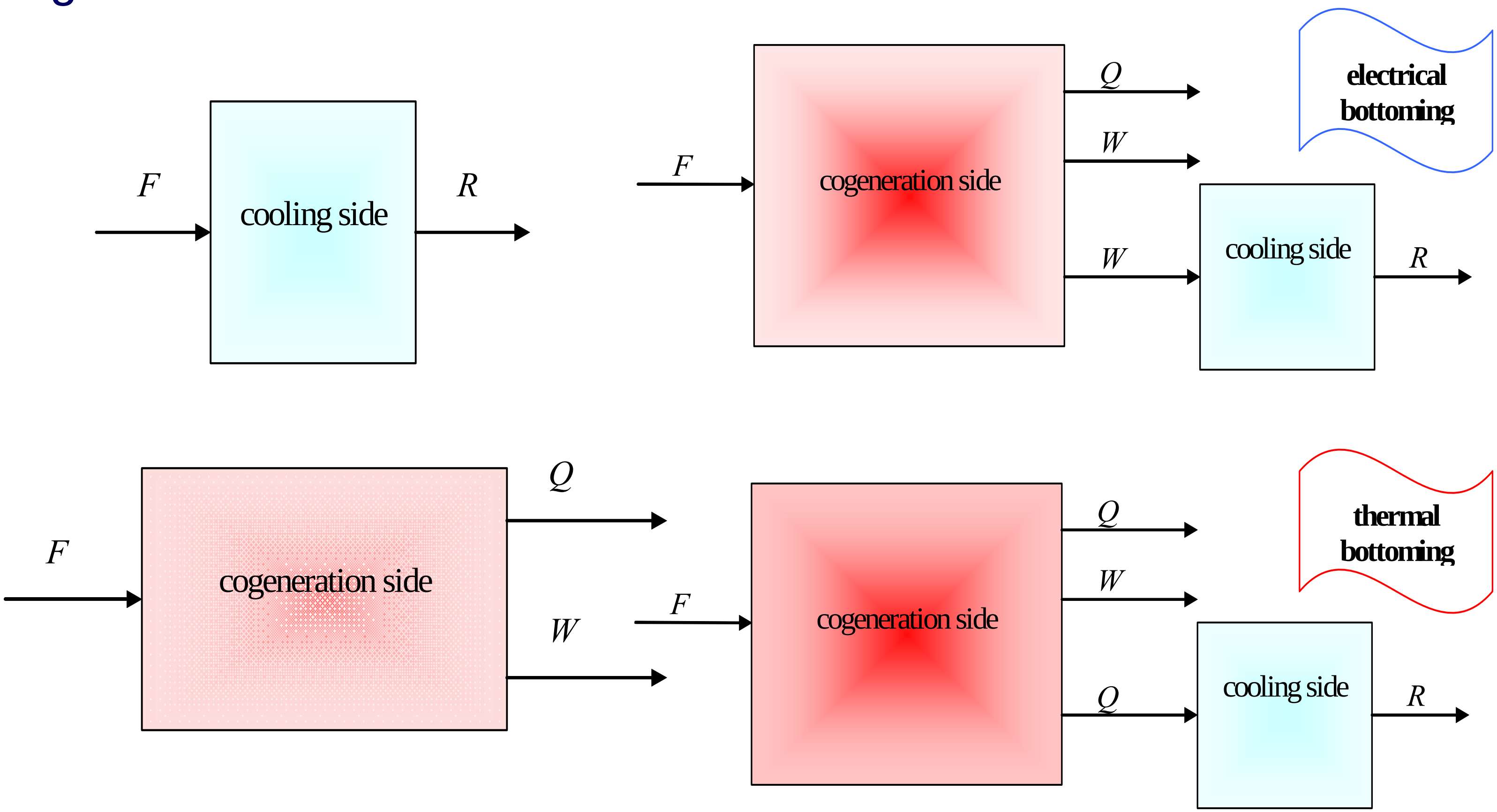
MODES OF OPERATION

- ***backup supply***
  - ✓ the local unit is *off-line* during normal operation and is switched on after a service interruption
  - ✓ the local unit can be combined with *storage* systems to act as UPS (Uninterruptible Power Supply)
- ***peak shaving***
  - ✓ the local unit is *always connected* to the distribution system
  - ✓ the local generation *never exceeds* the local load
  - ✓ the power flow is always *unidirectional* from the distribution system to the local one
- ***net metering***
  - ✓ the local unit is *always connected* to the distribution system
  - ✓ the local generation *may exceed* the local load
  - ✓ the power flow may be in *both directions* (from/to the local system)
  - ✓ *separate metering* of the energy flows in the two directions is required to account for time-dependent energy tariffs

MULTI-GENERATION SCHEMES

- Example for tri-generation with *separate* and *bottoming* cooling generation modes



separate ***bottoming***

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MULTI-GENERATION PLANT COMPONENTS

- Focus on *small-scale* multi-generation

- The *cogeneration side* is composed of
  - *cogenerator prime mover*, usually *gas*-fed (Internal Combustion Engines (*ICEs*) or Microturbines (*MTs*)

    +

  - *CHG* (Combustion Heat Generator) group, usually industrial boilers in *back-up* or *peak shaving* operation mode

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THE COOLING SIDE

- Alternative technologies may be used for the *cooling side* (including *reversible* machines):
- For *separate* schemes
  - ✓ *GARG*, *Gas Absorption Refrigerator Group* (direct-fired) (*GAHP*)
  - ✓ *EDC*, *Engine-Driven Chiller* (gaining market shares) (*EDHP*)
- For *bottoming* schemes
  - ✓ *CERG*, *Compression Electric Refrigerator Group* (standard reference for cooling production)
  - ✓ *EHP*, *Electric Heat Pump*
  - ✓ *WARG*, *Water Absorption Refrigerator Group (WAHP)* (fed by hot cogenerated water, classical "trigeneration" reference)
- Additional cooling/heat *storage* systems may be included

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EQUIPMENT PERFORMANCE

- *Separate* cooling/heat generation mode

Equipment	Operation mode	Performance indicator	Rated value
GARG	cooling	$COP_c = R/F_R$	0.7-1.4
	heating	$COP_t = Q/F_Q$	0.9-1.1
	heat recovery	$\varepsilon_t = Q/F_R$	0.5-2
GAHP	heating	$COP_t = Q/F_Q$	1.3-1.5
EDC	cooling	$COP_c = R/F_R$	1.2-1.8
	heat recovery	$\varepsilon_t = Q/F_R$	0.3-0.7
EDHP	heating	$COP_t = Q/F_Q$	1.5-2

COP = Coefficient of Performance

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EQUIPMENT PERFORMANCE

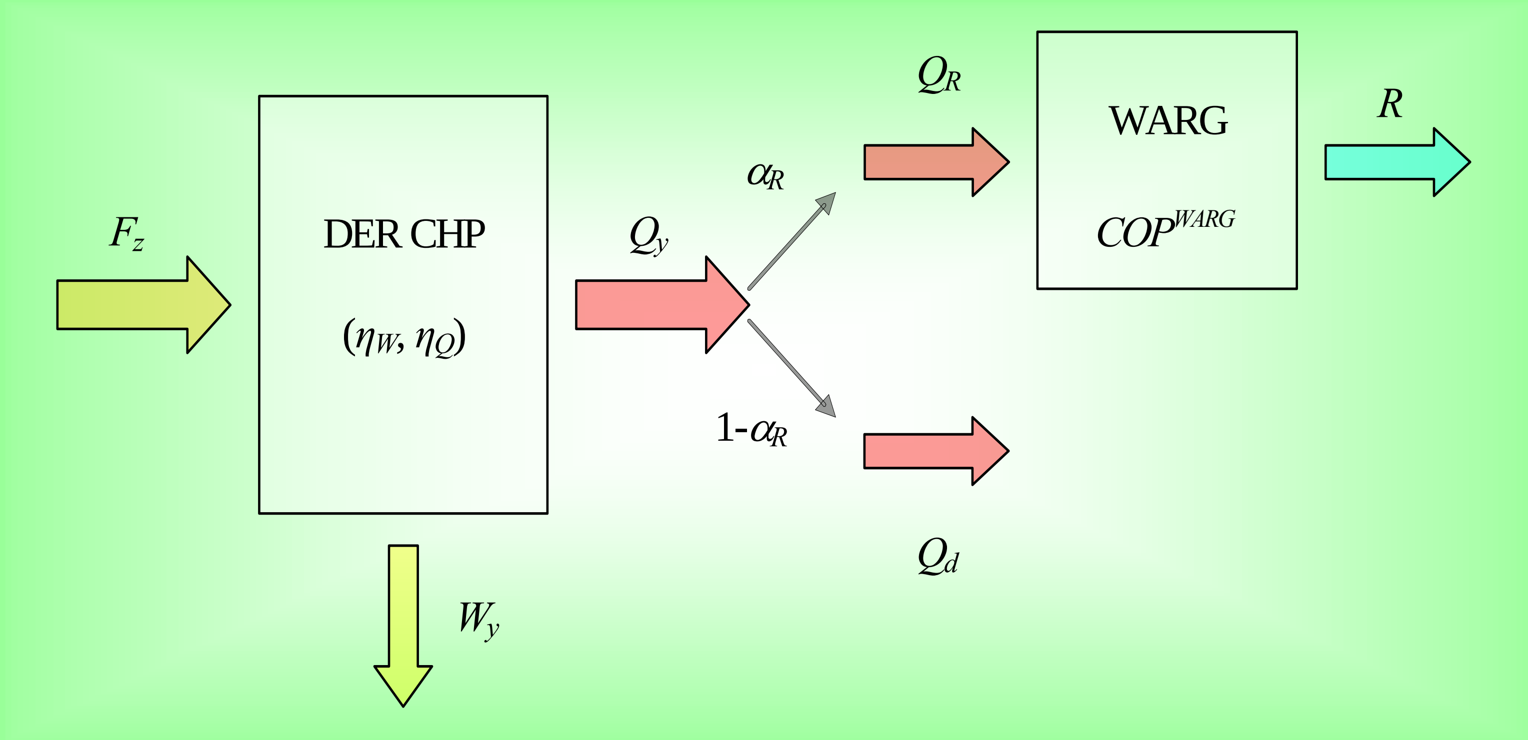
- *Bottoming* cooling/heat generation mode

Equipment	Operation mode	Performance indicator	Rated value
WARG	cooling	$COP_c = R/Q_R$	0.6-1-3
	heating	$COP_t = Q/Q_Q$	0.9-1.1
	heat recovery	$\varepsilon_t = Q/Q_R$	0.5-2
WAHP	heating	$COP_t = Q/Q_Q$	1.1-1.5
CERG	cooling	$COP_c = R/W_R$	3-5
	heat recovery	$\varepsilon_t = Q/W_R$	2-4
EHP	heating	$COP_t = Q/W_Q$	3-6
	cooling	$COP_c = R/W_R$	3-5

COP = Coefficient of Performance

CHP + WARG TRIGENERATION SCHEME

- Trigeneration scheme with the *black-box* approach



Q_R = thermal input to the WARG to produce the cooling power R

α_R = heat-to-cooling *dispatch factor*

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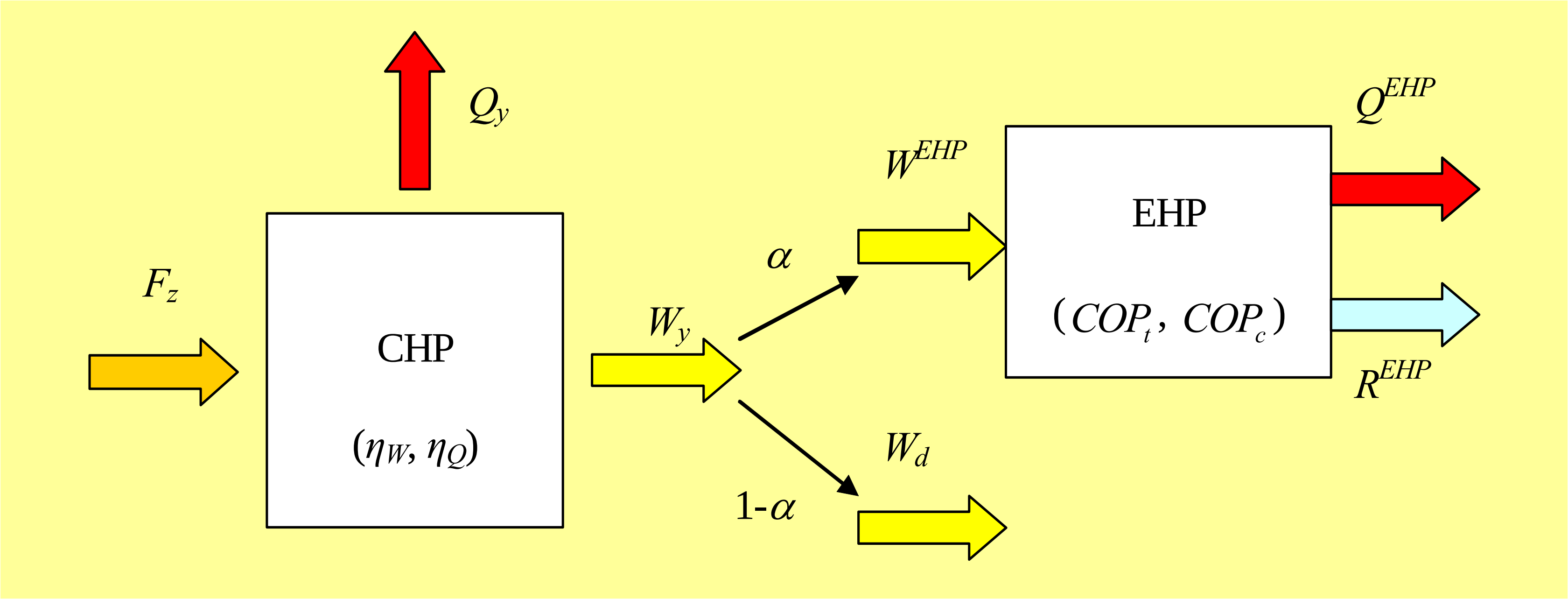
CHP + EHP MULTIGENERATION SCHEME

- Multi-generation scheme with the *black-box* approach
- *Quad-generation* with electricity, cooling and *two* thermal outputs



Q_y = "high" enthalpy level, Q^{EHP} = "low" enthalpy level
α = electricity-to-cooling or electricity-to-heat *dispatch factor*

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MICRO-GRIDS

- Micro-grids are small distribution systems containing generation and load, whose operation could be totally separated (*autonomous*) from the main distribution system or connected to it (*non-autonomous*)
- The *autonomous* micro-grid operation is critical, due to the possible problems in voltage and frequency control
- A *non-autonomous* micro-grid could help the main distribution system in feeding part of its loads in case of fault into the distribution system feeder
- This possibility would require revisiting the *protection schemes* and the standards of conduct of the distribution systems
- The micro-grid is operated from the *control center*, *monitoring* the energy demand/supply and *optimizing* the use of different distributed generators (DG), customers participating to demand response programs (DR) and distributed storage (DS)

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MICRO-GRIDS

- The network interface sees the *micro-grid* as a *single dispatchable* node
- *Advantages* of *micro-grids*:
    - ✓ high availability
    - ✓ management of the energy mix
    - ✓ modular operation planning
    - ✓ increase in economic efficiency
    - ✓ possible resource optimization inside the micro-grid
    - ✓ synergies for personnel resources, primary energy purchase, maintenance
- *Benefits* from a *micro-grid* system occur for different types of companies and organizations
    - ✓ rural communities far from the existing power grids
    - ✓ large industries with many local and scattered sites
    - ✓ industrial parks
    - ✓ island communities
    - ✓ power providers in developing countries lacking of infrastructure

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ENERGY HUBS

- Framework developed within the project "*Vision of Future Energy Networks*", in progress
- Focus set on the *long-term evolution* of the energy systems (time horizon of 30-50 years)
- Energy system structures revisited without considering the *limitations* provided by the *actual* constraints
- Specific consideration of *multiple energy carriers* (other than electricity) in the form of *energy interconnectors*
- Storage of different forms of energy in centralized *energy hubs*
- *Phases* of the project
  - ✓ development of the *modeling* and *analysis* framework
  - ✓ determination of *optimal system structures and operation strategies*
  - ✓ development of *tools* for comparing the optimal structures and strategies to the conventional ones
  - ✓ identification of *transition paths* from the existing status to the optimal solutions

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ENERGY CARRIERS

- Possible extensions refer to *multiple energy carriers*
  - ✓ *electricity* (deliverable at long distance with low losses)
  - ✓ *gas* (possible storage)
  - ✓ *compressible fuels* (delivered by packets)
- Multiple energy carriers enable *supply diversification*
  - ✓ supply no longer depending on a *single* fuel or network
  - ✓ needed to prevent reductions in *reliability* due to limited maintenance (in a market-orientated system)
  - ✓ more *degrees of freedom* for selecting the supply and for possible optimization
  - ✓ availability of *storage from* various sources (including hydrogen)
  - ✓ reduced energy system *vulnerability* through independent operation of various subsystems
  - ✓ deferring the *investments* on large generation systems

INTEGRATED ENERGY SYSTEMS

- Integrated Energy Systems (IES) programme launched in 2001 by the *US Department of Energy*
- Focus on the integration of distributed generation equipment with *thermally-activated* technologies
- Includes laboratory-based applications, e.g. for composed systems including microturbine with heat recovery, air conditioning and ventilation, desiccant and absorption chiller units
- Specific aspects
  - ✓ *maximize the efficiency of the energy use*
  - ✓ *reduce the emissions to the environment*
  - ✓ *improve power quality and reliability*
  - ✓ *study the characteristics of more flexible solutions for meeting the peak power demand with respect to large centralized power plants*
  - ✓ *formulation of mathematical models of individual devices and IES*
  - ✓ *development of test protocols and standards*

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VIRTUAL POWER PLANTS

- Framework of Virtual Power Plants (VPP) conceptually established in 1997
- Main objectives
  - ✓ enhance the *visibility* of the DER
  - ✓ provide suitable *interfaces* among the local components
  - ✓ activate *distributed control strategies*
  - ✓ promote the adoption of *ICT solutions*
  - ✓ address the *optimal* use of the available *capacity*
  - ✓ study the interactions with the *energy markets*
- Specific aspects of the VPP
  - ✓ characteristics similar as a plant connected to the *transmission system*
  - ✓ management of a *portfolio* of DER
  - ✓ possible *generation schedules*
  - ✓ internal *operating cost structure* (private information)
  - ✓ possibility of providing *system services*

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CONCLUSIONS

- The development of *DER* and *multi-generation* technologies is rapidly growing, with many promising solutions already at the small-scale level
- The main concerns for the *distributed multi-generation* (DMG) development in *urban areas* are
  - ✓the *integration* of various DER sources, in case benefiting from regulatory *incentives*
  - ✓the potential extended application of *clusters of units* (e.g., microturbines) to residential/commercial energy districts
  - ✓the possible exploitation of the *micro-grid* concept for managing dedicated areas as energy-integrated districts
  - ✓the limitations to the DMG expansion due to *regulatory constraints* imposing limits to the *local emission* of specific pollutants
  - ✓the development of *inverter* technologies for *network interface* of DMG, embedding controlling capability for power quality improvement
  - ✓the development of Information and Communication Technologies (ICTs) for *coordinating* the DMG management

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