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DISPOWER
A socio-economic analysis of technical solutions and practices for the integration of distributed generation

M. ten Donkelaar
M.J.J. Scheepers

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Abstract

This report analyses the socio-economic impacts of technical solutions and approaches that are being developed for the integration of distributed generation (DG) in electricity distribution systems. For this analysis an inventory was made of technical options, solutions and approaches on the basis of a questionnaire that has been distributed among DG (technical) experts. The questionnaire was not meant to give an exhaustive overview, but to gain insight in the possible technical solutions, options and approaches and the economic interactions between different actors in the electricity market. The different technical options and solutions have been divided into four main categories. Four technologies, one of each category, have been studied in more detail to analyse their impact on the financial relationships between the actors in the distribution network. The four technologies are:

- wind power prediction tool (planning tool),
- grid control unit (power quality device),
- power operation and power quality management system (ICT device),
- power storage device.

To assess the impact of the investments in the proposed technologies on all actors involved (and different from the actor investing), an assessment tool has been developed to qualitatively identify the economic impacts of a number of these options. This assessment tool takes into account the financial transactions between the parties on the distribution network. The analysis also discusses the allocation of the economic value of certain benefits through contracts and economic network regulation.

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ABBREVIATIONS

AC/DC	Alternating current/direct current
CAPEX	Capital Expenditures
CHP	Combined Heat and Power production
DEMS	Decentralised Energy Management System
DG	Distributed Generation
DISPOWER	Distributed Power (5th Framework Research Project)
DSO	Distribution System Operator
GCU	Grid Control Unit
ICT	Information and Communication Technology
IPP	Independent Power Producer
kV	kilovolts
LV	Low Voltage
MV	Medium Voltage
MW	Megawatt
NETA	New Electricity Trading Arrangements
OFGEM	UK Office of Gas and Electricity Markets
OPEX	Operational Expenditures
PANDA	Plan And Data Acquisition System
PoMS	Power operation and power quality Management System
R&D	Research and Development
RES	Renewable Energy Sources
SCADA	Supervisory Control And Data Acquisition System
SUSTELNET	Sustainable electricity networks (5th Framework Research Project)
TSO	Transmission System Operator
UoS	Use of System
VA	Volt Ampere
VAr	Volt Ampere reactive
WPPT	Wind Power Prediction Tool

EXECUTIVE SUMMARY

Distributed generation (DG), connected to the distribution network or at the customer side of the meter is gradually changing the electricity supply system in Europe. The share of DG is increasing due to a number of powerful drivers: technical developments in the field of generation technology, enhanced policies for climate change and sustainability, security of energy supply and the liberalisation of electricity markets.

DG influences the arrangement of the power system as it interacts in a different way with the network system than centralised generation. DG can be located at weak low voltage grids, can be of an intermittent nature and may require additional reserve capacity. Apart from these constraints, DG can present several advantages to the network. DG may be able, when located close to loads, to reduce losses in transmission and distribution networks, postpone necessary network investments and provide local ancillary services.

So far DG has been considered to be a passive appendage of the distribution network, not interacting with the network. For the future, this approach presents major challenges to the development of DG. It limits the further growth of DG as the network reaches its physical barriers or costly network upgrades will become necessary. An alternative is to look for more cost-effective network management and to view the distribution network and DG as an integrated structure, interacting and affecting each other.

Examples from Denmark, the country currently with the highest share of decentralised electricity production, show that substantial DG production can influence the whole network. For the UK, where the share of DG so far is relatively low, studies examining the impact of the UK's ambitious targets show that the additional costs for reserve and balancing may be substantial.

To cope with these problems, several alternative concepts have been considered, such as the active networks and Micro-grids concept. Although having slightly different features, both concepts see an important role for network control on medium and lower voltage levels.

As such concepts require special technical approaches, in this research the socio-economic impact of the application of these technical approaches in current liberalised electricity markets was studied. First an inventory was made of technical options and approaches to improve the integration of DG into distribution networks. To identify such specific technical solutions, options and approaches to improve the integration of distributed generation technologies a questionnaire has been developed and distributed among DG (technical) experts. The questionnaire was not meant to give an exhaustive overview, but to gain insight in the possible technical solutions, options and approaches and the economic interactions with different actors in the electricity market.

The questionnaire presented a number of options, varying from software tools (communication, planning supply and demand) to devices such as energy storage. The response of the questionnaire showed that excellent technical solutions are present at different levels of development that may smoothen the integration and interaction of DG with the network. When implementing these technologies in actual network management, however, one key issue remains: which party will invest in such a technology, especially when part of the benefits will accrue to another party?

To assess the impact of the investment in the proposed technologies on all actors involved (and different actors investing), an assessment tool has been developed to qualitatively identify impacts of a number of these options. This assessment tool takes into account the financial transactions between the parties on the distribution network according to Figure S.1. This research activity in the DISPOWER project merely provides an analytic tool how to identify the costs and benefits of a number of proposed technologies and how to allocate them between actors in the electricity market.

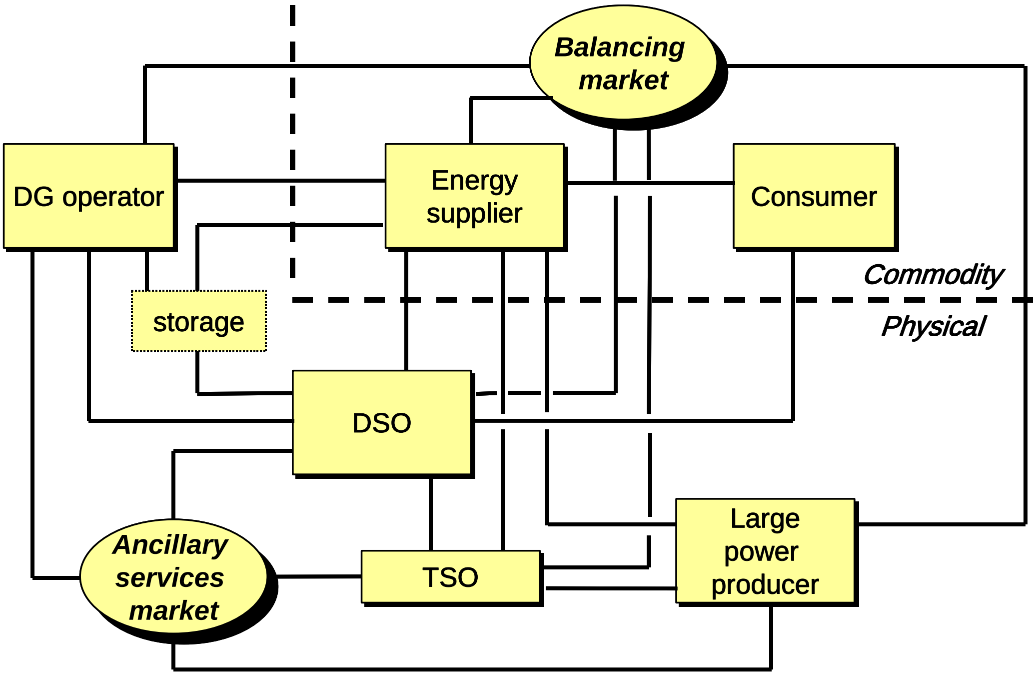

Figure S.1 *Transactions between actors in electricity network system*

The different technical options and solutions have been divided into four main categories. Four technologies, one of each category, have been studied in more detail to analyse their impact on the financial relationships between the actors in the distribution network. The four technologies are:

- wind power prediction tool (planning tool),
- grid control unit (power quality device),
- power operation and power quality management system (ICT device),
- power storage device.

Based on this analysis a number of conclusions can be drawn:

- Investments in the technical options have the potential to improve the integration of DG in several ways, for example:
  - increased or optimised power production (DG operator),
  - access to markets for balancing and ancillary services (DG operator),
  - reduced balancing costs (energy supplier),
  - ability to construct a more exact E-program, and better comply with the E-program (energy supplier),
  - improved power quality (distribution system operator),
  - reduced operational and capital expenditures (distribution system operator).
- Each of the three parties investigated, the energy supplier, the DG operator and the distribution system operator (DSO) have their own reason for investing in a specific technical option.
- All solutions have, next to a number of direct impacts for the actor investing, a number of indirect impacts to the other actors on the distribution network.

- For all parties to benefit optimally from the technical solution, an economic efficient allocation of costs and benefits will be needed, which should be carried out according to the following line:
    - the party investing receives the economic value of the benefits directly,
    - allocation of the economic value of benefits experienced by other parties through contractual arrangements (e.g. changes of contractual prices) or network regulation (e.g. changes of network charges).
- The DSO often plays a central role in many of the technical options and solutions, even if other parties do the investment. However, the DSOs cannot change the system of network charges themselves and are therefore restricted in the transfer of benefits and costs. It is important that this is recognised by policymakers and regulators.
- The allocation between energy suppliers and DSOs might be difficult because of absence of financial relationships. The regulatory framework should allow DSOs to enter contracts with energy suppliers, in particular because this will contribute to the transparency of the unbundling of utilities.
- The allocation of indirect benefits proves to be difficult because of the missing financial relationship with the party investing. Only via economic regulation the economic value of these indirect benefits (or costs) can be transferred via TSO and DSOs through network or system charges.

The analyses performed with the tool, developed in this research activity, showed a number of benefits and costs that can be taken into account when parties involved in the electricity supply invest in new technical solutions and options to integrate distributed generation. Follow-up research activities will have to quantify these benefits and costs identified and, of equal importance, the regulatory constraints that limit a ‘flexible’ allocation of costs and benefits between distribution network actors.

1. INTRODUCTION

Electricity supply systems were originally developed in the form of local generation facilities supplying local demands, being built and operated by independent companies. During the early years of development, this proved to be quite sufficient. Around the 1950s it was recognised, however, that an integrated system was needed that was both reasonably secure and economic. For this reason, the electricity supply system in Europe has been developed during the past 50 years into such a pre-dominantly centralised system with a limited number of large power producers. Electricity is nowadays mainly produced in large power stations and transported over a transmission network, sometimes over considerable distances, and passed down through a distribution network for delivery to the customers. However, recently there has been a revival of interest in connecting small-scale power generation plants, mainly small-scale renewable energy sources (RES) and combined heat and power (CHP) plants, to the distribution network or at the customer side of the network. This type of generation is also known as distributed or embedded generation[1].

The growing interest in distributed generation (DG) has been triggered by four major developments influencing the energy sector (ten Donkelaar, 2004):

- Technological developments in the field of generation and distribution technology.
- Liberalisation of the electricity markets, leading to stronger market competition and unbundling of generation and network facilities.
- The increasing importance of security of energy supply and the need for diversification of energy sources.
- The adoption of international environmental and sustainability targets (such as the Kyoto Protocol and the Renewable Electricity Directive) strongly influencing fuel choices for power generation.

Altogether these developments create opportunities for a gradual increase of the contribution of DG technologies that are better equipped than centralised power sources to meet the requirements of future electricity systems. DG facilities are normally located close to the site of the end-user, thereby reducing the need for transmission and distribution investment, while contributing to resolving many system constraints and reducing line losses.

Although many benefits of DG have been identified, there are a number of constraints that have to be overcome. First of all, there is a number of technical barriers on the network that can prevent a rapid increase of DG. An increasing share of distributed generation influences the arrangement of the power system. This is especially the case for renewable energy sources that have a much lower energy density than fossil fuels and so generation plants are smaller and geographically wider spread. In countries where the share of DG has been rapidly growing, the electricity networks are facing new challenges in terms of network stability and power quality, complicating the tasks of network operators. New technologies have to be developed to keep the electricity network running in an equally reliable way. The second barrier is of a more regulatory nature. The existing network regulatory framework, including grid connection, access to wholesale markets, balancing arrangements, etc. are usually biased in favour of centralised generation. Closely related to these issues are the economic barriers. DG incurs certain costs, but also certain benefits to the electricity network and society as a whole. Existing regulation, however, does not enable a proper allocation of these costs and benefits and therefore hinders a more (economically and technically) optimised integration of DG.

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1 Directive 2003/54/EC concerning common rules for the internal market in electricity defines distributed generation as “generation plants connected to the distribution system”.

1.1 The DISPOWER project

The cluster of DG research projects within the Fifth Framework Research Programme aims to tackle all technical, socio-economic and institutional barriers DG is facing in the current situation[2]. One of these projects is the DISPOWER project that, undertaken by 37 different research partners from 11 European Member States, intends to support the transition of nowadays electricity supply towards a more decentralised and market oriented supply structure with new concepts, strategies and tools. For maintaining a reliable and cost effective electricity supply, new efforts have to be undertaken for the management of electricity networks and the integration of RES and other decentralised units in the distribution networks.

Socio-economic research on technological solutions and options

The integration of DG into current electricity supply networks includes many socio-economical and institutional issues that can pose a barrier to this integration and to the further growth of DG potential. These issues are studied in Work Package 3 of the project. This Work Package involves four tasks (activities) aiming at the following issues:

3.1 Inventory of technical solutions and practices - Demand side.
3.2 *Inventory of technical solutions and practices - Supply side - This report*.
3.3 Analysis of consumer responses to new communication technologies.
3.4 Competition strength of DG and RES in a liberalised market and the roles of ICT and innovative distribution networks.

Task 3.2, included in this report, aims at analysing the technological solutions and practices that improve the overall integration of DG and RES into the existing distribution network. Such technical solutions include for example the dispatch of DG and RES, improving the system balancing and power quality, optimising use of generation and network capacity and improving ancillary services. The aim of this part of the study is to get some understanding of the costs and benefits of the technological solutions and options and the possible transfer of these costs and benefits between different actors in the electricity supply system.

For example a distributed generator might be dispatched automatically on basis of real time electricity market prices. Obviously, the operator of this distributed generator benefits from the automatic system, but so does the electricity supplier/trader that purchases the electricity. A third party, the network operator, may bear the costs of this automatic system, but may also benefit from this dispatch because DG reduces the network losses or can avoid network reinforcements. The proper transfer of costs and benefits in cases like this between different parties and functions in the electricity supply system (generation, trade, transmission/distribution, consumption) is vital for the implementation of DG. It may be difficult, however, to realise such transfers in liberalised energy markets where these separate functions are undertaken by separate parties.

This task makes an inventory of technical solutions and practices studied within the DISPOWER project and other DG projects that may facilitate the penetration of RES and DG. A distinction is made between ICT technologies (to improve communication and transfer of information on loads, prices, dispatch, etc.) and other innovations in distribution networks (storage, network configuration, etc.). In Task 3.4 the impact of the market structure and regulation on the use of these technical solutions and practices is analysed. The results of this analysis are published in a separate report.

[2] See for more information on these projects http://www.clusterintegration.org/.

1.2 Methodology of the work

An inventory has been made of technological solutions and practices that improve implementation of distributed generation and renewable energy sources. For the purpose of this inventory a questionnaire has been developed and further improved after a test among a small number of experts. The questionnaire aims at obtaining information from technical DG experts on benefits and costs of new technological solutions and approaches and the probable/estimated transfer of these benefits and costs between different actors in the electricity supply system. The questionnaire has been sent to participants in the DISPOWER project as well as in some other DG projects in the 5th Framework Programme (all part of the DG cluster). For this activity, a distribution list has been drawn up of approximately 140 experts, who received the questionnaire in the beginning of 2003. The respondents have been asked to present a certain technology and to determine its benefits and costs for the power distribution system. In case that not all benefits of the technology accrue to the party that is investing in the technology, the respondents were asked how the transfer of benefits (and costs) could take place. Results from the questionnaire have been integrated in further analysis of cost/benefit allocation of distribution network technologies.

1.3 This report

This report will start with a general overview of distributed generation and its interactions with the electricity network (Chapter 2) based on literature and information from other Fifth Framework DG Research. This interaction will be illustrated on the basis of concrete examples from European Countries. This chapter will shortly analyse new approaches in network management that are currently being developed. It includes a description of the electricity markets and the changing relations due to development and integration of distributed generation. Chapter 3 presents the results of the DISPOWER questionnaire and inquires socio-economic aspects of technical solutions. In Chapter 4, some of the cases from the questionnaire will be analysed into detail according to financial transaction schemes developed in this chapter. Results from this chapter will show how technical options, solutions and approaches impact on the revenues and expenditures of different parties in the electricity supply system. These schemes will be used later on in a follow-up report in the framework of Work Package 3.4 to make a detailed analysis of several promising options for the integration of DG into distribution networks.

2. DISTRIBUTED GENERATION AND INTERACTION WITH ELECTRICITY NETWORKS

The electricity supply system is experiencing two major developments, one is the opening up of the electricity market to new players and the unbundling of integrated energy companies, the second is the growing integration of distributed generation technologies in the electricity market. This chapter will describe some of the main features of distributed generation technologies and its interactions with the electricity network, both from a technical as an economical viewpoint. The interactions will be illustrated based on some country examples, such as Denmark and the United Kingdom. An increasing level of distributed generation may require technological adaptations to the network, but this increase can also be an incentive towards completely new ways of network development to facilitate a larger share of DG than would be possible within the current network infrastructure. Several new approaches for the development of the electricity network infrastructure will be investigated.

2.1 The changing structure of the power system

Modern electrical power systems have been developed over the last 50 years according to the following arrangement. Large central generators feed electric power up through generator transformers to a high voltage interconnected transmission network. The transmission system is used to transport the power, sometimes over considerable distances, which is then extracted from the transmission network and passed down through the distribution network for delivery to the customers. The conventional arrangement of a modern large power system offers a number of advantages. Large generating units can be made efficient and operated with only a relatively small number of personnel. The interconnected high voltage transmission network allows generator reserve requirements to be minimised and the most efficient generating plant to be dispatched at any time, and bulk power (e.g. from hydropower plants or coal power plants sites near coal mines) can be transported over large distances with limited electrical losses. The distribution networks can be designed for unidirectional flows of power and sized to accommodate customer loads only.

The conventional electricity supply system before electricity market liberalisation was relatively straightforward as it included one way transport of electricity from the producer through the transmission and distribution network to the consumers. This is shown in Figure 2.1.

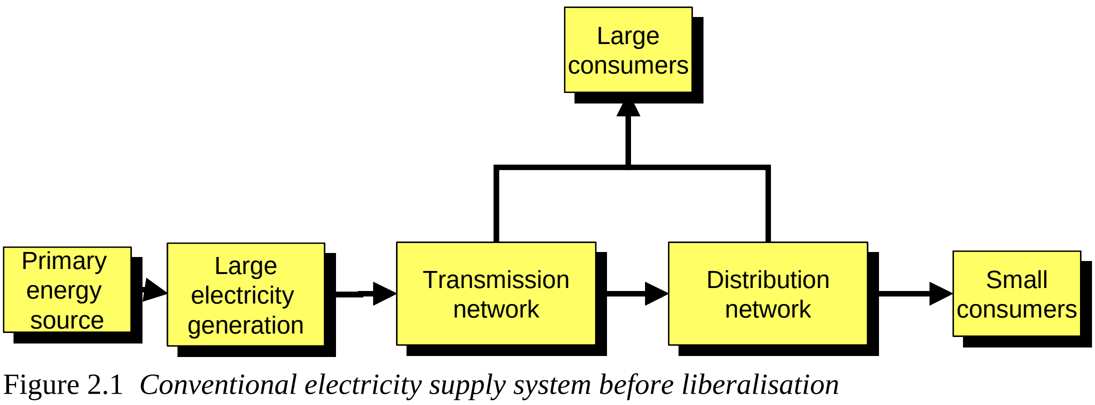

Figure 2.1 *Conventional electricity supply system before liberalisation*

When the electricity market was liberalised in most European countries during the late nineties, some of the activities of the previously integrated companies (responsible for production, transport and supply to the customer) were unbundled according to the requirements stated in the EU directives[3]. This situation is shown in Figure 2.2.

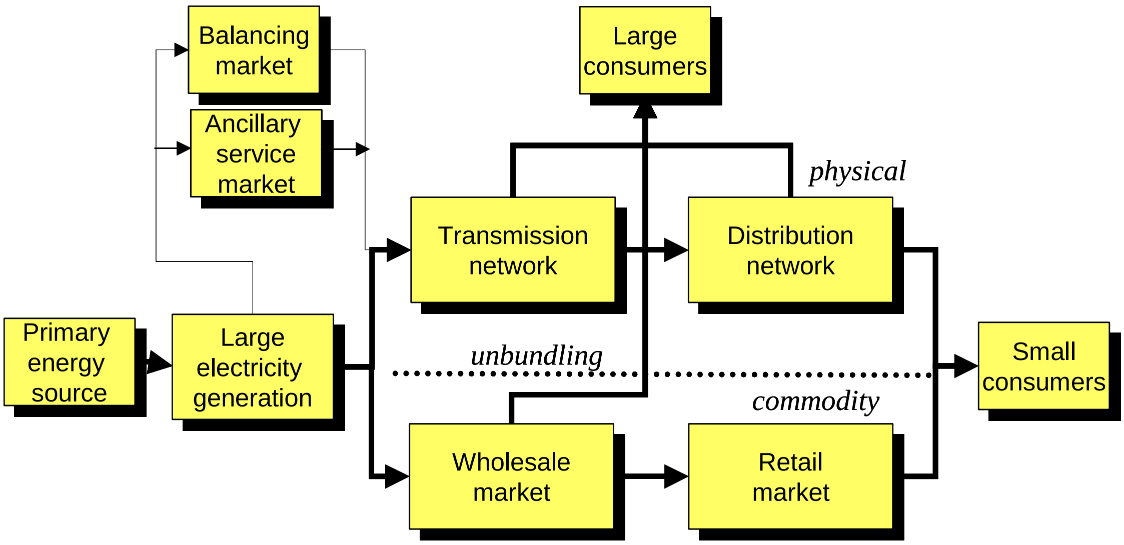

Figure 2.2 *Conventional electricity supply systems in a liberalised market*

The major difference with the previous system is that the physical transport of electricity through transmission and distribution networks is separated from the supply of the commodity to consumers through wholesale and retail markets. In some markets liberalisation also leads to the establishment of two other markets, the balancing and the ancillary services market. On the balancing market a power producer offers surplus power or the option of regulating the power generation output. The TSO, whose task it is to ensure system balance, purchases this surplus power or regulation option in order to correct unbalance between supply and demand. On the ancillary services market, other services related to reactive power, voltage control, etc. are being offered. As transport and distribution of electricity remain monopoly activities for the incumbent energy companies, new companies may enter the markets for generation, trade and retail. However, the operation of transmission and distribution networks should be unbundled[4] from the other activities to avoid abuse of the monopoly.

These figures only consider the (conventional) centralised electricity supply system. Since the 1980s, however, there has been a considerable increase in interest in distributed generation. In most countries, DG facilities were already present before the liberalisation and were operated by the incumbent, large power producers or by consumers. Environmental policy, also addressing climate change and support of renewable energy sources, led to an increased interest in investing in (mostly small-scale) renewable energy and combined heat and power units. In terms of the scheme in Figure 2.1 the only difference between these distributed energy sources and centralised electricity sources is the location of the connection to the electricity grid, the distribution network instead of the transmission network.

The liberalisation of the electricity market also changed the position of the small generating units, presenting new opportunities for participation on different markets. Their current position in the electricity supply system can be illustrated according to Figure 2.3.

[3] Directive 2003/54/EC of 26 June 2003 concerning common rules for the internal market in electricity and its predecessor Directive 96/92/EC.

[4] Directive 2003/54/EC requires legal unbundling. In some countries, more strict unbundling by ownership is required.

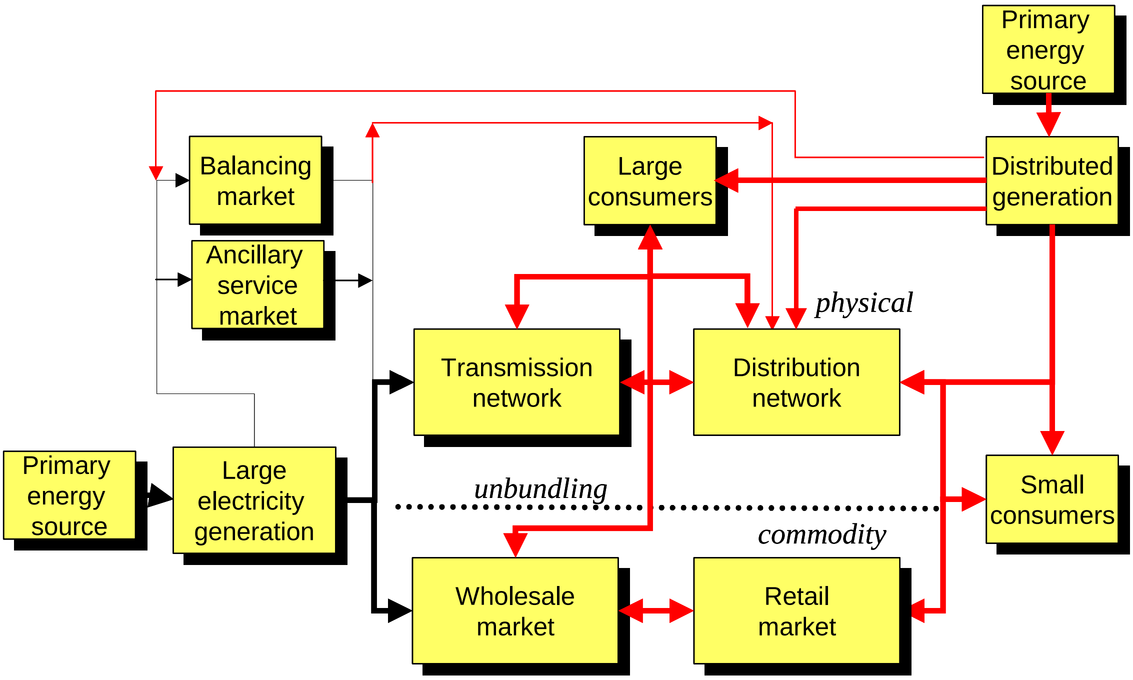

Figure 2.3 *Electricity supply system with DG/RES*

Distributed generators deliver electricity directly to (large/small) consumers or via the electricity (mainly retail) market to these consumers. In more developed electricity markets were DG has gained a more equal position, DG operators may also gain access to the balancing and ancillary services market. This is not yet the case in many countries, however.

The function of the distribution network will change, because the flows through the network may reverse. The networks no longer only distribute electricity but provide connectivity between the actors connected to the electricity system (see the two-way arrows in Figure 2.3). The full access of DG to electricity markets, including markets for balancing and ancillary services, may help in creating an equal position for DG compared to centralised generation, in other words, creating a *level playing field*. The SUSTELNET project (5th Framework Project) concludes that to create a level playing field and hence a possible change towards a more decentralised electrical system, has to be valued in economic terms in order to consider the benefits and costs of DG in the regulatory framework[5]. This is not a simple task, especially because there are short-term and long-term effects to the system. E.g. the introduction of DG will positively or negatively influence grid losses in the short-term, but will also in the long-term influence future grid extensions.

There is general agreement that a level playing field entails markets and regulation that provide neutral incentives to centralised versus distributed generation. This requires that all the values of DG are recognised, and that appropriate mechanisms are set up to put a monetary value to these values. Furthermore, incentives should be provided to network operators and generators to exploit these values in the best possible way. Access to all electricity markets - including wholesale, retail, balancing and ancillary service markets - are essential elements in reaching this level playing field.

[5] For more information about the SUSTELNET project see http://www.sustelnet.net/.

2.2 Definition of distributed generation

Although distributed generation has gained major importance, no general definition of what DG is has been agreed upon. There are, however, some commonly agreed features that characterise these sources (Jenkins, et al, 2000):

- DG is not centrally planned and is usually operated by Independent Power Producers (IPPs) or consumers.
- DG is not centrally dispatched.
- DG is normally smaller than 50 MW.
- DG is usually connected to the distribution network.
- The distribution system is taken to be those networks to which customers are connected directly and which are typically of voltages from 230/400 V up to 110 kV.

It appears difficult to pin down DG on specific numbers because this is country specific and relates to characteristics of the national (centralised) power system. Cogeneration (or Combined Heat and Power production - CHP) and renewable energy sources (RES) are often considered as DG. However, only a part of CHP and RES can be considered as DG. Within the SUSTELNET project an attempt has been made to divide categories of RES and CHP in large scale and distributed generation, as can been seen from Table 2.1. For example, renewable energy sources such as large hydropower plants and offshore wind parks with capacities of 100 MW and more that feed in electricity to the transmission grid cannot be considered as distributed generation.

Table 2.1 *Distributed versus large scale generation*

	Combined Heat and Power (CHP)	Renewable Energy Sources (RES)
Large-scale generation.	• Large district heating* • Large industrial CHP*	• Large hydro** • Off-shore wind • Co-firing biomass in coal power plants • Geothermal energy
Distributed Generation (DG)	• Medium district heating • Medium industrial CHP • Commercial CHP • Micro CHP	• Medium and small hydro • Onshore wind • Tidal energy • Biomass and waste incineration/gasification • Solar energy (PV)

* typically > 50 MW_e.
** typically > 10 MW_e.

2.3 Distributed generation and electricity networks

An increasing share of distributed generation influences the arrangement of the power system. One of the major reasons is that some types of DG, such as renewable energy sources, have a much lower energy density than fossil fuels and so the generation plants are smaller and geographically wider spread. For example *wind farms* must be located in windy areas, while *biomass* plants are usually of modest capacity due to the cost of transporting fuel with relatively low energy density. These small plants, typically of less than 50 MW in capacity, are then connected to the distribution system. In some countries, the majority of the new renewable generation plants are not planned by the incumbent utility but developed by independent power producers and are therefore not centrally dispatched. The intermittent nature of sources like wind energy cause that these sources only generate whenever the energy source is available, requiring the availability of reserve capacity. *Combined Heat and Power* (CHP) schemes make use of the waste heat of thermal generating plants for either industrial processes or space heating and are a well established way of increasing overall energy efficiency. Transporting the low temperature waste heat from thermal generation plants over long distances is often not economical and so it is necessary to locate the CHP plant close to the heat load. This again leads to relatively small generation units, geographically distributed and with their electrical connection at the distribution network. Although CHP units can, in principle, be centrally dispatched, they tend to be operated in response to the requirements of the heat load or the electrical load of the host installation rather than the needs of the public electricity demand. As CHP units are operated close to a residential or industrial heat load, this means that electricity loads are often located nearby and the power infrastructure is relatively strong. This is not always the case for other DG sources as wind, biomass and small hydro, often located in areas with weak lines.

2.3.1 DG network benefits and constraints

Distributed Generation facilities are nowadays connected to the distribution network at low voltage levels, at sites that were originally not meant to connect power generation facilities. Especially when large amounts of DG are connected at locations with little local load, this will increase the burden on the distribution lines. This new situation can create several problems for the distribution networks in terms of stability and power quality.

Due to the aforementioned issues, distributed generation is at present almost exclusively seen as a negative load and making no contribution to other functions of the power system (e.g. voltage control, network reliability, reserve capacity, etc.). But given the increased use of technologies such as fuel cells, micro-CHP, wind turbines and PV cells, ways to effectively integrating them into the electricity networks have to be found, preventing considerable impacts and costs of (distribution) network upgrades.

Apart from a number of constraints, distributed generation also presents several advantages to the electricity network[6]. DG can reduce transmission and distribution losses by reducing the current flow from the transmission system through the transformers and conductors on the distribution system. This largely depends, however, on the location of a specific DG facility. If a small distributed generator is located close to a large load then the network losses will be reduced as both real and reactive power can be supplied to the load from the adjacent generator. Conversely, if a large distributed generator is located far away from network loads then it is likely to increase losses on the distribution system. A further complication arises due to differing values of electrical energy as the network load increases. In general there is a correlation between high load on the distribution network and the use of expensive (peak) generation plant. Thus, any distributed generation plant that can operate in this period and reduce distribution network losses will make a significant impact on the costs of operating the network. However, if the DG supply exceeds the local electricity demand[7], network capacities have to be increased, in order to transport the electricity to other demand areas via the transmission grid, thereby increasing line losses.

Another specific network benefit is possible distribution capacity cost deferral. The development of small-scale DG facilities near a load can postpone necessary investments in additional distribution and transmission capacity. Network operators can benefit from these new DG facilities as they can reduce their investment costs in upgrading or extending the distribution network. Certain types of DG also have the ability to offer certain network ancillary services to the network operator, such as reactive power support and voltage control, improving power quality.

[6] An extensive overview of DG costs and benefits is presented in Appendix A.
[7] A good example is the case of wind energy in rural areas.

However, with these benefits come many operational, technical and commercial challenges for the Transmission System Operator (TSO) and especially for the Distribution System Operator (DSO)[8].

The majority of new and renewable energy plants being connected to the distribution network in most European countries at present is powered by wind or in the form of CHP and is generally connected at the 11-66 kV levels. This forces the DSO's to reconsider their approach to network design and management. If the future electricity system is to accommodate the expected growth in DG at lower voltages it will need to change from a design standpoint as well as from a management and commercial perspective.

The emergence of micro power units or small-scale DG[9], which may be located in the domestic home or small business, and connected to the distribution network via the metering system, could take the trend for lower voltage connection a step further. These units are often connected to the very low voltage level (< 1 kV) and often are single phase, which presents new challenges for the DSO. With the introduction of domestic CHP and small scale DG in general, the DSO faces potential technical challenges, which may require engineering and design changes to the system, and a more holistic approach to system management[10]. The present and future increase in DG facilities being connected to the distribution network at all levels means that the network characteristics such as bi-directional power flow, central dispatch of DG, provision of ancillary services by DG operators and islanding may become commonplace. Connection of generators will also have to become far simpler and more transparent at all voltage levels, particularly at the lowest voltage levels where the generating plant connections could be smaller and more numerous. In the case of small scale DG, the DSO may not even know of the connection until after it has taken place, which could have safety implications.

In countries with a large share of DG connected to the distribution network, such as Denmark and the Netherlands, it is already recognised that distribution networks can no longer be considered as passive appendages to the transmission network, but that the whole network must be operated as a closely integrated unit. For this purpose a number of technical improvements have to be developed and implemented. Conditions for central and local electricity production must be equalised bringing all power plants to contribute to system stability and flexibility.

Several technical experts have addressed the issue of growing DG levels in existing distribution networks (Nielsen, 2002a; Strbac & Jenkins, 2001). They argue that if the penetration level of distributed generation continues to grow while the distribution grid remains unchanged, a chain of technical conflicts may develop, unless such issues as operation, control, and stability of distribution networks with DG installations are properly addressed. There are several aspects that need to be fully understood in order to obtain maximum benefits from both DG and the power grid, mainly:
- The distribution network and DG are interacting and actively affecting each other.
- No generic conclusion can be made regarding the influence of DG on the grid, as various power sources have quite different characteristics. Instead, individual cases have to be treated separately.
- Both DG and the grid should be studied as one integrated, flexible, dynamic and complex structure, for to a great extend, they do have a major impact on operation, control and stability of each other.

8 For the operator of the distribution network (150 kV and lower) both the terms Distribution Network Operator (DNO) and Distribution System Operator (DSO) are used. Directive 2003/54/EC concerning common rules for the internal market in electricity defines the DSO as operator of the distribution network. The term DSO will also be used in this report.

9 The most common categories of small-scale DG are domestic CHP, photovoltaic, micro-wind, micro-hydro and fuel cells. In the case of the UK see Forrest & Wallace (2003), Domestic CHP is the most feasible option.

10 In DISPOWER WP9 a new approach in managing the LV network is proposed, see also Chapter 4.

The network constraints of DG can be solved to a certain extend when the capacity of the (distribution) network is reinforced. From an economic point of view, this is not very attractive as it concerns long-term investments. Other, more cost-effective ways of network management will have to be considered.

2.3.2 The role of ICT in network management and market operations

The random nature of loads in an electrical network and the limited capacity to store electrical energy in significant quantities, exemplifies some of the challenges involved in managing electrical networks. This in addition to the fact that, electrical networks are never in a steady state condition, but rather in a perpetual dynamic state. When large amounts of distributed generation are included in the electricity network, the need for information exchange and operational control will grow. In the classical electricity network, with its predominantly top-down structure, little operational co-ordination was required between the transmission and distribution networks, both under normal conditions and in emergency situations.

In today's electricity networks, communication is, and will be in an even greater extent, a necessary tool for the operation of the electrical networks, both for technical as well as for administrative purposes. In the (even recent) past communication remained a limiting factor. Due to the rapid developments in ICT technology, the increasing communication capacity now provides possibilities for operating the electrical network in a different and, quite often, more efficient way. Increasing the communication capacity is not only required because of the integration of large amounts of DG on the distribution network, but also due to the establishment of electricity markets.

The establishment of electricity markets (e.g. markets for wholesale, balancing) has major implications for network management as it increased the need for exchanging information between the network operators, the power exchange and the market players. The transmission system operators, for example, must treat all players neutrally and in a non-discriminatory way, meaning that all the information given to one player must also be given to another player. The largest challenge for the TSO to manage this system is to co-ordinate all the decisions and actions of producers (how much electricity is produced with what power plant). This requires an enormous amount of data exchange and IC technology has been a necessary tool to support the operation of the electricity market.

The classical ways of communication through narrow-band solutions (range of 100 bit/s) have in many cases, at the introduction of fibre optics solutions, been replaced by broadband communication highways (range of 100 Mbit/s). It is only with the development of modern communication methods that systems like SCADA and PANDA have become feasible:

- *SCADA* - The Supervisory Control and Data Acquisition System is concerned with providing the system operator with remote information and the control of remote facilities in order to operate in the most reliable, efficient and economical manner. The advantage of this scheme is that the operator is acting upon data, which represent the actual operation condition throughout the whole system at any given instant. There is a good possibility to develop a web-based SCADA system.
- *PANDA* - The Plan And Data Acquisition System is concerned with providing the market operator with schedules, measurements and the ability to make settlements.

Due to the introduction of electricity markets, two parallel systems have evolved. The control and the market system could be integrated into one overall TCP/IP network and at the same time make the communication system an integrated part of the electrical network (Nielsen, 2002b).

2.4 Integration of DG into existing networks

The issue of increasing levels of DG on the lower and medium voltage level is now discussed and investigated in many European countries, such as Denmark, Germany, the Netherlands and the United Kingdom. This section will give an illustration of the situation in two countries:

- The United Kingdom, having ambitious RES targets but experiences difficulties to combine electricity market liberalisation with an increased use of CHP and RES.
- Denmark, introducing massive support for wind energy and CHP but lagging behind in network regulation.

2.4.1 Integrating DG in the United Kingdom

Several years ago, the United Kingdom adopted an active strategy regarding measures to prevent climate change. This climate change policy includes also ambitious targets for renewable energy, the aim being to generate 20% of electricity from renewable energy sources by 2020 (compared to 3% in the year 2000). A large part of this share will be in the form of distributed generation.

The United Kingdom is facing two main barriers in reaching these ambitious targets:

- The existing UK network regulation does not favour the full integration of RES and CHP into the distribution network.
- Technical barriers of integrating DG when operating the network in the traditional way.

The primary source of income for DG is sale of energy. How much energy DG can sell in the UK and the risks associated with this activity are largely dependent upon the electricity market structure and the regulatory environment in place. For example the New Electricity Trading Arrangements (NETA) implemented in the UK in 2001 introduced a number of risks for distributed generation.

The key element of NETA that introduces significant risks for distributed generation is the *penal dual cash out prices* of the balancing mechanism. If a generator delivers less energy than it has contracted for in a settlement period then it must pay the system buy price (SBP) for the shortfall. This is the weighted average of offers accepted in the period. If it over generates in a period then it receives the, normally lower, system sell price (SSP) for the excess. This is the weighted average of bids accepted in the period. The mechanism was designed to encourage market participants to contract in the markets and power exchanges at gate closure. In the first few months of NETA, SBP was extremely volatile and so the earnings risk if a generator failed to deliver its contract position was high. NETA awards predictable plants, as the contract position for the generator must be submitted at gate closure, which is currently 1 hour ahead of the delivery period. A large part of DG in the UK consists of Combined Cycle Gas Turbines (CCGT) that have a relatively predictable output. It might therefore be expected that the earnings risk for these generators due to imbalance will be low. This depends, however on the type of generator (intermittent or non-intermittent) and the level of the SBP. The volatility of the SBP may be such that a forced outage occurring during a price spike could have serious effects on the earnings of an independent generator.

Anticipating on the increase of the share of DG in the electricity supply system Strbac & Jenkins (2001) have analysed the security of the UK electricity supply system in the context of a growing penetration of distributed generation technologies. Under the present conditions the owners and operators of the distribution networks, the DSOs, anticipate that they can integrate only a very limited amount of generation capacity without major reinforcement. The potential bottleneck for RES and DG targets for 2010 and beyond in the UK (and perhaps in more European countries) is the distribution system, and it may be necessary to change the operational practices of distribution networks in order to accommodate the expected increase in renewable and CHP generation.

Another study (ILEX Consulting & Strbac, 2002) shows that increasing the share of DG from 10 to 20/30% may substantially increase the costs for network reinforcements. Depending on the location of the DG plants and the share of intermittent sources (e.g. wind) the reinforcement costs may increase with 150 up to 900 million GBP per annum[11]. This reinforcement mainly includes costs for balancing and reserve capacity, when introducing large amounts of (intermittent) power sources such as wind turbines to the power system. The costs for the distribution system vary between 6 - 55 million GBP per annum. The costs for the transmission networks will be mainly influenced by the location of new renewable generation plants. In the UK, significant wind resources can be found in Scotland and the North of England, far away from the major loads in the south of England. A significant growth of wind power in the North will increase the requirement of transmission reinforcements and the level of transmission losses.

Alternatively, if the additional renewables were more evenly developed across Great Britain, transmission reinforcement costs could be negligible and transmission losses might be reduced.

When integrating large amounts of DG into the distribution network, the role of the Distribution System Operator (DSO) is viewed to be crucial. So far the major, and sometimes only responsibilities of DSOs are:

- to maintain voltage fluctuations on the system within limits (specified by standards), and
- to ensure that the quality of power delivery is adequate.

This ‘passive’ approach to network operation considerably limits the amount of DG that can be connected and DG is effectively excluded from the opportunity to support the DSOs in carrying out the main duties.

Regulatory incentives need to be designed to encourage DSOs to consider assets and services of all network users (such as DG) for the provision of voltage control and service quality. This would lead to unbundling of distribution network services and the development of commercial arrangements within which the DSOs would carry out their responsibilities efficiently and at least cost, considering the assets and services offered by all participants.

In order to increase the ability of the existing distribution network to absorb large amounts of distributed generation (without considerable reinforcement of the power grid), *active management of distribution networks*[12] may be the most economic solution. Such an active approach requires the involvement (dispatch) of DG installations in tackling network problems such as voltage control in rural areas. It is well known that in rural networks the voltage rise effect is the main limiting factor for connecting DG. The voltage profile in distribution networks with DG can be controlled effectively within an active network approach. Preliminary investigations show that the amount of DG that can be connected to an existing system can be increased with a factor of 3-5 by the use of these approaches.

Maintaining the current level of system security with a generation mix containing significant renewable generation will become more difficult. However, it is believed that all the issues can be addressed by technically feasible engineering approaches within reasonable economic constraints.

- Up to 2010 the main priority will be to integrate the operation of DG and distribution networks and no significant issues related to system security are likely to emerge.
- In the medium-to-long term, with a considerably larger contribution of DG, maintenance of system security will require integration of this generation in the operation and development

[11] 1 GBP = 1.47 Euro (March 2004 exchange rate)
[12] For a detailed description of active management of distribution networks see Section 2.5.1.

of the entire power system. Balancing demand and generation will be a matter of primary importance and a considerably increased generation margin will be required to deal with intermittency of the new renewable generation. The new generation (together with storage and Demand Side Management) would have to assume responsibility for security through flexible operation. Incentives for maintaining generation capacity and flexibility need to be developed.

The concept of Power Zones

Ofgem, the UK Office of Gas and Electricity Markets, has recently introduced the concept of power zones in one of its discussion papers (Ofgem, 2003). Ofgem is of the opinion that the network developments necessary to accommodate the growing capacity of DG are most likely to be achieved efficiently if innovative solutions and technologies are employed.

Most of the DG capacity connected in the UK in the past 10 years has been connected on a ‘fit and forget’ basis. In other words, the DG plant is connected in such a way that no active control is required by the DSO. This approach is feasible when the penetration of DG is low, but new technical and commercial strategies are required when the number and capacity of DG plants is increasing. This will ensure that network connection, reinforcement and operating costs are maintained at efficient levels. Ofgem believes that DG connection costs are likely to rise if the fit and forget approach continues and in certain circumstances connection may not be possible unless new technologies and solutions are developed, proven and adopted.

There are, however, a number of risks associated with the application of the new technologies, options and approaches by the DSO. This mainly includes certain business risks, as the mentioned approaches do not belong to the day-to-day business of DSOs.

The ‘Registered Power Zones’ proposal is intended to offer DSOs a sufficient incentive to encourage them to pursue network projects with this higher risk profile. The drivers supporting the Registered Power Zones concept can be summarised as follows:

- To encourage DSOs to integrate appropriate technical development plans as part of their wider business innovation.
- To deploy new technologies, and encourage their wider application, where this enables distributed generation to be integrated more effectively and efficiently, to help meet the government’s targets for renewables and CHP.
- To signal to potential generators and other interested parties the DSOs’ development intentions or the network capabilities at a particular location.

2.4.2 Integrating DG in Denmark

The country with the largest share of DG on its electricity supply system is Denmark. Especially Western Denmark can be seen as a testing ground for implementing large amounts of DG into the distribution network as it has already reached a high percentage of this due to decades of promotion of wind turbines and medium and small-scale CHP in the Danish energy policy. Danish energy policies have, as of 2001, led to the building of approximately 1600 MW of dispersed CHP production and approximately 1900 MW of wind turbines in Western Denmark (60% of the country consumption, with Eltra as TSO). About 50% of power production is now ‘bound production’, i.e. either dependent upon the amount of wind available or, for the local CHP plants, the demand for district heating. The majority of these distributed generation facilities are connected to voltage levels of 60 kV and lower, as can be seen from Figure 2.4 (Hindsberger, 2003).

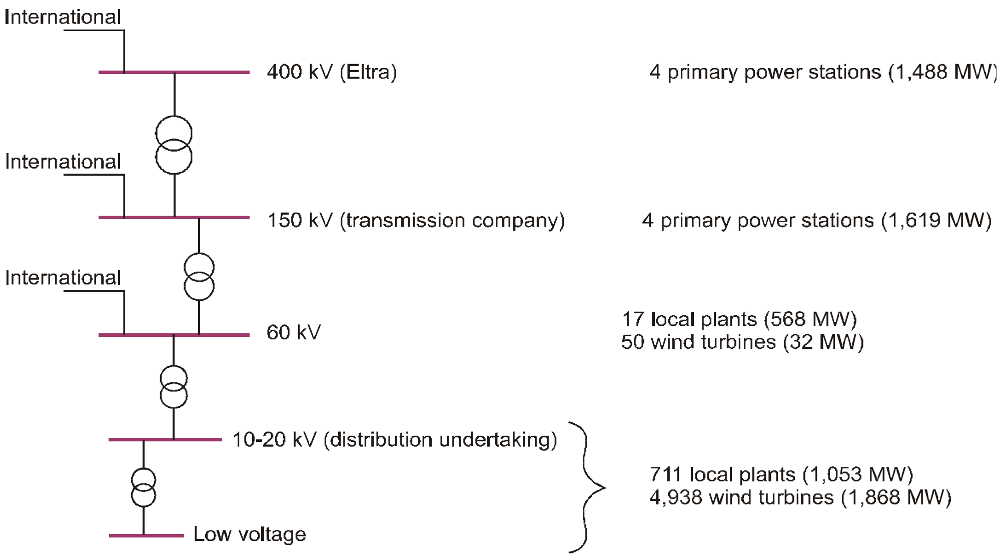

Figure 2.4 *Production capacity at each voltage level in the Western Part of Denmark*

Compared with the values in Figure 2.4, the wind capacity has increased even further. By the end of 2002 there was a capacity of 2155 MW connected to 60 kV or below (another 160 MW, the Horns Rev offshore wind power park is connected to 150 kV). Together with the approximately 1600 MW of small-scale CHP, the DG in Western Denmark can produce as much as the peak load of the area, which in 2002 was 3685 MW, while the minimum load of 1189 MW often can be supplied by wind turbines alone.

The costs of network reinforcements, the so-called deep connection costs, have rapidly increased during the 1990s. In the period from 1992 to 2001 the extra investments made represent more than DKK 630 million (of which DKK 400 million is due to due wind power)[13]. This corresponds to DKK 300,000 per MW for wind power and DKK 500,000 per MW for CHPs. As a comparison, the cost of building a wind turbine on land currently is in the order of DKK 6-7 million per MW (Hindsberger, 2003).

In many situations, operators have to reinforce the grid to enable the power supply, even though these reinforcements are of no benefit in terms of distributing energy to consumers. Wind turbines and local CHP plants have displaced central units, which are being decommissioned, as there is no longer any commercial basis for them. It means that the balancing units disappear in areas where the need for balancing capacity is growing. The balancing must then be effected by the local CHP plants and the wind turbines. Eltra, the Western Denmark TSO, is therefore working on getting these services from the DG operators through changes in the regulation, the requirements set-up for new units, and through support to R&D in technical solutions. From a transmission system operator's point of view, it is critical that the earlier 'passive' production units are transformed into active elements so they can deliver the ancillary services required by the grid.

Small-scale production has priority access to the network in Denmark, and distribution companies are obliged to connect it. The producers pay only shallow connection costs, i.e. the costs just to the nearest 10 kV connection point, even if grid reinforcement or the addition of another connection point is needed, with the distribution company paying the rest (i.e. costs are socialised through the Use of System charges to the consumers). By 2001 this energy policy has resulted in approximately 50% of the electricity production in the Eltra region having priority access of this kind. Therefore, small-scale CHP and wind power cannot be regarded as secondary production.

[13] 1 DKK = 0.14 Euro (March 2004 exchange rate).

At present, balancing a power system like the Danish one can only be done if it is connected to areas with other types of production. The large proportion of 'bound' production puts pressure on the transmission capacity within the Eltra area and on neighbouring areas. The flow towards transmission level causes problems with regard to regulating transformers and with regard to the voltage profiles in the distribution networks having lower voltages at the points of transformation than the points of infeed of the wind power. Distribution companies therefore often connect wind power at separate outlets, where consumption is not connected. This gives rise to more networks than needed for consumption only.

Excess power arising from bound production can be exported, provided that capacity is available on the interconnections to Norway, Sweden and Germany. However, if the oversupply becomes larger than available capacity, then there will be a critical power overflow. During a critical overflow, there is a risk of disturbances, and of a system breakdown (Jensen, 2002).

As overflow situations may well become critical during the next few years, ways have to be found to balance the system by means of the following measures:
- closing down local CHP plants,
- closing down wind turbines,
- introducing flexible loads,
- installing heat pumps.

At the moment, Eltra is also analysing the possibility of dispatching the local CHP plants. However, the use of any of these measures will require changes in the taxation system.

Several international studies have presented ideas for the integration of distributed electricity production. For the Eltra electricity system in Denmark some principles have been identified by Nielsen (2002a) as part of a long-term solution:
- A control hierarchy consisting of a central control centre (at the TSO) and a number of regional control centres will be established. Each region consists of a number of local areas. Each local area will be connected to the transmission system via one 150/60 kV substation. An unambiguous operational responsibility must be defined for each local area.
- Prioritising of electricity from local DG (CHP/RES) plants should be cancelled so that these power plants can be operated in the same way as conventional power plants in accordance with price signals from the (day-ahead and real-time) market. This principle offers network access on equal terms for all producers and opens up for a better utilisation of the network.
- The balance of reactive power within each local area must be kept within certain limits to be defined in a new set of rules. There must be local responsibility for observing these rules and the control of local reactive resources (including capacitors and local CHP plants) must be local as well.
- New rules for measuring must provide all necessary data for the regional control centres and to the extent necessary for the TSO. Reliable information on the state of the system and data for accurate system analysis must be available at any time.

2.5 Future networks

The previous section showed that integrating large shares of DG in existing networks may present problems in terms of network stability etc. This section looks at new ways of managing networks with high levels of DG. For that purpose two visions are described, the 'active networks' and 'Micro-grids'.

2.5.1 Active networks

The paper '*Active Networks as facilitators for Embedded Generation*' by van Overbeeke and Roberts (2002) presents a vision for 'Active Networks' as facilitators for DG. The authors foresee that passive distribution networks, as we know them, have to evolve gradually into actively managed networks. From their viewpoint it is both technically and economically the best way to facilitate DG in a deregulated electricity market.

In the active networks vision, the principles of network management differ from the classical view of networks, being only one-way lanes for electricity transport from high-voltage to low-voltage grids. First of all, the network should not be considered as a power supply system but as a highway system that provides connectivity between points of supply and consumption. Second, the 'infinite network' as customers used to know it, no longer exists. A network interacts with its customers and is affected by whatever loads and generators are doing.

To change the network infrastructure based on these principles a structural solution is proposed, based on the following concepts:

- Interconnection of networks as opposed to dominantly radial networks, i.e. switch from thinking one-directional to bi-directional flows.
- Local control areas ('cells') - using automation to support relatively small control areas.
- System services are specified attributes of a connection - referring to the way in which system services provided by different units are charged to individual customers.

Such an interconnected network can best be compared with Internet and telephone networks:

- Energy transport is not dependent on one single part, so the vulnerability to component failures is significantly reduced.
- Preventing the domino effect (faults propagating over a very large area) by isolating faults so that the rest of the system can operate normally.

The most revolutionary change of the proposal is the introduction of 'cells', which are in fact 'local control areas[14]' on the MV level (see Figure 2.5). The cell concept does not have a large impact on the topology of the power network, the difference is the control hierarchy.

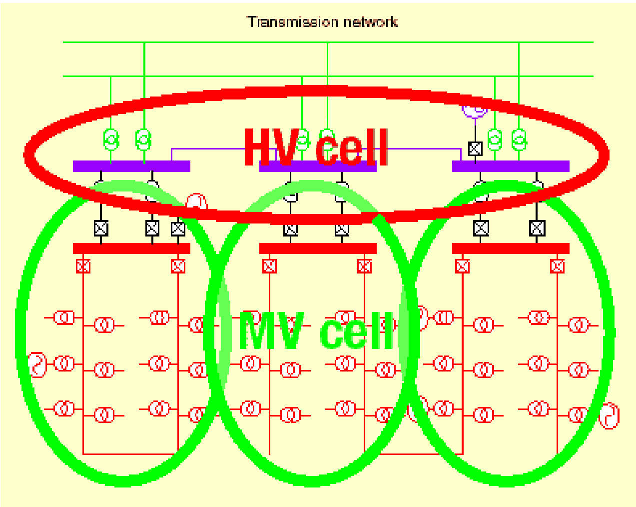

Figure 2.5 *Network divided into cells acting as independent islands.*

Each cell will eventually have its own power control system, essentially computer based, which manages the flow of power across the cell's boundaries. In the future this means that control

[14] Comparable with the Local Control areas described by Nielsen (2002a).

systems of adjacent cells will negotiate in real time how much power will be transferred over their mutual interconnection.

For each cell, the Active Network will be in control of:
- Local voltage control and reactive power (Var) control.
- 'Negotiated' exchange of power with adjacent cells.
- Managed operation of connection with adjacent cells.
- Faults are managed and isolated within a cell so that the effect will not propagate to other cells. 'Islanded' operation is available as an emergency condition: If a cell is not capable of importing/exporting as much power as needed, local generator/loads will be controlled in order to achieve balance.
- Each cell will have its own computer-based power control system that manages the flow of power across the cell's boundaries.

The most obvious advantage of introducing Active Networks is that the changes proposed ask for virtually no physical reinforcement, meaning significant economic benefit. Those reinforcements are unavoidable if we are to accommodate larger amounts of DG within a traditional system. The Active Networks vision has the following economic advantages above traditional forms of upgrading:
- Only a few additional power lines required - basically to provide interconnection between islands.
- Reinforcement of existing lines - applicable mostly to tapered circuits where local voltage control is uneconomical.
- No new transformers required - interconnection improves security of supply, existing transformers can be operated to a higher percentage of the rated load.
- More switchgear - increase options for inter- and disconnection; all switches have to be remotely operated.
- More control systems - limit level of investment by phased introduction.

For example in the Netherlands, the definition of system services is more or less restricted to a number of stability issues for which the transmission system operator has responsibility. The most obvious system service is the balance of reactive power, and in many cases it is more cost-effective to ensure that balance locally. This means that the Distribution System Operator also provides that as a service.

2.5.2 Micro-grids

EPRI in the USA is enabling utilities to consider new options in the design and operation of power systems that can provide improved efficiency, the potential for ancillary services, improved reliability, and lower cost of operation. One of these options is the concept of Micro-grids (Lasseter, 2002). Micro-grids are small power systems that can operate independently of the bulk power system. They are composed of distributed energy production and energy-storage resources interconnected by a distribution system. They may operate in parallel with the bulk supply system during normal conditions and transform to islanded (stand-alone) operation during abnormal conditions such as an outage in the bulk supply or emergency. Micro-grids may also be created without connection to a bulk supply and operate full-time as an independent island.

The common question of how much penetration of DG the grid can handle before stability problems result is not an issue with Micro-grids because they are designed to satisfy their predetermined local load without creating any stability problems for the transmission system.

Potential Micro-grid designs range in size from a single house operated independently up to a large substation-scale system that serves many feeders where total load may approach 100 MW.

Micro-grids offer the potential for improvements in energy delivery, efficiency, reliability, power quality and costs of operation as compared to traditional power systems. Micro-grids can also help overcome constraints in the development of new transmission capacity that are beginning to impact the power industry.

Research done on the Micro-grids concept[15] reviewed potential architectures, engineering issues and economic factors. One of the more interesting findings is that the use of uniformly distributed generation on Micro-grids facilitates the ability to build distribution systems that do not need any high-voltage elements; they are entirely low-voltage. This low-voltage approach has potential for significant cost-savings and power quality/reliability improvements and can provide improved safety benefits as well.

A key motivation of Micro-grids is the desire to move control of power reliability and quality closer to the point of end-use so that these properties can be optimised for the specific loads served.

The power grid can benefit from Micro-grids by reducing congestion and other threats to system adequacy if they are deployed as interruptible, or controlled loads that can be partially shed as necessary in response to changing grid conditions. Furthermore, Micro-grids could provide the possibility to operate some or all of its end users at lower costs than would be possible on the traditional grid. The costs of delivered energy from the traditional power system includes losses, customer services, congestion, and other costs that together typically exceed the generation cost alone.

2.6 The values of DG

The technical implications as mentioned in this chapter represent a certain economic value, this may be in the form of a cost but also in the form of certain benefits. Some parties may gain additional benefits while others have to cover new unexpected costs. When implementing DG, a proper transfer of costs and benefits between different functions in the electricity system (generation, trade, transmission/distribution, consumption) is vital, but this may be difficult to realise in liberalised energy markets were these separate functions are undertaken by separate parties. Reaching a proper allocation of costs and benefits requires a more innovative approach in managing the different financial streams. Economic regulation of networks, mainly on the distribution level, plays an important role in this matter. To identify all these financial streams it is important to investigate all relationships between the stakeholders in the electricity network, taking also into account the recent developments in the field of energy market liberalisation.

Costs and benefits or *values* of DG can generally be separated in two broad categories: those that are capital related and those that are operational related. Moreover, the values can also be separated into whether they are inside or outside the network. Within each category and subcategory there can be a range of different values to the Distribution System Operator, the customers and society as a whole. Each value tends to be highly technology-, site- and time-specific; they do not necessarily apply equally or at all to every individual DG case (Scheepers & Wals, 2003).

To summarize the impact of DG, in Table 2.2 an overview of the main DG values is presented. Within the given categories there can be a range of different benefits and/or costs to DSOs, customers and other stakeholders.

[15] For more information about the FP5 project Micro-grids see http://microgrids.power.ece.ntua.gr/.

Table 2.2 *Overview of DG values*

	Capital	Operational
Attributed to network operator	• Distribution capacity cost deferral • Reliability • Connection costs	• Voltage support • Reactive power • Line losses
Outside network	• Metering • Reserve capacity • Avoidance of overcapacity in generation	• Balancing • Transaction costs

Values can also be short-term or long-term, depending on the timeframe in which the benefits or costs arise for the DG operator or DSO. For example, avoided network losses are short-term benefits that DG could generate for DSOs. On the other hand, avoided network investments (distribution capacity cost deferral) are long-term benefits. It is important to draw a distinction concerning the timeframe of the DG values in order to construct a level playing field. Especially with respect to the energy related benefits and costs one has to differentiate between intermittent and controllable DG contributions. The more controllable and hence reliable the benefits are, the higher is their economic value.

In the short term, some of the mentioned declared benefits of DG might actually be additional costs to the system. There might be a need for additional grid capacity because of DG entering a market with overcapacities; there might also be a need for additional balancing power because of the intermittent character of wind plants or PV. And if the reliability of the system is already very high, the possibility that DG will improve this situation is very low. But in the long run, a more decentralised system seems to be superior to a centralised system in economic terms, and therefore the long-run benefits must already be considered today in some way (Leprich & Bauknecht, 2004).

When looking specifically at additional costs of DG, such as connection costs, metering costs, balancing costs, and costs for additional system services, it can be concluded that they mostly consist of short-term costs. They cannot directly be calculated against the long-term benefits of DG because different players are involved that do not bear the costs or reap the benefits equally. So one has to think about an adequate allocation of these costs with respect to an optimisation of the system.

When DG connects to the distribution grid, it generates operational and capital costs for the DSOs that are paid via the respective tariffs. However, a number of the benefits or costs they generate are not always considered. In order to achieve a level playing field, all these values of DG should be recognised, assigned - if possible -a monetary value and be allocated between DG and DSOs. Moreover, long-term and short-term values should be considered separately. The recognition and assignment of a monetary value can sometimes prove difficult because not all values are always individually measurable. It should also be stressed that in many cases values can be positive (benefit) or negative (cost), depending on the particular situation[16].

2.7 Conclusion

Taking current developments into account, the following major impacts on the distribution system can be expected:

- Distribution networks of the future are likely to be managed actively with considerable amount of computer, communication and control technologies applied to manage physical flows on the network as well as the flows of information between various devices controlling the behaviour of the plant and equipment.

[16] E.g. DG can have positive or negative impacts on distribution losses, depending on the penetration level and the location of DG facilities on the network.

- Distribution System Operators will have to take more responsibilities for the provision of security related services. This would be a new task, which DSOs would need to conduct. This will be necessary if various forms of DG are to be integrated in the operation and development of the entire system in order to ensure its secure operation and adequate service quality.
- An increasing penetration of DG could potentially challenge the fundamental paradigm of central management of system security. With a very large penetration of small-scale generation (millions of various units), i.e., with the increased number of independent decision-making entities, a radical change from the central to a distributed management of the entire system operation will be required.
- This technical challenge will, in turn, impose serious questions as to what market and commercial arrangements are needed to manage the balance between demand and supply in a system composed of millions of small generators and what regulatory approaches would facilitate evolution of the system from its present to its future form.

3. TECHNOLOGICAL SOLUTIONS AND PRACTICES

3.1 The DISPOWER questionnaire

The main objective of the DISPOWER questionnaire was to provide an overview of possible technological solutions and practices that improve the integration of distributed generation and renewable energy sources. The questionnaire has been developed during 2003 and further improved after a test among a small number of experts. The questionnaire aims at obtaining information on benefits and costs of new technological solutions and approaches and the probable/estimated transfer of these benefits and costs between different actors in the electricity supply system. The questionnaire has been sent to participants in the DISPOWER project as well as to participants in some other DG projects within the Fifth Framework Programme (all part of the DG cluster). For this activity, a distribution list has been drawn up of approximately 120 experts, who received the questionnaire during spring of 2003. This resulted in a number of 30 questionnaires in return, analysing a broad scale of new technological solutions, options and approaches leading to an improvement of the integration of distributed generation and renewable energy sources into the distribution network.

The aim of the questionnaire was not to provide a complete inventory of relevant technologies, but to gain insight in the technical solutions and practices towards DG integration. The experts were asked to present a technological solution or practise enabling a smooth integration of DG into distribution networks. This chapter will analyse the outcomes of the questionnaire into detail. The questionnaire was divided into two parts:

- *Part A* was aimed at technological solutions and options in different stages of development (laboratory research, demonstration, pilot scale, niche applications), except technologies and approaches that are already used on full scale. Also technological solutions and options that improve generation (higher efficiency, better reliability, lower costs, etc.) have not been taken into account.
- *Part B* (*benefits and costs*) was aimed at seeking answers to possible ways of allocating costs and benefits.

3.2 Part A - Description of technology

The questionnaire started with some general questions about the proposed solution, option or approach. The respondents were asked to give a general description of their technology and its main aim.

3.2.1 Name of the solution

1. *Name of solution/option/approach*
2. *Description of solution/option/approach*

All single technical solutions, options and approaches are described in more detail in Appendix B. to group all the different options, a categorisation into four groups has been made:

- Planning and design tools (both for operational as for investment use) - optimising supply and demand.
- Power quality devices - tools managing physical power output, local voltage control, harmonics compensation, reactive power.

- Communication devices, including ICT applications - managing power flows through transfer of data.
- Storage devices - storage of surplus electricity until needed for use.

3.2.2 The status of the technology

3. *Characterisation of the status of the technology*
- Concept phase
- Experimental/laboratory phase
- Demonstration/pilot phase
- Niche application
- Fully implemented.

Is the technology based on:
- New technology
- Existing technology used in new area
- Improvement of existing technology
- Other, please specify: …

The presented solutions differed in their stage of development; technologies presented by the respondents differed from concept phase to fully implemented technologies. The majority of the presented technologies were already in a certain phase of application, but up to now only applied in other areas. Some of the presented solutions consisted of improvements of existing technologies.

3.2.3 Type and location of the technology

4. *How would you characterise the solution/option/approach (more answers are possible)*
- Planning and optimisation tool for investments
- Planning and optimisation tool for operational use
- Design tool
- Device to improve power quality
- Load management device
- Control device (e.g. switch)
- Metering device
- Communication device
- Load balancing device (e.g. storage)
- Network device
- Generator device
- Other, please specify: …

If you describe a technical solution or option, where will this solution or option be located (more answers are possible)?
- Part of the transmission network
- Part of the distribution network
- Part of the generator
- Part of the appliances of consumers
- Other, please specify: …

To enable classification of the different technologies, the respondents were asked to categorize their presented solution. In general, all categories of devices were mentioned more than one time. Load balancing devices, control devices and devices to improve power quality were most frequently mentioned. But also planning tools were frequently mentioned, so both technical devices and planning tools, covering the whole spectrum of possibilities, were analysed. Most of the options described were located near distribution network and/or the generator, covering issues that specifically address the integration of DG into the distribution network.

3.2.4 The use of ICT technology

5. Does the solution/option/approach make use of ICT-technology (*Information and Communication Technology*)?

- Yes
- No (please continue with part B)

Is data communication used between different locations and/or market parties?
- Yes
- No (please continue with part B)

What type of data communication is used (more answers are possible)?
- Mobile telephone
- Power line communication
- Telephone or TV cables (incl. optical fibre)
- Radio
- Specific cables
- Other, please specify: …

Is the communication by Internet Technology an essential part of the solution/option/approach?
- Yes
- No

What sort of data is transferred (more than one answer is possible)?
- Price information:
- Network information (Breaker status)
- Generator information (kV, MW, MWh, Mvar, Mvarh)
- Load information (kW, kWh, kvar, kvarh)
- Control signals
- Other, please specify: …

A specific question regarding ICT technologies was included in the questionnaire to gain insight in the importance of ICT for the integration of DG in electricity distribution networks. About two-thirds of the solutions presented included some form of data communication and/or ICT technology. This shows that ICT technology (e.g. data communication) is of major importance for managing modern electricity (distribution) networks and integrating DG into these networks.

The other questions led to the following answers:
- Power line communication and telephone/TV cables (including internet) were the most frequently mentioned types of data communication among the respondents.
- Communication by internet-technology was presented in about 50% of the options that included some sort of data transfer.

- Data transfer through the presented ICT technologies included all the categories listed in the questionnaire. Most frequently mentioned data types were generator information, load information and control signals.

3.3 Part B - Benefits and Costs

Part A of the questionnaire dealt with the technical details of the solution. Part B analysed the socio-economic issues of the technologies and mainly the transfer of benefits and costs of the given solutions. This part dealt with the major issue of the socio-economic research of DISPOWER: *how can benefits and costs of technical options and solutions for the integration of DG be allocated in a fair and efficient way among all stakeholders?*

The broader objective of this part of the questionnaire was to find out how designers/developers of technological devices were considering the possible benefits of their technology for the (electricity) market and how the transfer/allocation of costs and benefits of the particular technology could be arranged in economic terms.

3.3.1 Benefits related to the solution, option or approach

6. *What kind of benefit is related to the solution, option or approach?*

- Lower connection costs and network charges for generators
- Lower network costs
- Lower engineering costs
- Lower investment costs, please specify: …
- Lower operational costs, please specify: …
- Lower transaction costs, please specify: …
- Better access to the wholesale electricity market
- Better access to markets for balancing, reserve capacity, congestion
- Management of ancillary services
- Improved power quality
- Improved reliability (less outages)
- Lifetime extension of network equipment
- Environmental benefits, please specify: …
- Other, please specify: …

Almost all possible benefits for the electricity system listed in the questionnaire were mentioned at least once by the respondents. However, a few of them were prevailing. As far as the technical network benefits of the technologies were concerned, network issues such as *improved power quality* and *improved reliability* were most frequently mentioned. As regards the economic benefits, the most frequently mentioned issues were *lower connection costs*, *lower network costs* and *better access to markets for balancing, reserve capacity, and congestion*. Comparison of the responses and categorisation in technical and economic benefits did not result in any special ranking, i.e. the respondents were not particularly in favour of technical or economic benefits.

3.3.2 Stakeholders benefiting from the solution, option or approach

7. Who would benefit from the improvement directly or indirectly?

- DG/RES generator
- Large scale generator
- Transmission Network Operator (TNO/TSO)[17]
- Distribution Network Operator (DNO/DSO)[18]
- System Operator (SO)[19]
- Market Operator (MO)[20], please specify type of market: …
- Electricity trader
- Electricity supplier
- Consumer
- Other, please specify: …

The majority of the solutions chosen by the respondents are specifically aimed at DG generators and the distribution network. Two-thirds of the solutions have a positive impact for DG/RES generators as well as for the DSO. Other stakeholders benefiting from the improvements were the system operator, consumers and to a certain extent electricity traders and suppliers.

3.3.3 Valuation of benefits

8. How could benefits be optimally valued economically?

- Avoided investment costs
- Avoided purchases (e.g. electricity)
- Increased sales
- Reduced internal costs
- Shadow prices
- Other, please specify: …
- Benefits are difficult to value economically, because

Most respondents were able to point out the economic benefits of the proposed technologies. The first four issues, avoided investment costs, avoided (electricity) purchases, increased (electricity) sales and reduced internal costs, were prevailing. Only in three cases respondents announced that benefits are difficult to value economically. The reason they gave was that the proposed solution differs from current practise.

A number of specific answers given by the respondents on the valuation of benefits were (*related to a specific technology*):

- The user (of the technology) eliminates or at least reduces the number of stops of his productive process due to dip or line voltage interruption. From the point of view of the electricity supplier, this advantage of the user makes it possible to sell electricity at a higher price (…*in case of electricity storage…*).

[17] The Transmission Network Operator (TNO) is the organisation responsible for operating the transmission network. In integrated utilities, the TNO and/or DNO is one of the activities of the utility, but administratively or legally separated from other activities.

[18] The Distribution Network Operator (DNO) is the organisation responsible for operating the distribution network. In integrated utilities, the TNO and/or DNO is one of the activities of the utility, but administratively or legally separated from other activities.

[19] The SO is the (independent) system operator of the electricity network. In some countries the SO is joined together with the TNO in the TSO (Transmission System Operator) or the DNO joined together in a DSO.

[20] The market operator sets conditions and facilitates trade in electricity. The role of the market operator can differ per country, related to its authority to control the (electricity) market.

- The technology helps to increase (network) system reliability (…*in case of dynamic simulation of the grid with DG and RES…*).
- Costs (for the user of the technology) are minimised depending on the user case (…*in case of a Decentralised Electricity Management System…*) … (…*if the user is a DG generator, DSO, etc*….).
- Benefits are difficult to value economically because the increased energy-economic benefit of fluctuating RES (e.g. wind power) by increased energy system compatibility is based on forecasts and profiles/schedules.
- Players and roles (*in the distribution network*) will be different from the current situation (… *Demand* - *Supply side management using new ICT* - *solution in its concept phase* …).

3.3.4 Costs related to the solution, option or approach

9. What kinds of costs are related to the party using the solution, option or approach?

- Network charges (connection and system charges)
- Investment costs
- Operational costs
- Purchase costs
- Transaction costs
- Other, please specify: …

According to the respondents, the costs for the party using the solution, option or approach are mainly related to investment and operational costs and to a lesser extent also to network charges and purchase costs.

3.3.5 Parties bearing the costs

10. Who will have to bear the costs (e.g. who has to invest/to purchase)?

- DG/RES generator
- Large scale generator
- Transmission Network Operator (TNO/TSO)
- Distribution Network Operator (DNO/DSO)
- System Operator (SO)
- Market operator
- Electricity trader
- Electricity supplier
- Consumer
- Other, please specify: …

The party that has to invest or purchase is, in most of the cases, the DG/RES generator and the DSO. System operator, electricity supplier and consumer (both household and industry) were also mentioned frequently. It is noteworthy that the majority of the respondents answering in question 7 that the DG/RES generator benefits from the option (13 out of 17 respondents) also respond that these DG/RES generators have to bear the costs for the proposed technology. To a lesser extent this link also holds for the benefits and costs of the proposed technology for the DSO (9 out of 16 respondents). One of the respondents raised a specific comment: it is necessary to take into account that the (storage) device can be paid by the user or by the electricity supplier or shared between them. This is, of course, an option that can be a solution in more of the cases presented.

3.3.6 Compensation mechanisms

11. The party that has to bear the costs:
- Will be compensated because he enjoys all the benefits
- Will be compensated because he enjoys part of the benefits
- Will be compensated because he can transfer the costs (partly) to others that enjoy the benefits
- Is not compensated and transfer of costs to others that enjoy the benefits is difficult
- Other, please specify: …

Only a few of the respondents announced that transfer of costs and benefits is difficult and could not name a way of cost compensation. Mainly in the case of ICT related technologies (some of them are still in the concept phase and are not yet applied) a standard transfer of benefits and costs is difficult. The majority of the respondents announced that the party investing in the technology enjoys all or part of the costs or can transfer them. This answer is in line with the result of questions 7 and 10 that resulted in a link stating that DG/RES generators and DSOs that benefit from the option in most of the cases also have to cover the costs.

Not for all cases a standard transfer takes place, where one party invests and the other party benefiting provides a certain sum in return. One of the mentioned options was, for example, the *trading network reinforcements*. In this option, the DG generator agrees with the DSO to reduce the power output in cases that the local load is low, in return for a reduction of its connection costs. This means that the DG Generator will face reduced revenues in exchange for reduced reinforcement costs, but there is (almost) no initial investment cost that must be compensated.

3.3.7 Transfer of benefits and costs among stakeholders

12. How can benefits or costs be most optimally transferred?
- Increase or reduction of the network tariff (connection charge or use of system charges)
- Increase or reduction of the system charges (charges of the System Operator for balancing, reserves, ancillary services)
- Compensated by a (higher or lower) electricity price (i.e. commodity price)
- Compensated by a separate value (like green certificates)
- Compensated by another special charge or market price, please specify: …
- Benefits and/or costs are difficult to transfer because …

The aforementioned question was related to the mechanisms of transfer of benefits and costs. The respondents generally preferred the following solutions:
- changes in network tariffs,
- changes in the system charges, and
- to a lesser extent changes in electricity prices.

The introduction of special charges (or separate values) in the form of e.g. green certificates was not proposed very often. Some specific solutions were presented in combination with question 13.

13. What needs to be done to create a better (fairer/more efficient) allocation of costs and benefits?

This open question was included to give the respondents the chance to propose a personal proposal to the allocation of benefits and cost. A number of proposals to create a better or fairer and more efficient allocation of costs and benefits were presented.

Solutions related to network charges:

- The system operators (SO) or distribution system operators (DSO) should pay to the owners of the DG/RES generators for their contribution to network services like compensation of reactive power; feed-in of reserve active power or voltage stabilisation. → *Change of network regulations*.
- Distributed generators may benefit from the extra flexibility of ongoing use-of-system charges instead of up-front connection charges but this is riskier for the network owner who must invest up-front. → *Move from connection charges to Use of System charges*.
- Proposal to have new rules integrated into *new technical standards* that allow market deregulation but also clearly define sharing of duties and of expenses among all interested partners. For example, if an independent producer of energy has the right to connect his generators to the main network, he/she must also have the duty of providing the correct shape of wave voltage, the correct frequency, etc. → *Connection to the grid includes charges and obligations for both DSO and DG operator*.

Solutions related to other financial mechanisms/support:

- Development of *a market for reserves and storage*. → *Ancillary services market*.
- Evaluate the costs and benefits of using DG on a distribution grid → *cost & benefit analysis*.
- Where consumers are involved, a reward should be given for the higher investment (in case of a power quality improvement tool) → *rewarding network related benefits*.
- Have a specific tariff for variable (depending on wind) guaranteed power generation (short term) → *special tariffs or reward for the contribution to network security*.

Solutions related to compensation of external (not network related) costs:

- *Internalisation* of external energy related costs of all power sources.
- Including all known (direct and indirect) costs influencing the particular sort of generation.

The answers appear to be very broad in scope, but are comparable to a certain extend. Most of the proposals include a certain (new) way of valuation of DG benefits, but they are presented in different forms: internalisation of external costs, rewarding specific types of DG, creation of a market for reserves and storage.

14. Additional remarks

Additional remarks were mostly related to product information and the status of the technology in a given country. For the research, the answers were of little relevance.

3.4 Use of the questionnaire

The questionnaire resulted in an overview of different technologies, solutions and approaches aiming at an increasing share of DG into the distribution network. Although the number of returned questionnaires was limited, it gave a good overview of the types of technical solutions that will be needed for an improved integration of distributed generation into electricity networks.

3.4.1 The value of the results

The results of the questionnaire gave an overview of existing technologies and approaches to include DG into distribution networks. The analysis of the answers should be taken with caution, however. A few examples:

- In question 8, the majority of respondents mentioned some way of valuating the DG benefits. This does not necessarily mean that valuating the economic benefits of DG is an easy task. When presenting a question with a number of answers, it is easier for respondents to choose between the presented options than to give an own specific answer.
- The answers to questions 7, 10 and 11 were in line some way. When asking respondents about the party benefiting from the solution (question 7) and the party bearing the costs (question 10), in a large number of questionnaires the same party was mentioned (in most cases the DG generator or the DSO). In question 11 most of the respondents announced that the party investing in the technology enjoys all or part of the costs, which is in line with the findings from questions 7 and 10.
- The questionnaire included a number of very different technologies, solutions and approaches. Comparing these technologies must be done with great caution.

3.4.2 Conclusions

Interesting findings of the questionnaire are the following:

- Two-thirds of the mentioned solutions included some form of data communication and/or ICT technology illustrating the growing importance of ICT based technologies.
- When aiming to value the benefits of the presented technologies, most frequent answers were aimed at (network related) investments and the avoided purchase of (balancing) power.
- Parties bearing the costs of the solution often are the same as the party benefiting from the technology.
- Changes in network tariffs and/or system tariffs are viewed to be the most suitable ways to allocate costs and benefits of the presented solutions.

4. COSTS AND BENEFITS OF DISTRIBUTION NETWORK TECHNOLOGIES

This chapter will analyse the impact of the technological solutions, options and approaches on the financial relationships between the actors in the distribution network. It will show how the costs and benefits of different actors in the electricity market can be analysed and how the application of technologies influences cost and benefit streams. The analysis is based on a description of transactions between the actors in the electricity market and the costs and revenues for these main actors (DG operator, energy supplier, DSO). For four new technologies, a qualitative research is carried out showing what changes are taking place in the transactions, dependent on the actor that is investing. A distinction is made between direct and indirect impacts. The direct impacts directly influence the costs and revenues of the actor investing in the given technology. The indirect impacts, derived from the direct impacts, influence the costs and revenues of other actors than the one investing in the technology. This research activity in the DISPOWER project merely provides an analytic tool how to identify the costs and benefits of a number of proposed technologies and how to allocate them between actors in the electricity market.

4.1 Financial relations in the electricity network

To enable a thorough analysis of the impact of the technical solutions, options and approaches on the actors in the electricity network, a schematic overview of these actors has to be presented[21]. Figure 4.1 shows the financial transactions and information exchange of the energy market actors at distribution and transmission level. It includes all the stakeholders on the distribution level: the DG operator, the DSO, a separate energy supplier, the large power producer connected to the transmission network, the TSO and the final consumer. The scheme also includes a fuel supplier. This actor is not of importance for network operation as such, but it is an important cost for both DG and large power producers. Note that the physical power streams from the DG operator/large power producer through the transmission and distribution networks (TSO/DSO) to the consumer have been separated from the commodity trade between DG operator/large power producer through the energy supplier to the consumer. In some markets, separate metering companies exist. In this analysis we presume that this party is part of the DSO, the actor responsible for the physical power streams. Therefore, the DSO provide metering data to the energy supplier.

[21] These analytical schemes are partly based on the methods of constructing business models for new energy market activities developed in the BUSMOD project. See for more information Akkermans and Gordijn (2004) and http://busmod.e3value.com/.

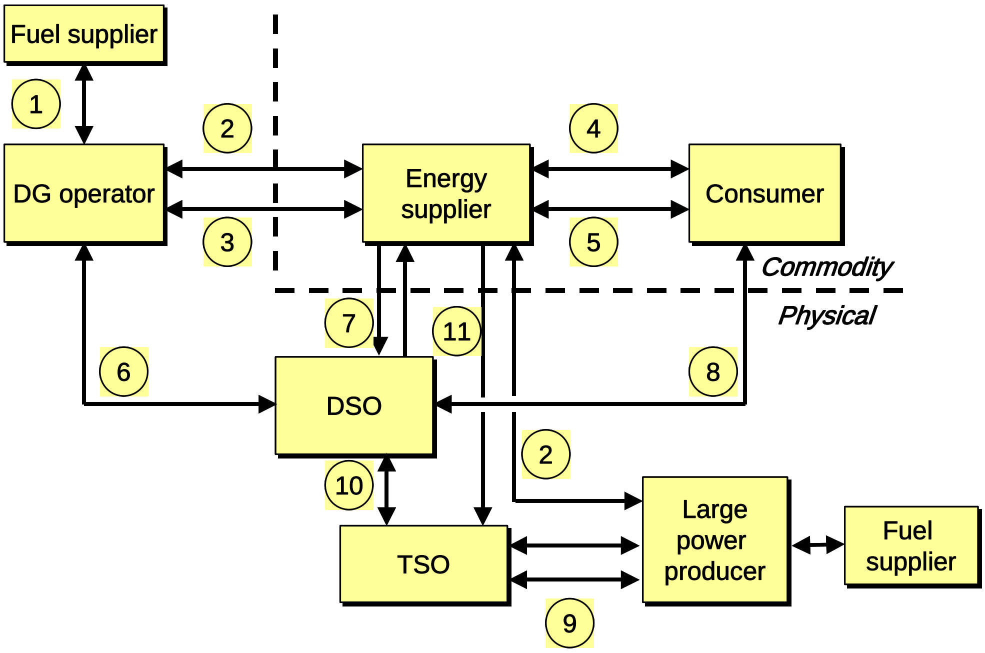

Figure 4.1 *Overview of electricity market transactions and information exchange*

Table 4.1 shows the financial transactions and information exchange between all the actors, related to the energy services offered and the ways of payment received in return.

Table 4.1 *Financial transactions and information exchange between energy market actors*

	Actor	Offers	To	Expects in return
1	Fuel supplier	Fuel (gas, oil, biomass, coal)	DG operator/Large power producer	Payment for fuel on basis of contracted fuel price
2	DG operator/Large power producer	Electricity	Energy supplier	Payment for electricity on basis of wholesale contract
3	Energy supplier	E-program management	DG operator	E-program responsibility
4	Energy supplier	Electricity	Consumer	Payment for electricity on basis of a retail contract
5	Consumer	Outsources E-program responsibility	Energy supplier	E-program management
6	DSO	Grid access and use	DG operator	Payment of connection and use of system charges
7	Energy supplier	Switching data	DSO	
	DSO	Generation & consumption data	Energy supplier	
8	DSO	Grid access and use	Consumer	Payment of connection and use of system charges
9	Large power producer	Balancing power	TSO	Payment on basis of balancing contract
	TSO	Grid access and use	Large power producer	Payment of connection and use of system charges
10	TSO	Ancillary services	DSO	Payment of ancillary service costs
11	Energy supplier	E-Program	TSO	
	TSO	Balancing services	Energy supplier	Payment for deviations

In many European countries the ongoing liberalisation of the energy market has led to the establishment of a separate balancing market and a separate ancillary services market, apart from the wholesale and retail market. Access to these markets is mainly limited to the large power producers and the TSO, but theoretically DG operators have also access to these markets. Figure 4.2 shows the electricity market actors including their connection to the ancillary services and balancing markets. This figure shows the ideal (future) situation where both large power producers as DG operators have access to the ancillary services and balancing markets and both the TSO and the DSO are able to purchase their services on these markets. It is assumed that demand response by consumers and storage are also available options in the electricity market. The transactions that are less common in the existing electricity market are shown with dotted lines.

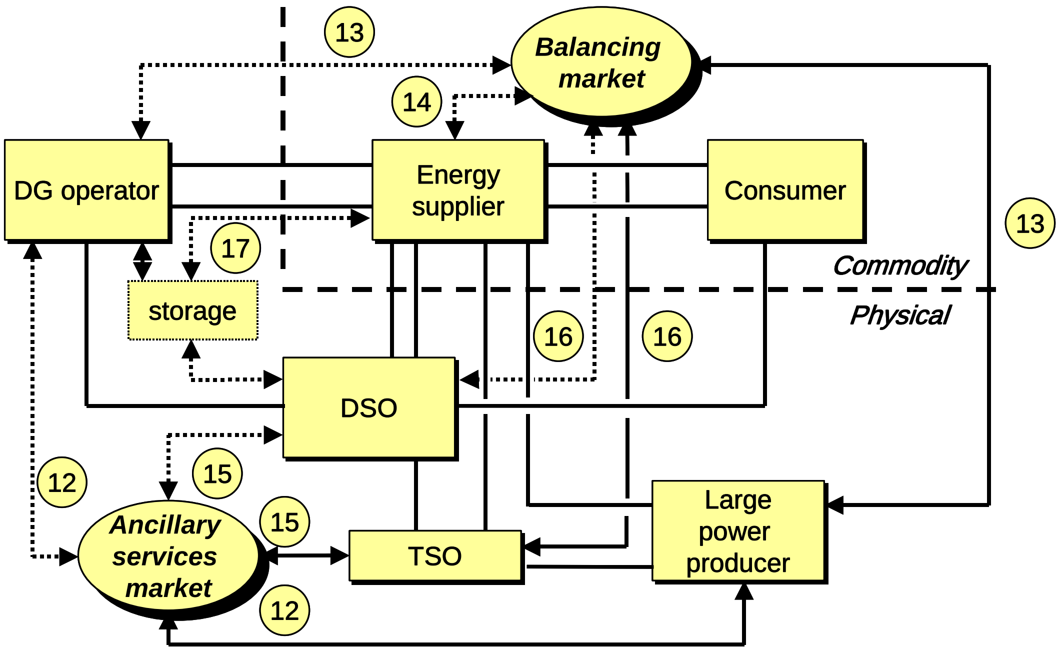

Figure 4.2 *Electricity market transactions in ancillary services and balancing market*

The relationships between the actors are shown in Table 4.2.

Both Figure 4.1 and Figure 4.2 show the electricity market in the case of complete unbundling, meaning that all the activities in the electricity market, production, transmission, distribution and supply, are undertaken by different parties. This may not be the case for the situation where integrated companies control more than one activity[22]. This research, however, requires that the situation on the electricity market is considered for complete unbundling, showing all possible interrelations and financial transactions. Another relation excluded in this research is the auto-production of DG electricity. This is the direct consumption of electricity produced on-site by a consumer, skipping the purchase/sale process through the energy supplier. This connection is excluded as there are little transactions of relevance taking place for the analysis.

[22] i.e. integration of energy supply and power generation and/or fuel supply. According to the European Electricity Directive operation of the transmission and distribution networks should be unbundled from electricity generation and supply.

Table 4.2 *Financial relations and transactions in balancing and ancillary services market*

	Transactions between actors			
	Actor	Offers	To	Expects in return
12	Large power producer	Ancillary services	Ancillary service market	Payment on basis of ancillary services contract
	DG operator	Ancillary services	Ancillary service market	Payment on basis of ancillary services contract
13	Large power producer	Balancing power	Balancing market	Payment if dispatched
	DG operator	Balancing power	Balancing market	Payment if dispatched
14	Energy supplier	Balancing power (indirect)[23]	Balancing market	Payment to producers (via energy supplier)
17	DG operator/DSO/ energy supplier	Storage services	DG operator/DSO/ energy supplier	Payment for storage service
	Transactions on markets			
	Market	Offers	To	Expects in return
15	Ancillary services market	Ancillary services	TSO	Payment
	Ancillary services market	Ancillary services	DSO	Payment
16	Balancing market	Balancing services	TSO	Payment
	Balancing market	Balancing services	DSO	Payment

4.2 Revenues and expenditures of distribution network actors

4.2.1 The DG Operator

To obtain a clear picture of the costs and benefits of DG for the distribution network, one should study the revenues and expenditures of the main actors on the distribution network, the DG operator, the DSO and the energy supplier. Figure 4.3 shows the revenues and expenditures that come with the operation of a DG facility.

The operation of a DG facility presents a number of expenditures to the operator. First of all there are the investment costs, these consist of the following items:

- Investment in the generation unit.
- Acquiring the land (e.g. in the case of wind power).

Secondly, there are operation and maintenance costs. These mainly include:

- Fuel costs (e.g. gas, oil or wood for CHP and biomass plants).
- Operation and maintenance of the production unit.

The third item consists of the network costs, which can be divided over three parts:

- Upfront connection charges (to cover the costs for grid extension made by the DSO). Depending on existing network regulation, Distribution System Operators charge shallow or deep connection costs (see also Appendix A2), meaning the DG operator solely pays for the connection to the nearest grid or the connection to the nearest grid *plus* possible upgrades of the existing grid respectively.
- Use of System (UoS) charges, a charge depending on the amount of kWh fed into the grid. In most markets consumers pay such a charge for the use they make of the electricity system when consuming electricity. UoS charges for DG operators are not yet common, but variable UoS charges may reward DG operators for their benefits to the network (UoS is

[23] Electricity offered by DG operator or large power producer with energy supplier as intermediary or avoided electricity consumption by the consumer (demand response).

negative, i.e. turns into a revenue) or charge them for the extra costs they bring to the network[24].

A DG facility generates the following revenues:

- The main source of income is the sale of electricity and heat (in the case of a CHP unit), received from an energy supplier or directly from the consumer.
- In most EU Member States, DG operators receive a premium payment for the external benefits they generate in terms of environmental protection and improving energy efficiency. Such a premium include the following financial schemes:
  - Investment subsidy for a specific environmentally sound technology, this is usually a fixed amount received to make the upfront investment possible.
  - Subsidy or other form of extra revenue for the green value of the electricity (feed-in tariff or the sale of a green certificate), this subsidy is received per kWh of DG electricity produced.
  - Subsidy for the fuel used or a tax exemption (e.g. natural gas consumed for CHP operation may be free of energy tax.).
- In the future, a third revenue stream may gain importance. Participation in the balancing and ancillary services market, e.g. sale of these services to the DSO, should lead to additional revenues from electricity system benefits. Here we can distinguish two different types of revenues:
  - System benefits, benefits that occur to the network when a DG facility is connected without any special activity undertaken, e.g. a DG facility close to a load can 'automatically' reduce network losses.
  - Ancillary services, special services that have to be 'actively' provided by the DG operator, e.g. providing reactive power.

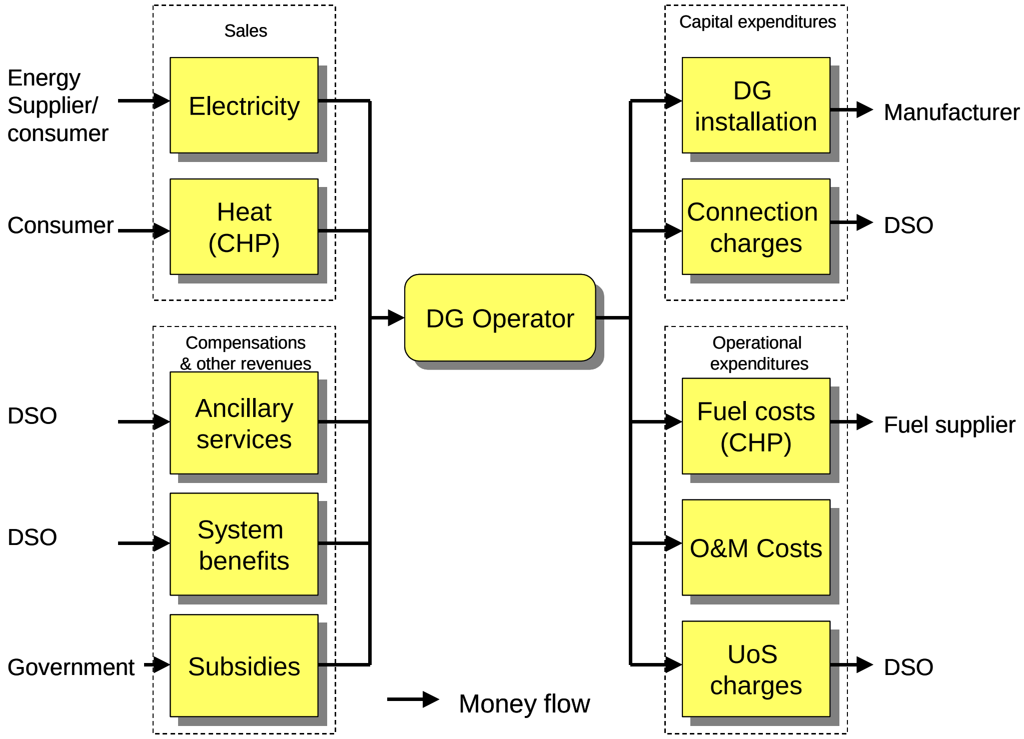

Figure 4.3 *Revenues and expenditures of the DG operator*

[24] These extra costs also include the balancing costs for the TSO of the new facility. Balancing costs are not directly paid by the DG operator but covered through connection costs or Use of System charges to the DSO, who then pays the TSO. Balancing costs may also be covered through a wholesale contract with the energy supplier, who will adjust the wholesale price of electricity accordingly.

There are a number of other factors that may influence the height of the costs and benefits and finally the cost-effectiveness of the DG operator:

- Technology specific issues, e.g. depending on the sort of fuel used and the price development of this fuel. A good example is the gas price development that to a great extent influences the operational costs of CHP installations and the profitability of the CHP installation as a whole.
- Controllable and non-controllable (intermittent) loads: controllable loads have a more positive impact on the electricity network and market and have more possibilities to obtain revenues through ancillary services and balancing markets.
- The ownership structure: the DG facility may be operated as a joint venture (e.g. with energy suppliers) or as an independent power producer. Both constructions have their specific features:
    - Consumers may act as an independent power producer (IPP) mainly producing for own use. The consumer's advantage is not being dependent on fluctuating (wholesale) prices on the electricity market. Producing electricity for own use means avoiding purchase of electricity against retail price (being higher than wholesale price), which is in many cases profitable. Not producing for own use eliminates this advantage.
    - DG facilities in joint venture usually sell the electricity on the market. These units are often used to balance the E-programs of the energy supplier.

4.2.2 The Distribution System Operator

The economics, costs and revenues of a Distribution System Operator (DSO) are illustrated in Figure 4.4.

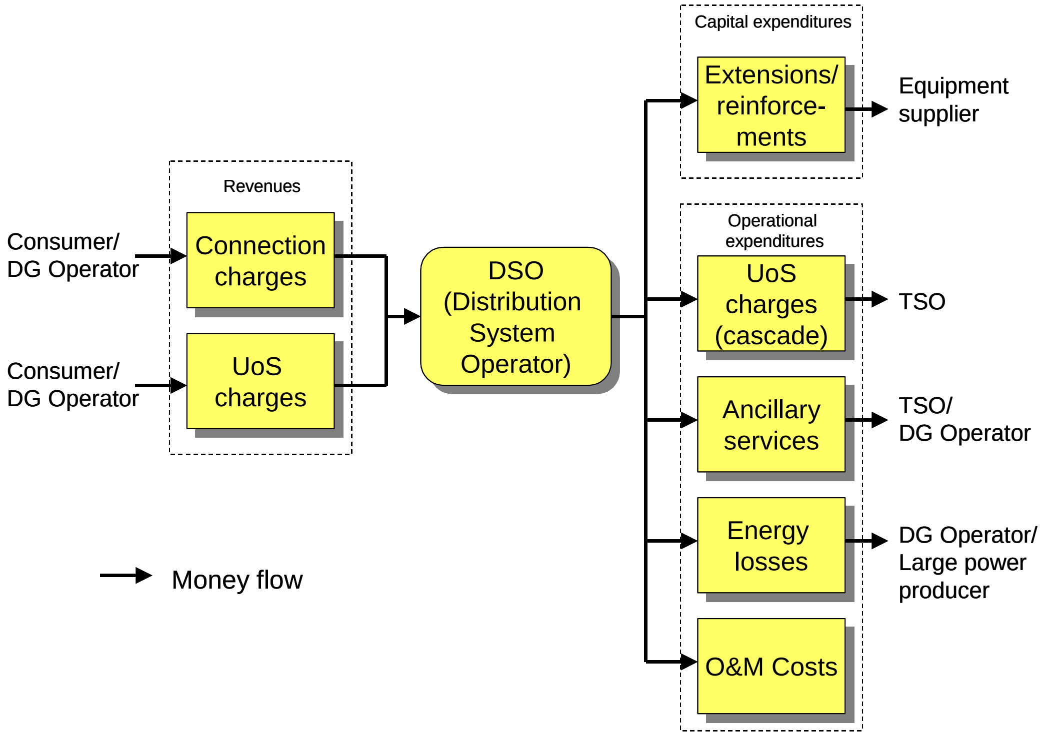

Figure 4.4 *Revenues and expenditures of a Distribution System Operator (DSO)*

The main revenues of a DSO are in the form of network charges:

- Use of System charges (per unit kWh and/or kW) received from consumers and (in some countries) from power producers (i.e. DG).
- Connection charges from consumers, some of them owning DG facilities, in the form of shallow or deep connection charges.

The main costs of a DSO exist of:

- Capital expenditures (CAPEX) - investments in the network, extension of the grid, reinforcement of existing lines or investments in other supporting devices.
- Operational expenditures (OPEX) - these include (1) maintenance of the network, (2) UoS charges paid to the TSO[25], (3) electricity to cover energy losses and (4) ancillary services such as reactive power management and voltage control. Up to now, ancillary services are mainly purchased from the Transmission System Operator, but they may also be purchased from DG operators[26] (directly or through the ancillary services market) that are able to provide these services (mainly DG units with controllable production).

Note that the revenues for the DSO are subject to economic regulation. The tariffs they are allowed to charge are based on operational and capital expenditures and regulated profitability.

4.2.3 The energy supplier

Due to unbundling of the electricity market, an (independent) energy supplier that is separated from the network activities can be identified. The energy supplier purchases electricity from producers and sells it to consumers. Figure 4.5 illustrates the costs and revenues of an energy supplier.

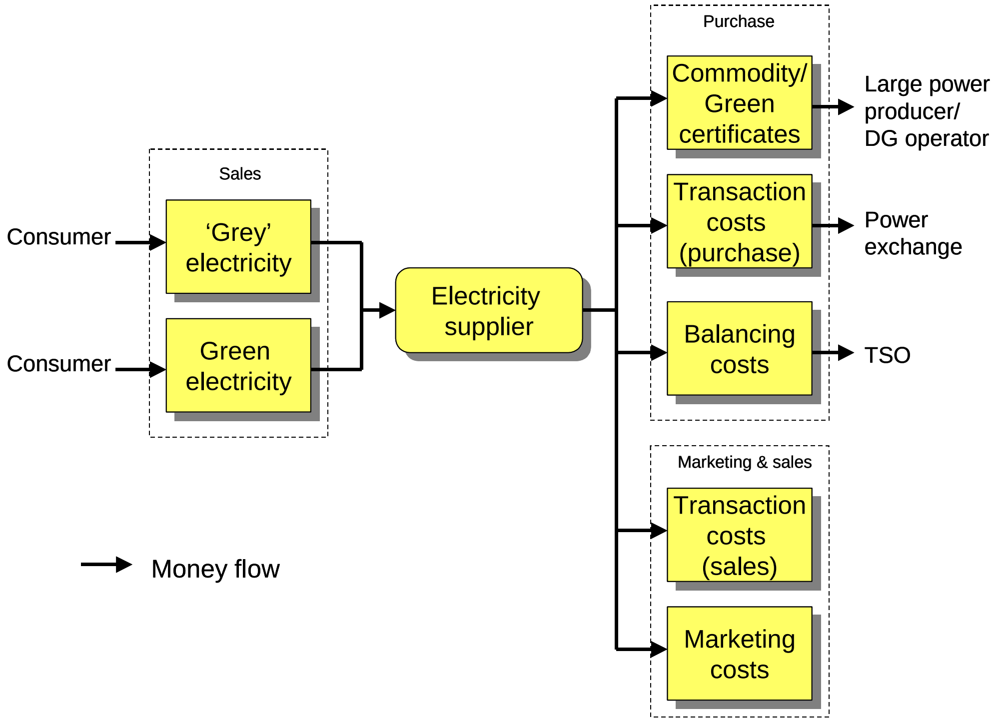

Figure 4.5 *Revenues and expenditures of an electricity supplier*

As the figure shows, the main revenue stream of the electricity supplier concerns the sales of electricity against retail price, after electricity is purchased at wholesale price from DG producers and large power producers. Energy suppliers may try to increase their income by offering the customers other energy and non-energy related services and products. These products can exist of energy advisory services, sale of different technologies, etc. The revenues generated by these

[25] The network tariff structure is often based on the cascade principle: consumers pay for the costs of the network level to which they are connected to and the costs of all higher network levels proportionally to the use of these network levels. Therefore, the DSO pays the TSO for the use of the transmission network on basis of the power flow towards the distribution network.

[26] Since January 1, 2004, DSOs in the Netherlands have the possibility to purchase ancillary services from third parties, which may be other (DG) producers.

services are not presented in the figure as they are not within the scope of this research. The main costs for the energy supplier, apart from the purchase of electricity from power producers, consists of the balancing costs charged by the TSO. Other costs concern the transaction costs for purchase and sale of electricity, including costs for access to the power exchange.

Other factors influencing the costs and revenues from the electricity supplier are the following:
- In energy markets the energy supplier may be part of a company also owning production capacity. This means that the energy supplier can optimise power production with supply activities and vice versa.
- The type of power source the supplier purchases is also of influence to the costs. When purchasing from intermittent sources (with fluctuating power output) the energy supplier may face increasing balancing costs (i.e. buying power from spinning reserve or to pay balancing costs to the TSO) to comply with its E-program (agreed supply and demand)[27].
- Green electricity, purchasing green certificates and selling green power.

4.3 Impact of new technologies and approaches

In Section 3.1, the different technical options and solutions have been divided into four main categories. In this section, four technologies, one of each category, will be studied to analyse their impact on the financial relationships between the actors in the distribution network. The four technologies are:
- Wind power prediction tool (planning tool).
- Grid control unit (power quality device).
- Power operation and power quality management system (ICT device).
- Power storage device.

For each of the 4 technologies a distribution power scheme is drawn like the one in Figure 4.2. First a reference case is described, presenting the power scheme with DG but without any additional devices and describing one or more constraints that could be solved with the given technology. After the technology is implemented by one of the actors in the distribution power scheme (DG operator/energy supplier/DSO), all other circumstances remain the same. Then the possible direct effects (costs and benefits related to the party investing) and indirect effects (costs and benefits related to third parties) are described. The analysis remains qualitative in nature. It was not within the scope of this research to analyse specific DG cases.

4.3.1 Planning tools

Planning tools include software and other operation and design tools that aim at optimising the integration of DG/RES in distribution systems. Implementation of such a tool will lead to optimisation of (local) production and loads. An example of such a tool is the Wind Power Prediction Tool. Depending on the situation the DG operator, the energy supplier or the DSO can invest in such a tool and gain certain benefits for their own business, but also influencing the economics of others.

Wind Power Prediction Tool

The need for and benefit of wind energy forecasting have been increasingly recognised in recent years. As wind energy penetration increases, the need for forecasting is recognised by system operators as essential in accommodating this intermittent energy source into the electricity network. In liberalised electricity markets, supply and demand of electricity must be balanced in specific (e.g. hourly or quarter of an hour) trading periods. This requires up to date information

[27] The energy supplier that manages the E-program responsibility for (intermittent) DG producers will ask a contribution from the DG producer in the balancing costs. This may be in the form of an adapted (lower) wholesale price of electricity, or a certain payment, depending on the contract between the energy supplier and the DG operator.

of the power output of wind farms. Improved forecasting of the wind power can help the party responsible for the E-program to improve balancing of supply and demand. This may give a higher value to the wind energy installed and possibly also reduce the need for balancing costs.

A wind power prediction tool (WPPT) is a relatively new approach in managing power output from wind farms. It utilises up to date information from meteorological stations for certain areas (e.g. 10 x 10 km grids) and the information is communicated through automatic (on-line) operational schemes. In the DISPOWER questionnaire, wind power prediction through remote control of operational wind farms making use of the Nordex ‘Control 2’ SCADA system has been described[28]. This technology allows off-site access to operational parameters of the wind farm, such as: wind speed, ambient temperature, machine vibration, voltage, power output, trips, alarms, etc. The information can be accessed daily by the owner/operator using a modem link. Benefits of the solution to the owner are related to lower operational costs through remote access to performance data and the possibility of remote control. The most important benefit, however, is related to improved forecasting of the wind power output. The following actors in the distribution power system are directly involved when the wind power prediction tool is utilised:

- The energy supplier, the party that is usually responsible for the E-program and that has to match supply and demand. A WPPT would provide him with better power output forecasts.
- DG operator, the operator of the wind farm. The tool enables the operator to improve the wind power output prediction and provide the energy supplier or DSO with improved output information. As could be seen form the DISPOWER questionnaire, the WPPT in connection with remote control can also lower the operational costs of the plant for the owner/operator.
- The DSO is in control of the flows through the network and responsible for power quality. A wind power prediction tool may help the DSO to keep the flows within the technical safety limits of the network system.
- The TSO responsible for the balance in the whole electricity supply system.

The transactions between the actors

The financial transactions between the actors on the distribution network are illustrated in Figures 4.6 to 4.9. The reference situation of the electricity distribution system with a DG wind power operator integrated, before implementation of the wind power prediction tool, is shown in Figure 4.6. This figure only shows the relevant actors that will be influenced in case a wind power prediction tool is implemented (e.g. such a tool has minimal influence on the energy consumer who is, therefore, not shown in this picture).

[28] Within Work Package 5 of the DISPOWER project, several (internet-based) information systems for energy management are examined, giving special attention to forecasting of intermittent generation. Within Task 5.3 the two most important wind power prediction tools are adapted and proved in a practical application in the UK.

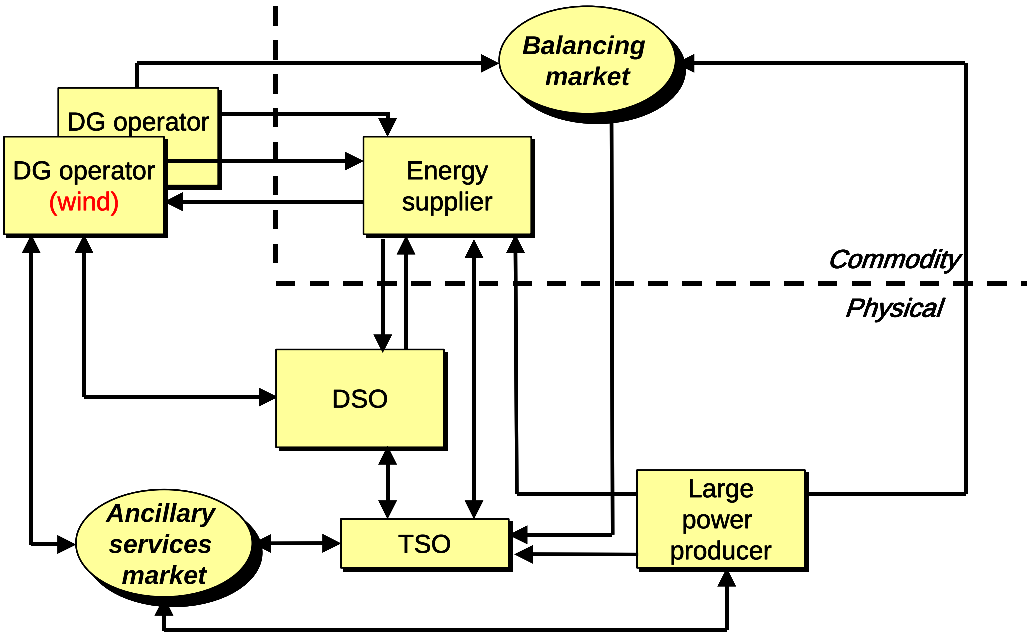

Figure 4.6 *Power distributed scheme with DG (wind) operator*

In the reference case, an energy supplier purchases its electricity from a large power producer and one or more DG operators from which at least one is a wind power producer. The energy supplier buying power from a wind turbine is unsure about the power output. This output can change within hours, i.e. after the E-program is submitted to the TSO. A deviation of the actual power (registered by the DSO) from the E-program is penalized by the TSO. The TSO will compensate the difference between actual power flow and E-program by dispatching power from large power producers (or DG) offered on the balancing market. With the information of the WPPT the energy supplier can either change his E-program (if he is allowed to) or adjust the supply of other generators (or loads) to match the E-program.

Use of the wind power prediction tool

USE BY THE ENERGY SUPPLIER

Figure 4.7 and Table 4.3 show the financial transactions and information exchanges in case the energy supplier invests and utilises a wind power prediction tool (WPPT) as described before. All other conditions and activities of other actors remain equal to the reference situation. In the following distribution network schemes (Figure 4.7 and further), the bold lines present the direct impacts for the party investing in the technology. The thin black lines present the indirect effects of the technology to third parties. The grey lines present the transactions/information exchanges that are not affected by the technology.

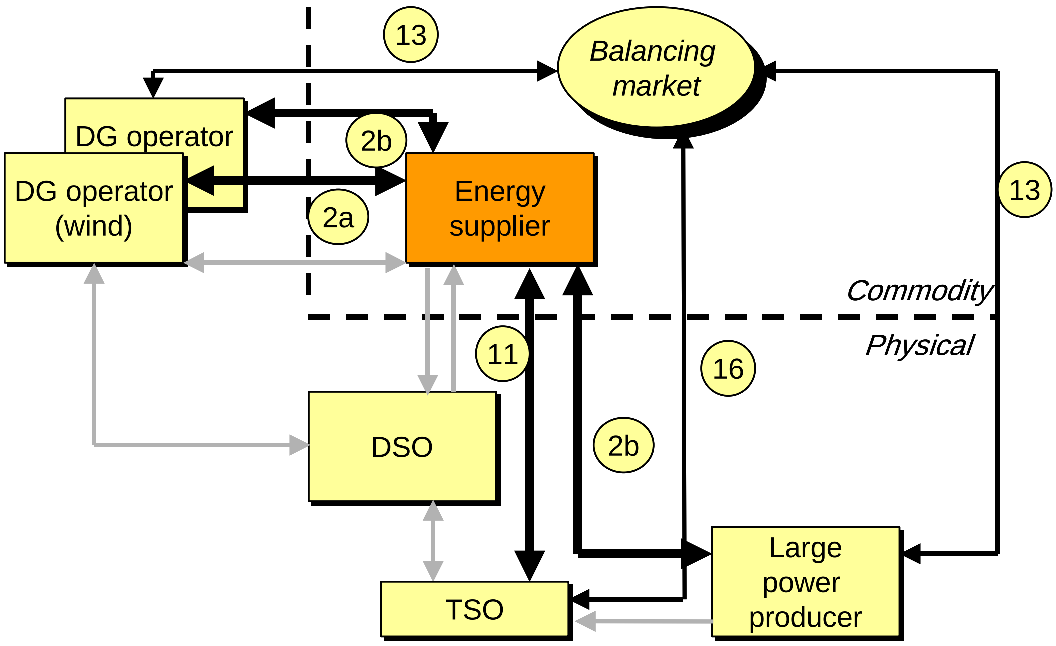

Figure 4.7 *Wind power prediction tool implemented by the energy supplier*

The wind power prediction tool enables the energy supplier to forecast changes in the power output (line 2a) and adjust its E-program by contracting extra power from a large power producer or controllable DG (line 2b). Instead of penalty costs (line 11) the energy supplier buys more peaking power in case of lesser wind and less peaking power in case of more wind. This is a cost saving for the energy supplier. An indirect benefit accrues to the TSO that has to compensate lesser deviations and also saves costs due to lower purchases on the balancing market (line 16). As a result, the revenues from the large power producer and the (controllable) DG producer from the balancing market may decrease (line 13).

Table 4.3 *Changed transactions with WPPT implemented by the energy supplier*

	Actor/Market	Offers	To	Expects in return	Change to reference case
Direct impacts					
2a	DG wind operator	Electricity	Energy supplier	Payment (wholesale contract)	Improved forecast power output
2b	DG operator/ Large power producer	Peak electricity	Energy supplier	Payment for peak generation	Purchase of peak generation based on adjustments
11	Energy supplier	E-program	TSO	Balancing services/ Unbalance charges	Less balancing charges
Indirect impacts					
13	Large power producer DG operator	Balancing power	Balancing market	Payment if dispatched	Less dispatch of balancing power
16	Balancing market	Balancing services	TSO	Balancing payment	Decreased purchase balancing service

USE BY THE DG OPERATOR

Figure 4.8 and Table 4.4 show the financial transactions and the benefit streams in case the DG operator invests and utilises the wind power prediction tool.

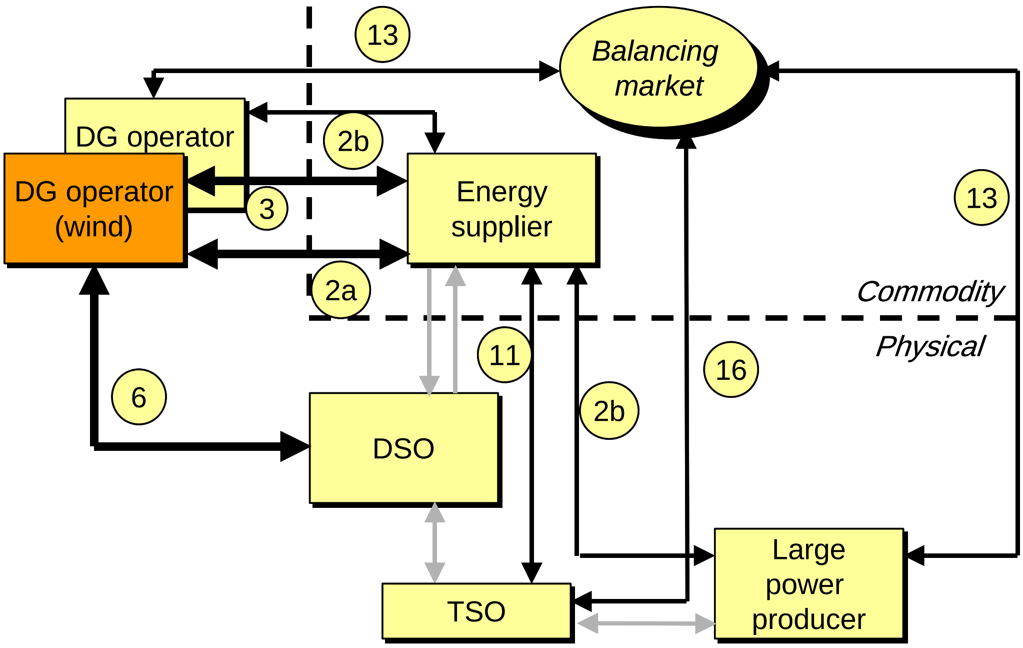

Figure 4.8 *Wind power prediction tool implemented by the DG operator*

A wind power operator that invests in a wind power prediction tool can forecast changes in power output and provide the energy supplier with more reliable information. The energy supplier may offer a higher electricity price to the wind power operator (line 2a) in return because he will have an easier job in meeting his E-program (line 3) and lower his balancing costs (line 11).

As the energy supplier can control his E-program, total costs for balancing the power system for both the energy supplier and the TSO will decrease (line 11). Therefore, indirect benefits are attributed to the TSO in the form of lower balancing costs (line 16). Finally, decreased demand for balancing power may decrease the revenues from the balancing market for other DG and large power producers (line 13).

The wind power operator is able to predict, in some cases even control, its power output, which is a benefit for the DSO because network operational costs decrease (line 6). The DG operator may be rewarded by the DSO for this benefit through lower connection of use of system charges. The DG operator and the DSO may also agree upon a lower production in case of strong winds but low demand. This can also be rewarded by the DSO in the form of lower connection or use of system charges for the DG operator. Another possibility is that the DSO allows the DG operator to connect more wind power capacity, enabling the DG operator to sell more electricity to the energy supplier (line 2a).

Table 4.4 *Changed transactions with WPPT implemented by the DG operator*

	Actor/Market	Offers	To	Expects in return	Change to reference case
Direct impacts					
2a	DG wind operator	Electricity	Energy supplier	Payment (wholesale contract)	Higher wholesale prices or increased power output[29]
3	Energy supplier	E-program responsibility	DG operator	Information about power output	Easier E-program management
6	DSO	Grid access and use	DG operator	Payment of connection and use of system charges	Decreased connection or use of system charges
Indirect impacts					
2b	DG operator/Large power producer	Peak electricity	Energy supplier	Payment for peak generation	Purchase of peak generation based on adjustments
11	Energy supplier	E-program	TSO	Balancing services/ Unbalance charges	Less balancing charges
13	Large power producer DG operator	Balancing power	Balancing market	Payment if dispatched	Less dispatch of balancing power
16	Balancing market	Balancing services	TSO	Balancing payment	Decreased purchase balancing service

USE BY THE DSO

Figure 4.9 and Table 4.5 show the financial relations and the benefit streams in case the DSO invests and utilises the wind power prediction tool.

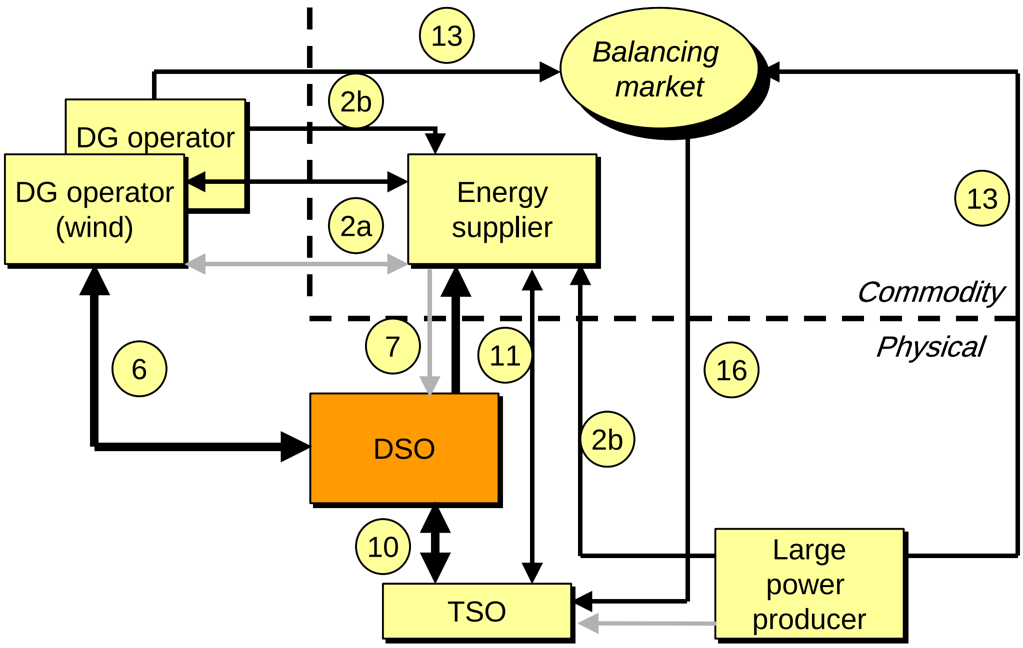

Figure 4.9 *Wind power prediction tool implemented by the DSO*

In case the DSO invests and utilises the wind power prediction tool it will improve the ability to control the power flows in the distribution network (line 6). The main benefit for the DSO in this respect is to control the peak load in the network system and to control power quality, i.e. improving voltage control and reactive power management. This can eventually lead to lower costs for the purchase of ancillary services by the DSO from the TSO (line 10) or lower investments in the distribution network. The utilisation of the WPPT by the DSO may increase the capacity of wind power connected to the network, meaning higher revenues for the DG operator

[29] Increased power output only in case the DG (wind) operator may connect more wind power capacity to the grid.

(line 2a). The DSO operating the WPPT will have to provide the energy supplier with forecasts of power output to the energy supplier (the DSO is obliged to do so). This again enables the energy supplier to optimise the E-program and benefit in terms of lower balancing charges/fines (line 11). This again influences the transactions on the balancing market (lines 13 and 16).

Table 4.5 *Changed transactions with WPPT implemented by the DSO*

	Actor/Market	Offers	To	Expects in return	Change to reference case
Direct impacts					
6	DSO	Grid access and use	DG operator	Payment of connection and use of system charges	Improved grid access, adjusted connection or use of system charges
7	DSO	Generation and consumption data	Energy supplier		More reliable wind power output data
10	TSO	Ancillary services	DSO	Ancillary service fees	Decreased ancillary service fees
Indirect impacts					
2a	DG (wind) operator	Electricity	Energy supplier	Payment (wholesale contract)	Increased electricity supply or higher wholesale price
2	Large power producer DG operator	Peak generation	Energy supplier	Payment for peak generation	Purchase of peak generation based on adjustments
11	Energy supplier	(Adjusted) E-program	TSO	Balancing service/fines	Less balancing services required
13	Large power producer DG operator	Balancing power	Balancing market	Payment if dispatched	Less dispatch of balancing power
16	Balancing market	Less balancing services	TSO	Balancing payment	Little balancing payment

A DSO investing in a device like a wind power prediction tool requires a more active approach of the DSO. The DSO will have to act as an active entrepreneur, not only transporting electricity but actively operating the network through connecting DG in the best possible way. Since the DSO's activity is related to a specific region the DSO can excellently provide the wind power predictions to all wind power producers in this region.

Cost and benefit overview of the wind power prediction tool

The previous three figures showed a number of changes occurring in the distribution power system when the energy supplier, wind power operator or DSO invests in a wind power prediction tool. The following impacts on cost/benefit streams can be identified:

- The energy supplier will improve the forecast of power output of the DG (wind power) operator when investing in the WPPT. This enables the energy supplier to improve supply and demand matching (through more/less purchase of peak generation capacity) and prevent unbalance charges to be paid to the TSO.
- The DG operator can provide better information about power output to the energy supplier that provides him with higher electricity prices in return due to benefits in the field of E-program and balancing.
- The DSO can improve its network management through better information about power loads, thereby lowering network operational costs, lowering ancillary service purchase and reducing or postponing investments.
- The TSO will experience lower balancing costs, as the party investing in the WPPT will be able to improve own balancing of supply and demand, decreasing the balancing efforts to be done by the TSO.

The benefits and the application of a technology as the *Wind Power Prediction Tool* as was shown above, highly depend on national regulatory-, technology- and site-specific issues. The analysis showed the possible impact of investment of one of the energy market actors and the effects of costs and benefits. National circumstances, however, strongly determine which party invests in a wind power prediction tool:

- In the UK, power producers are obliged under the New Electricity Trading Arrangements (NETA) to remain within the agreed power output. In case an owner of a wind park cannot stay within this band, relatively high penalties are charged (see also Section 2.4.1). Therefore, it is in the interest of the DG operator to invest in a Wind Power Prediction Tool.
- In Germany the case is different. Here the TSO/DSOs are solely responsible for the system balance and obliged to connect any wind producer and purchase all RES electricity offered to them. Therefore, in Germany a TSO or DSO will be the party to invest in a WPPT.
- In the Netherlands, the electricity supplier is usually the party bearing E-program responsibility on behalf of small-scale wind power producers. The energy supplier will have to cover any unbalance costs, existing of the electricity price on the balancing market and a fine, and is therefore motivated to invest in the WPPT.

4.3.2 Power quality devices

There are several power quality devices that have the ability to improve the integration of DG into the distribution network. Power quality devices manage local voltage control, harmonics compensation, reactive power, etc. Such devices therefore influence the physical power output and can improve the economics of both the DG operator and the DSO.

The Grid Control Unit

A *Grid Control Unit* (GCU) is a power quality device that can influence the operational behaviour of renewable and other power stations (wind turbines, photovoltaic plants, CHP or small hydroelectric power plants) similarly to conventional power plants[30]. Grid control units can play an active role in grid support, particularly by manipulation of the grid voltage due to regulated reactive power feed-in. The GCU system is currently in a demonstration phase and is to be composed of a GCU central unit and decentralised located measurement data acquisition units. The data exchange between the GCU central unit and the measuring data acquisition units is carried out by a suitable communication bus. The GCU can thereby improve the communication between decentralised production units (e.g. isolated wind turbines).

The transactions between actors

In the reference case, a DG operator requests the DSO to connect its production unit to the distribution network. Especially when the type of generation is intermittent, the DG capacity to be connected to the distribution network may be limited or the DSO may have to purchase additional ancillary services from the TSO to manage the distribution network or to reinforce the network. This means that the DG operator cannot connect the amount of DG capacity it wishes or the DSO will face larger capital and/or operational costs in the form of increased ancillary services purchase. The investment in a grid control unit, by the DG operator or the DSO, can improve the ability of the network to integrate DG and at the same time manage ancillary services at distribution level. The grid control unit is one of these technical reinforcements that can improve the integration of DG into the network. As the GCU consist of multiple units, located at DG operator sites and more central network locations. the operation of the GCU will most likely be in the hands of the DSO. One or more DG operators can, however, contribute to the investment in the GCU.

USE BY THE DSO

When the DSO invests in the GCU (see Figure 4.10 and Table 4.6) this leads to improved power quality. Since the DSO is responsible for providing a guaranteed power quality, this is a direct benefit to the DSO (line 6). This way an increased DG capacity can be connected to the distribu-

[30] The Grid Control Unit has been developed by ISET e.V. , see for more information http://www.iset.uni-kassel.de/ or Arnold (2002).

tion network, a major benefit to the DG operator (line 2). The costs made by the DSO for the grid control unit should be covered (partly) by other actors benefiting from the GCU. When the DG operator benefits from the technology, there are two ways of possible cost allocation:

- The DSO increases the connection charges (upfront investment for new capacity) or increases in the UoS charges.
- Require investment share in the GCU from DG operator.

As a result of improved power quality the DSO may have to purchase less ancillary services, from the TSO (line 10) or the ancillary services market (line 15) influencing its own cost streams. The parties offering their services on the ancillary services market (DG operator or large power producer) will also be influenced by these lower purchases of the DNO (line 12). In case the investment in the GCU is shared between DSO and DG operator, then the decreased ancillary services purchase by the DSO will also benefit the DG operator.

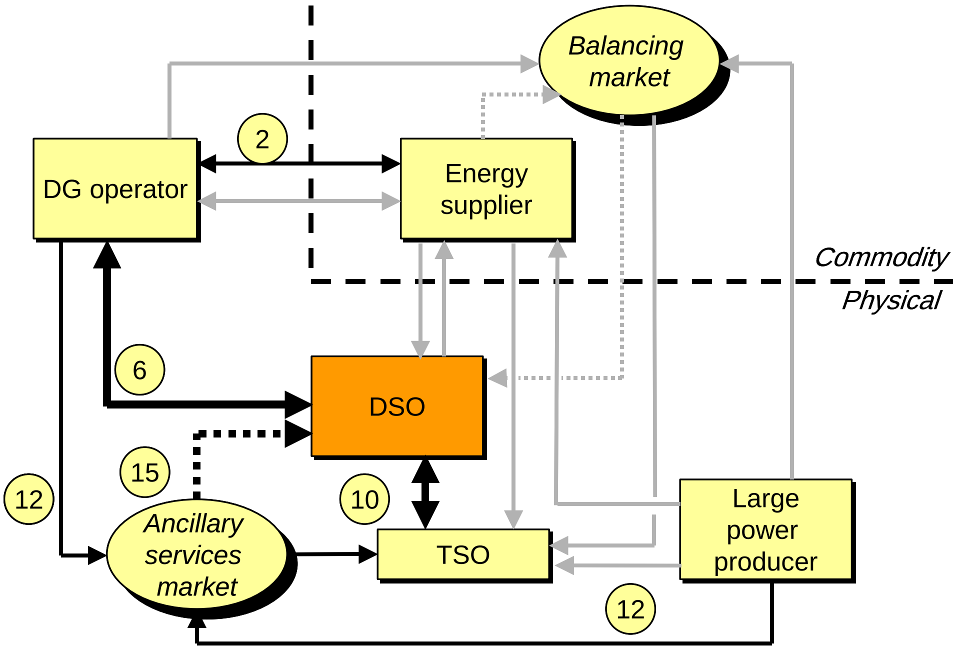

Figure 4.10 *Grid control unit operated by the DSO*

Table 4.6 *Changed transactions with GCU implemented by the DSO*

	Actor/Market	Offers	To	Expects in return	Change to reference case
Direct impacts					
6	DSO	Grid access and use	DG operator	Connection and use of system charges	Improved grid access, adjusted charges
10	TSO	Ancillary services	DSO	Ancillary service fees	Decreased fees
15	Ancillary services market	Ancillary services	DSO	Payment	Decreased ancillary service purchase
Indirect impacts					
2	DG operator	Electricity	Energy supplier	Payment (wholesale contract)	Increased electricity sales
12	DG operator/large power producer	Ancillary services	Ancillary services market	Payment for ancillary services (contract)	Decreased revenues from ancillary services market

Cost and benefit overview of the Grid Control Unit

As presented here, the most likely party investing in the GCU is the DSO, although the DG operator may share in the investment. The main benefits of the GCU accrue to the DSO. In case (part of) the investments are done by the DG operator, it should be compensated for the contribution to network services. This could be the compensation of ancillary services such as feed-in of reactive power or voltage stabilisation. The way of compensation depends of course on the network regulation existing in a given country. Also the ability of the DSO to purchase ancillary services from parties other than the TSO depends on the existence of an ancillary service market or the possibility (right) to purchase ancillary services from third parties.

4.3.3 Communication devices

Most (ICT-based) communication devices are rapidly developing and form an excellent way of combining both power production and load data, this way optimising power supply from large-scale and small-scale (DG) generators as well as consumption. *PoMS* (Power operation and power quality management system), a novel ICT application developed by Fraunhofer ISE, implements active management of distributed generation, controllable consumption, storage and power quality devices in low voltage grids, and covers economic optimisation as well as interventions in case of irregularities.[31]

The main hypothesis of the developers of PoMS was that to allow high penetration of distributed generation in low voltage grids in a technically and economically optimised way, active management of such grids will become necessary. The motivation to use systems like PoMS can be manifold:

- Energy suppliers might wish to perform peak shaving to save money within their power delivery contracts with their (central) power producers optimising the use of local resources.
- Special contracts with DG operators can be made enabling PoMS to actively optimise a grid segment.
- Keep control over the grid even in presence of many DG units.
- The management of energy flows in island grids, e.g. Micro-grids.

In regular operation, PoMS receives data about actual cost of production and generation from the DG components and the control centre at higher voltage levels. Furthermore, restrictions of control (e.g. for CHP units with limited heat storage capacity) are transferred to PoMS. The control centre can also request certain schedules to be implemented by the grid segment (giving an according price/value of this). PoMS then conducts load flow calculations and finds an economically and technically (in respect to power quality) suitable operation of all involved units and implements it.

Analysing the impact of a local power management tool like PoMS starts with the reference case as shown in Figure 4.11. In this basic situation, the DG operator (and the large power producer) sells electricity to the energy supplier against wholesale price and the energy supplier sells this electricity to the consumer against retail price. The DSO is ‘passively’ distributing electricity and acquiring its ancillary services exclusively from the TSO. The DG operator is only rarely trading on the ancillary services market, as the DSO (the most likely buyer next to the TSO) is not yet purchasing from this market.

In the reference case, the energy supplier is not able to influence the DG power output and the power consumption by consumers. Based on forecasts the energy supplier will make an E-program of these uncontrollable loads. Differences between actual power flows and the E-program will be compensated by the TSO with balancing power (obtained through the balancing market). The energy supplier has to pay penalties to the TSO in case of these deviations. Also the flows through the distribution network are only managed to a limited extent. The distribution network in the reference case has to be designed for the worst situation possible. This is the case with a high peak load and no supply from distributed generation, when power production

[31] Within work Package 9 of DISPOWER a power operation and power quality management system (PoMS) is developed for the facilitation of distributed generation in low voltage grids. See for more detailed information Jantsch et al (2003).

of distributed generation combines with minimum load in the distribution network or when network failures occur. With high shares of intermittent DG, extreme load-supply situations can occur more often, e.g. in the case that wind power output is at its maximum during the night but load is at its minimum.

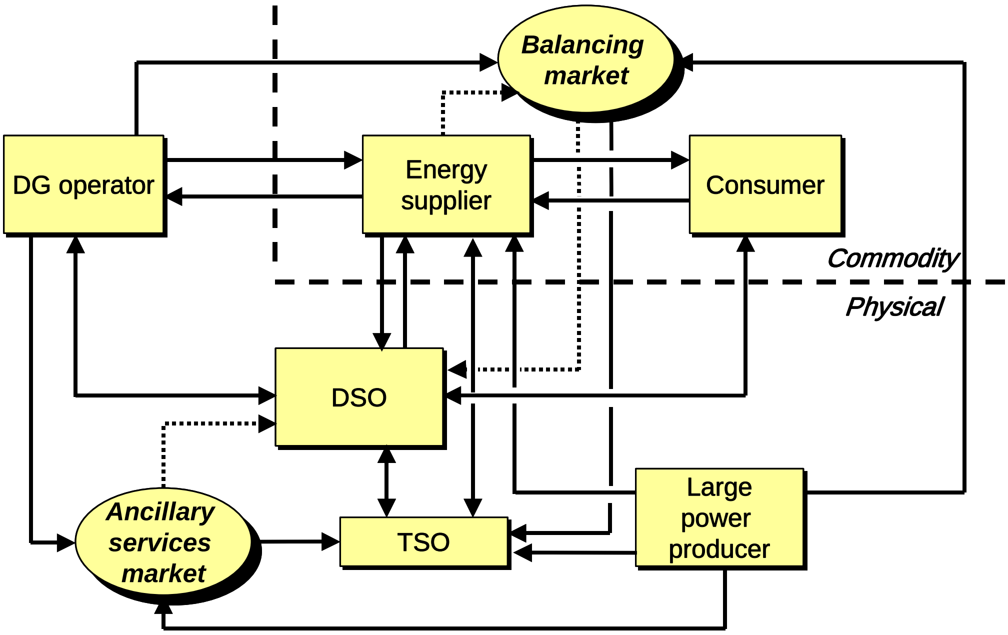

Figure 4.11 *Basic power distribution scheme*

Given the relative complexity of the PoMS tool, managing the whole LV segment below a MV connection point, it is not likely that a DG operator will be among the parties investing and operating. Management of distribution networks fall outside the scope and responsibilities of the DG operator. Therefore, this theoretical exercise is limited to two options, a local power management tool operated by the energy supplier or by the DSO.

USE BY THE ENERGY SUPPLIER

Figure 4.12 shows the power distribution scheme in case the energy supplier invests in and utilises the local power management tool.

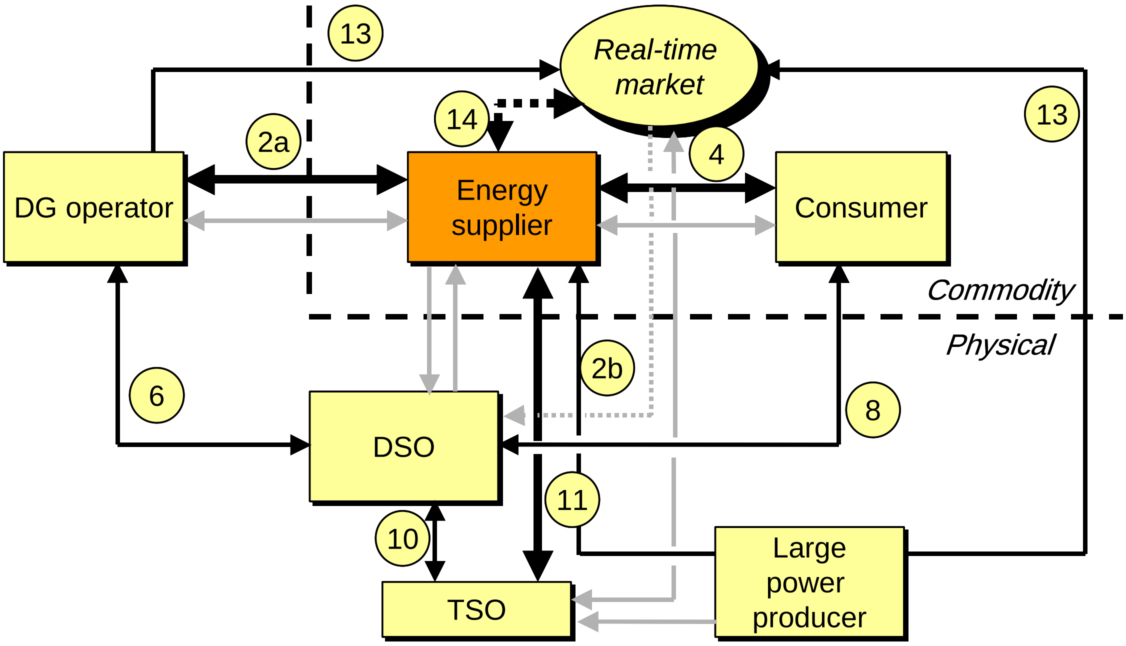

Figure 4.12 *Local power management tool used by the energy supplier*

The main impacts of the utilisation of the local power management tool by the energy supplier are the following (see also Table 4.7):

- Power output from the DG operator can be optimised, producing power at times that demand is high or not producing when demand is low, leading to an increased (average) electricity price for the DG operator (line 2a).
- Within the framework of PoMS it is possible to decrease consumer demand at peak periods (optimised power consumption). This can be done by (automatically) postponing electricity intensive processes until periods of low demand or scheduled interruptions in power supply. The consumer can be rewarded by a lower average electricity price (line 4).
- For the energy supplier it will then be easier to match supply and demand following its E-program leading to lower balancing costs (line 11). When using a local power management tool, matching supply and demand can largely take place at LV/MV level, needing less peaking power from large power producers (line 2b).
- An indirect benefit to the DSO and TSO is the decrease of transportation (operational) costs due to better spreading of consumption of electricity. This may be of influence when production of electricity takes place outside peak times with minimum load (lines 6 and 8).
- The energy supplier, when having a demand response agreement with consumers, can offer avoided power consumption on the real-time (balancing) market[32] (line 14).

[32] In this case, the balancing market is replaced by a real-time market, trading not only in balancing power but all power traded on short-time scales (e.g. < 15 minutes).

Table 4.7 *Changed transactions with local power management tool implemented by the energy supplier*

	Actor/Market	Offers	To	Expects in return	Change to reference case
Direct impacts					
2a	DG operator	Electricity	Energy supplier	Payment (wholesale contract)	Higher price (due to optimised output)
4	Energy supplier	Electricity	Consumer	Payment (retail contract)	Decreased price (due to optimised consumption)
11	Energy supplier	E-program	TSO	Balancing services/payments for deviations	Decreased payments for deviation
14	Energy supplier	Participation	Real-time market	Payment	Offers from surplus production/avoided consumption
Indirect impacts					
2b	Large power producer	Peaking power	Energy supplier	Payment for peak generation	Less purchase of peak generation
6	DSO	Grid access and use	DG operator	Connection and use of system charges	Charges adjusted to use
8	DSO	Grid access and use	Consumer	Connection and use of system charges	Charges adjusted to use
10	TSO	Ancillary services	DSO	Ancillary service fees	Decreased payment
13	Large power producer	Balancing power	Balancing market	Payment if dispatched	Less dispatch

USE BY THE DSO

Figure 4.13 shows the impact on the distributed power system in case the DSO utilises the local power management tool. As with most of the described tools mentioned in this research, investment of a DSO in the tool requires an active approach of this organisation, integrating DG, storage and purchasing ancillary services from the market.

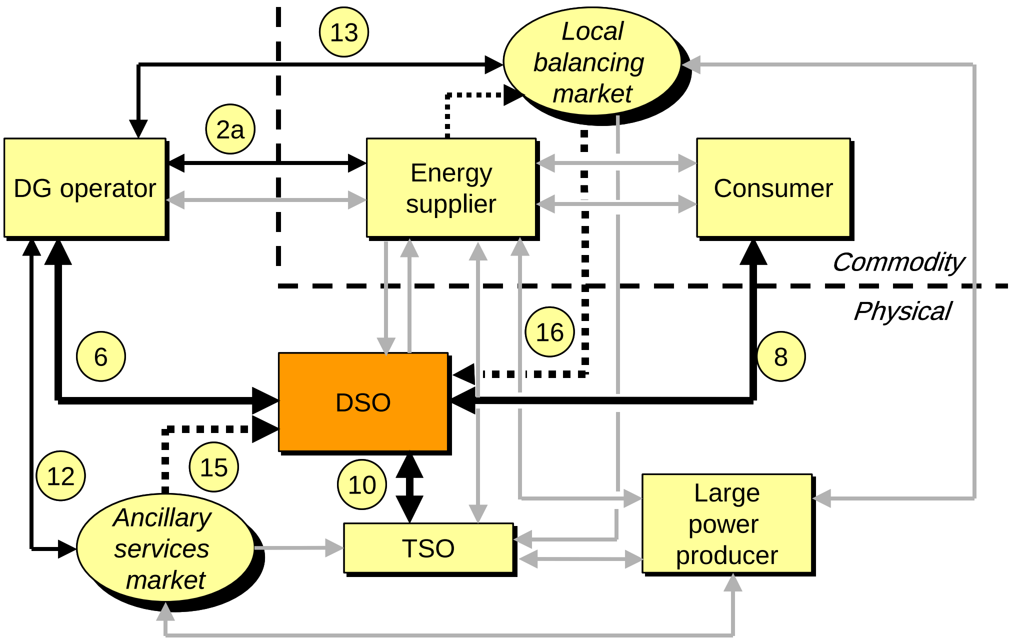

Figure 4.13 *Local power management tool used by the DSO*

The main impacts of the utilisation of the local power management tool by the DSO are the following (see also Table 4.8):

- Optimised power supply and demand leads to lower network costs for the DSO as power flows in the network are better matched to the developments in demand, leading to lower operational costs. Ultimately this can also lead to postponed network investments as more efficient use is made of the existing distribution network. Charges to consumers and DG operators will be adjusted and can be reduced (lines 6 and 8).

- Applying the tool enables better utilisation of DG benefits in the field of balancing and ancillary services. DG operators can offer their ancillary services to the DSO through the ancillary services market, enabling the DSO to make a choice from ancillary services offered at different price levels instead of just purchasing these services from the TSO (lines 10, 12 and 15) or making grid investments.
- The DSO purchases balancing services on the local balancing market, enabling to physically match supply and demand on this LV segment (line 16).

Table 4.8 *Changed transactions with local power management tool implemented by the DSO*

	Actor/Market	Offers	To	Expects in return	Change to reference case
Direct impacts					
6	DSO	Grid access and use	DG operator	Payment of connection and use of system charges	Charges adjusted to use
8	DSO	Grid access and use	Consumer	Payment of connection and use of system charges	Charges adjusted to use
10	TSO	Ancillary services	DSO	Ancillary service fees	Decreased payment
15	Ancillary services market	Ancillary services	DSO	Payment	Increased purchase by DSO
16	Balancing market	Balancing services	DSO	Payment	Increased purchase by DSO
Indirect impacts					
2	DG operator	Electricity	Energy supplier	Payment (wholesale contract)	Higher price (due to optimised output)
12	DG operator	Ancillary services	Ancillary services market	Payment (contract)	Increased revenues from ancillary services market
13	DG operator	Balancing power	Local balancing market	Payment if dispatched	Increased revenues from balancing power
14	Energy supplier	Participation	Local balancing market	Payment	Offers from surplus production/avoided consumption

The possibility of these transactions taking place depends on the willingness of the main actors, consumers and DG operators to pay more for the different services.

Cost and benefit overview of the power management tool

Both the energy supplier and the DSO can invest in the local power management tool, both having their specific benefits. The *energy supplier* can optimise both supply (DG operator) and demand (consumer) on the LV level. This enables him to improve his E-program and pay less for deviations. Any surplus power (extra production or avoided consumption) can be offered on the balancing or real-time market. Optimised supply and demand means for the *DSO* a decrease in operational costs, making more efficient use of the network and improving power quality. Local management of the power grid generally leads to better utilisation of DG benefits, meaning a decreased need of ancillary services. Local power management also enables local balancing of supply and demand on a local balancing market.

4.3.4 Storage devices

Energy storage systems can play a major role in the development and exploitation of medium and low voltage networks. They can be decisive in the following cases/circumstances:

- For obtaining a sufficient power quality degree.
- In controlling power flow for better matching generation with the demand profile.
- For supporting the introduction of intermittent energy production.
- For avoiding network investments (i.e. load management) increasing reliability.

Energy storage systems can be profitable both in grid connected applications for deferring the installation of new peaking generation and in stand alone applications for improving reliability and quality of supply.

Responses from the DISPOWER questionnaire learned that some types of energy storage (e.g. flywheel technology) function as an important element of power quality systems. It presents a new technology to improve power quality and reliability, creating a more constant power flow, which is beneficial to both energy supplier and consumer. For the electricity supplier storage of electricity is an option to balance demand and supply and save balancing costs. Storage can even be used for trading electricity, i.e. price arbitrage between different moments in time. However, in this research the focus is on the integration of DG and not on improving the economic efficiency of electricity markets. Finally, storage can be used by a DG operator of an uncontrollable load to make its electricity supply more controllable. The DG operator offers the energy supplier a more predictable supply from its DG unit.

Figure 4.14 shows the position of the storage technology in the distribution network. The energy storage technology can be linked to three different actors, the DG operator, the energy supplier and the DSO. This analysis looks at the different parties investing in the technology; therefore three actors can act as the investor.

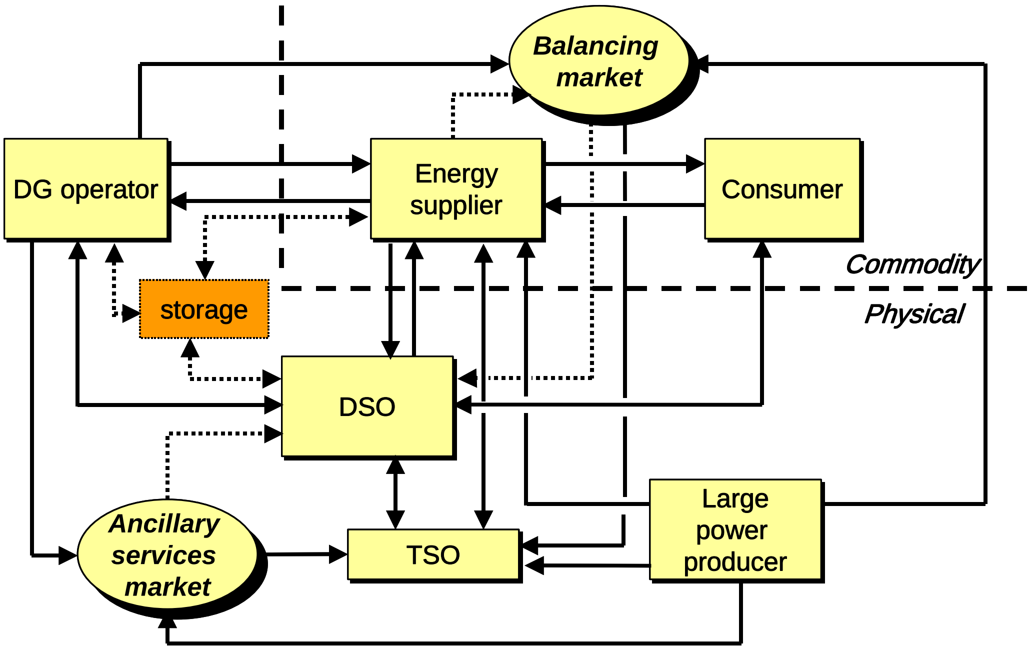

Figure 4.14 *The location of a storage device in a distribution power scheme*

The transactions between actors

USE BY THE ENERGY SUPPLIER

An energy supplier may be interested in investing in a storage device to better match his E-program, especially when he has contracted a number of (intermittent) DG operators. The impacts are shown in Figure 4.15 and Table 4.9.

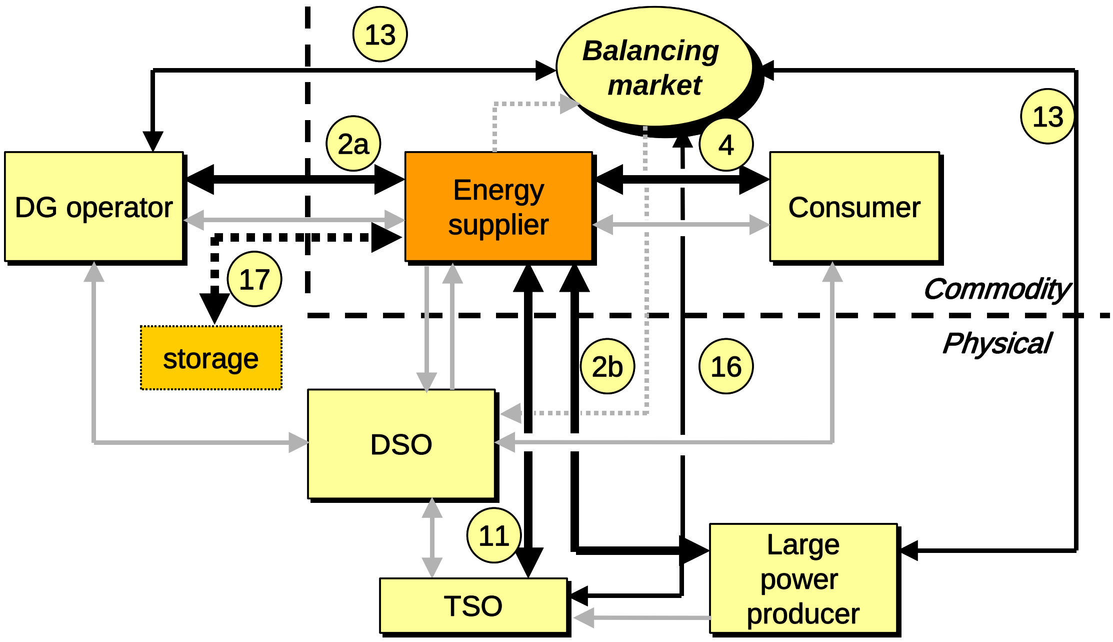

Figure 4.15 *Energy storage device implemented by the energy supplier*

Before investing in storage technology, the energy supplier was unsure about the power output from the DG operator (line 2a). This uncertainty/intermittency can influence his possibility to meet his E-program. Deviations from the E-program will lead to balancing costs paid to the TSO or purchase costs to controllable DG/large power producer (line 11). With a storage device (line 17), the energy supplier is able to level out any demand peaks and valleys and control the power output from uncontrollable DG units (line 2). This limits the purchase of peaking power (line 2b) or the balancing costs the energy supplier has to pay to the TSO (line 11). The TSO gains an indirect benefit from the connected storage device in the form of lower balancing costs (line 16). This again influences the transactions on the balancing market (line 13).

Table 4.9 *Changed transactions with energy storage implemented by the energy supplier*

	Actor/Market	Offers	To	Expects in return	Change to reference case
Direct impacts					
2a	DG operator	Electricity	Energy supplier	Payment (wholesale contract)	Optimised power output
2b	Large power producer	Peak generation	Energy supplier	Payment for peak generation	Less/optimised peaking power purchase
4	Energy supplier	Electricity	Consumer	Payment (retail contract)	Higher retail price (more reliable delivery)
11	Energy supplier	E-program	TSO	Balancing charges/fines	Less balancing fines
17	Energy supplier	Storage			
Indirect impacts					
13	Large power producer	Balancing power	Balancing market	Payment if dispatched	Less dispatch
16	Balancing market	Balancing services	TSO	Balancing payment	Decreased purchase balancing service

USE BY THE DG OPERATOR

The impacts of investment in a power storage device by the DG operator are illustrated in Figure 4.16 and Table 4.10.

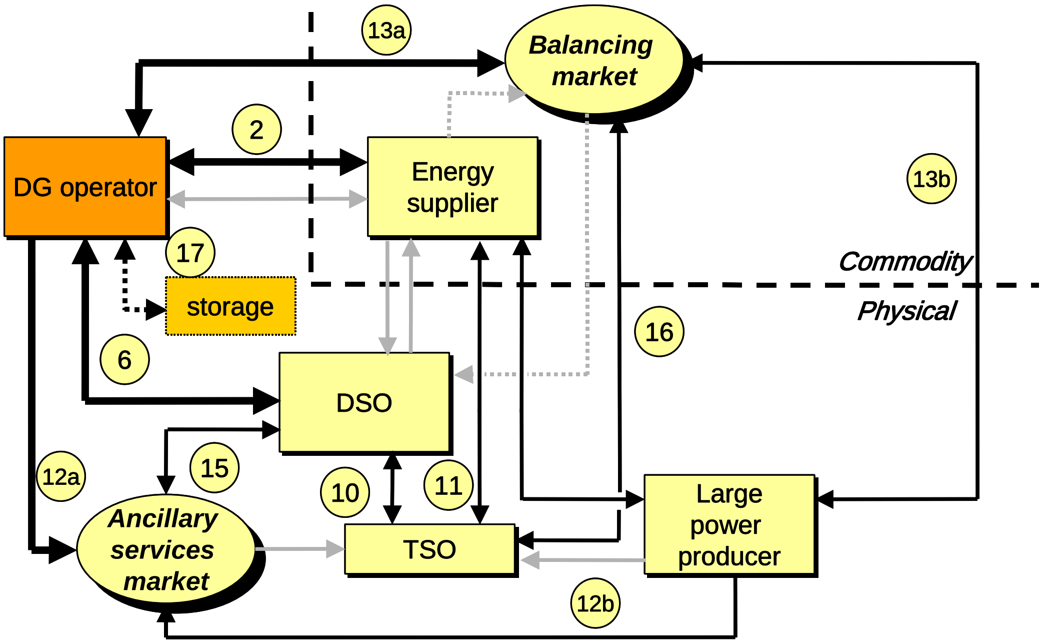

Figure 4.16 *Power storage device implemented by the DG operator*

The most direct benefit for the DG operator is the optimisation of the power output (to periods with peak demand) leading to higher revenues from electricity market prices (line 2). Another benefit is related to the influence on the distribution network. The DG facility will have a lower burden on the distribution network (levelling off peaks), decreasing the network costs for the DSO. The DSO may reward this in the form of lower connection or use of system charges (line 6). Participation in the ancillary services market or balancing market now also belongs to the possibilities for the DG operator with intermittent energy resources, creating additional sources of revenue (lines 12 and 13). This (indirectly) influences the transactions of large power producers on the ancillary services and balancing markets (lines 12 and 13). The transactions between DSO and TSO (line 10) and DSO and ancillary services market (line 15) may also be influenced.

Table 4.10 *Changed transactions with energy storage implemented by the DG operator*

	Actor/Market	Offers	To	Expects in return	Change to reference case
Direct impacts					
2a	DG operator	Electricity	Energy supplier	Payment (wholesale contract)	Optimised power output
2b	Large power producer	Peak generation	Energy supplier	Payment for peak generation	Less/optimised peaking power purchase
6	DSO	Grid access and use	DG operator	Connection and use of system charges	Decreased charges
12a	DG operator	Ancillary services	Ancillary services market	Payment (ancillary services contract)	Increased payment
13a	DG operator	Balancing power	Balancing market	Payment if dispatched	Increased dispatch
17	Energy supplier	Storage			
Indirect impacts					
10	TSO	Ancillary services	DSO	System service fee	Decreased purchase ancillary services
11	Energy supplier	E-program	TSO	Balancing charges/fines	Less balancing fines
12a	Large power producer	Ancillary services	Ancillary services market	Payment (ancillary services contract)	Decreased payment
13a	Large power producer	Balancing power	Balancing market	Payment if dispatched	Less dispatch
15	Ancillary services market	Ancillary services	DSO	Ancillary services payment	Increased purchase ancillary services
16	Balancing market	Balancing services	TSO	Balancing payment	Decreased purchase balancing service

USE BY THE DSO

The impacts of investment in a power storage device by the DSO are illustrated in Figure 4.17 and Table 4.11.

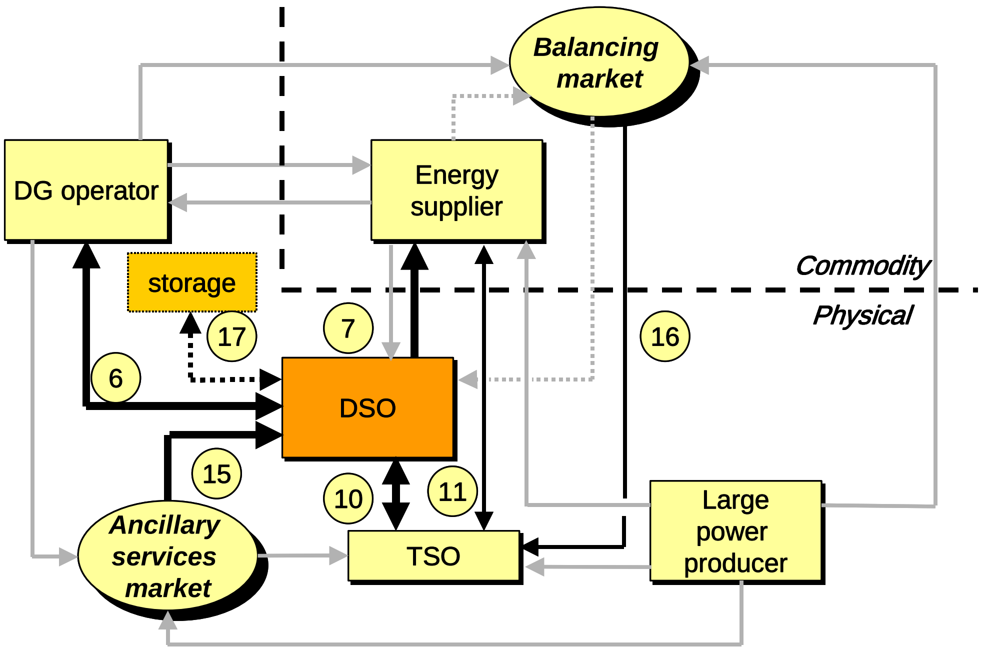

Figure 4.17 *Power storage device implemented by the DSO*

The most direct benefit for the DSO is the decrease of network investment and operation costs (line 6). The storage device can optimise the power output, preventing situations like high production at minimum load, a situation that is the most demanding to distribution networks. This can lead to lower network investments and eventually lead to lower costs for ancillary services the DSO purchases from the TSO (line 10) or on the ancillary services market (line 15). Due to the storage capability of the distribution network the power from intermittent resources to energy suppliers will be more stable and reliable, making E-programs simpler (line 7) and reducing balancing costs for the TSO (line 16).

Table 4.11 *Changed transactions with energy storage implemented by the DSO*

	Actor/Market	Offers	To	Expects in return	Change to reference case
Direct impacts					
6	DSO	Grid access and use	DG operator	Connection and use of system charges	Improved grid access/adjusted charges
7	DSO	Generation and consumption data	Energy supplier		Improved reliability on power supply
10	TSO	Ancillary services	DSO	Ancillary service fees	Decreased fees
15	Ancillary services market	Ancillary services	DSO	Payment	Increased ancillary service purchase
Indirect impacts					
16	Balancing market	Balancing services	TSO	Balancing payment	Decreased payment

4.3.4.1 Cost and benefit overview when storage of electricity is applied

With a storage facility:

- the energy supplier buying power from uncontrollable generators or intermittent energy resources (wind, solar) can better comply with its E-program and will be able to reduce balancing costs,
- a DG operator can influence the operational behaviour of the generation facility, enabling the DSO to better manage its network tasks and enabling the energy supplier to better operate his E-program,
- a DSO will be able to limit extreme situations due to low loads in combination with high peaks in power supply (or vice versa) and therefore to stabilize conditions in the grid (i.e. remain power quality and provide balance in energy and/or reactive power). Consequently, DSOs will save on operational and investment costs.

The application of energy storage technology can also anticipate on future network regulation. Regulation for the integration of DG should be integrated with new technical standards clearly defining the sharing of duties and of expenses, among all parties interested.

A respondent from the DISPOWER questionnaire states that “If the DG producer has the right to connect his generators to the main network, this producer must also have the duty of providing appropriate network quality in the form of correct shape of wave voltage, the correct frequency etc. Energy storage systems can in many ways provide for these issues”.

4.4 Allocation of costs and benefits

The assessment of the technical options in Section 4.3 showed the potential for improved integration of DG and the ability to provide a number of benefits to the main actors concerned.

Every technical option has its specific impact, but for each of the three actors investing a similar set of benefits can be distinguished as is presented in Table 4.12 for all distribution network actors.

Table 4.12 *Overview of benefits of technical solutions and practices for distribution network actors*

	DG operator	Energy supplier	DSO
Primary benefits	• Increased or optimised power output • Access to markets for balancing and ancillary services • Increased DG capacity on the network	• Reduced balancing costs • Detailed power output information, ability to construct a more exact E-program, and better comply with the E-program • Access to balancing/real-time market through demand response	• Improved power quality • Reduced operational expenditures
Benefits gained when other actors invest	• Optimised (reduced, cost-based) network/connection costs • Increased electricity (wholesale) price	• Increased electricity (retail) price margin	• Optimised (increased, cost-based) revenue from network charges • Reduced capital expenditures

The table shows that in case a *DG operator* invests in a technology improving the access of DG, the operator gains a number of primary benefits mainly related to increased/optimised power production and the access to markets for balancing and ancillary services. The other actors, the energy supplier or DSO, may also benefit from the investment of the DG operator, e.g. lower balancing costs or a higher stability in the network. These actors will be able to allocate (part of) the economic value of these benefits by increasing the electricity price or lower the network charges, however, only under the condition that a financial relationship exists. If no direct financial relationship exits the transfer of benefits is more difficult.

In case an *energy supplier* invests in the technology, its main benefit is related to avoided or reduced balancing costs. E.g. in case of the wind power prediction tool or local power management the DSO may also benefits because the better prediction and control of loads respectively. However, in current electricity markets there are no financial relationships between the energy supplier and DSO (only information exchange). Allocation of the benefits of the DSO to the energy supplier is therefore difficult.

Another possibility is that the *DSO* invests in a network device. The DSO gains some direct benefits in the form of improved power quality on the network and reduced operational expenditures. The DG operator, without participating in the investment, may gain some benefits in the form of increased power supply to the network and thereby increasing its revenues. The DSO could recover part of its investments in the network technology/device by increasing the network charges for DG operators (and consumers). This leads to an allocation of the benefits from DG operators to the DSO.

The use of different technology and solutions for the integration of DG may also have an impact on other actors in the electricity system, e.g. the TSO and large power producers. These impacts are often of a more indirect nature (e.g. reducing purchase/sale of balancing power) and the economic value is more difficult to transfer. Only within the regulatory framework the economic value of these indirect costs or benefits can be corrected, mainly via TSO and DSOs (i.e. network or system charges).

Benefits can be of short-term (operational expenditures) or long-term nature (capital expenditures). Due to the fiscal depreciation rules technology investments will result in long lasting capital expenditures. Financial transactions (contracts or network charges) are, however, short term unless based on long-term contracts, but in liberalised energy markets long-term contracts are not very common. The regulatory framework for networks can provide a stable investment climate for DSOs, and therefore DSOs may be in a better position to invest in the new technical options and solutions. However, if the benefits do not occur within the regulatory period (i.e.

before the ‘evaluation’ or ‘price reviews’), the economic efficiency incentive may cause a barrier for DSOs to invest.

4.5 Conclusion

The examples in this Chapter show that the DSO has an important position in the process of allocating costs and benefits. In principle the DSO has the possibility to allocate part of the benefits that DG operators (or consumers) acquire to themselves by e.g. increasing network charges. In case the DG operator does the investment, the operator is dependent on the DSO as regards the allocation of costs and benefits. This shows the importance of the DSO in integrating DG into the distribution network. It is important that this is recognised by policymakers and regulators since DSOs cannot change the system of network charges themselves.

To optimally implement the technologies described above, both direct and indirect benefits and costs should be allocated preferable to one actor, since this will help to optimise the profitability of the technology. The possibility to allocate costs and benefits depends on the circumstances. In the simplest case, the party investing in a given technology will reap all the benefits. Section 4.3 showed, however, that in an electricity market with complete unbundling there are (almost) always a number of benefits that other actors experience. Logically all other benefits and cost should be allocated to the actor that already benefits the most. However, this depends on the encountered problems of transferring the benefits and costs. Allocation of costs and benefits through (changing) contractual arrangements is a possibility. For example, costs and benefits can easily be (re-)allocated between an energy supplier and DG operator via their supply/purchase contract. Also the DG and DSOs can (re-)allocate benefits and costs via the network charges. In this latter case however the regulatory framework can provide restrictions to the DSOs possibility to change charges and conditions. The most difficult allocation could be between energy suppliers and DSOs because of the current absence of financial relationships. The regulatory framework should, however, allow DSOs to enter contracts with energy suppliers, in particular because this will contribute to the transparency of the unbundling of utilities.

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APPENDIX A THE VALUES OF DG

A.1 Overview of DG values

To summarize the costs and benefits of DG, in Table A.1 an overview of the main DG values is presented. Within the given categories there can be a range of different benefits and/or costs to DSOs, customers and other stakeholders.

Table A.1 *Overview of DG values*

	Capital	Operational
Attributed to network operator	• Distribution capacity cost deferral • Reliability • Connection costs	• Voltage support • Reactive power • Line losses
Outside network	• Metering • Reserve capacity • Avoidance of overcapacity in generation	• Balancing • Transaction costs

Each value tends to be highly technology- and site-specific and requires a specific analysis. The main costs and benefits, analysed in the SUSTELNET project and divided over capital and operational values are described by Leprich & Bauknecht (2004) and Swisher (2002).

Capital values are mainly related to the generation and distribution facilities:

- *Distribution capacity cost deferral* - The development of small-scale DG facilities near a load can postpone necessary investments in additional distribution and transmission capacity. DSOs can benefit from these new DG facilities as it can reduce their investment costs in upgrading or extending the distribution network. The costs of distributing electricity differ from location to location and placing DG facilities in ‘high-cost areas’ may reduce costs for DSOs.
- *Connection costs* - The connection of the DG plant to the distribution network incurs expenses regarding connection lines and grid upgrade, depending on the location of the DG facility. When choosing the location of a DG facility close to an existing grid may reduce connection costs.
- *Metering* - Metering of DG production presents a cost that is allocated outside the network, and can be attributed to the DG operator. The costs for a management and control system that collects automatically metering data and provide control signals to the DG plants should, however, be attributed to the DSO.
- *Reserve capacity* - When installing a large capacity of intermittent DG sources (e.g. wind and PV generators) a certain backup of power needs to be available. This can be another DG source (illustrating that DG can act as reserve capacity also). DG that is 'controllable', such as CHP plants that can be operated independently form heat demand, can contribute to reserve capacity.
- *Avoidance of overcapacity* - Avoidance of overcapacities or at least reduction of reserve margins compared to more centralised systems. In traditional power systems an increasing demand of electricity was solved by installing a new ‘central’ power plant. In today’s market environment, over-dimensioning of power plants may be a risky investment. Small-scale DG plants are better equipped to respond to short-term demand changes.

Operational values, distributed generation can reduce costs in the operation and maintenance of the distribution system. These operational values include:

- *Reduction of losses* - DG can reduce system losses by reducing the current flow from the transmission system through the transformers and conductors on the distribution system. DG based loss reduction also reduces the distribution utility's total installed capacity (and corresponding costs) as seen by the transmission system.
- *Voltage support* - DG can provide voltage support in areas of the distribution system that suffer large drops at high loads, replacing voltage regulators and line upgrades. DG can also regulate voltage by balancing fluctuating loads with generation output.
- *Reactive power support* - DG can help balance reactive power flows on a distribution system with both real and reactive power injection. Real power injection reduces current in the conductors, which is a major source of reactive power demand that is typically treated with banks of capacitors. Improved reactive power flow (as indicated by a high power factor) reduces current and losses on transmission and distribution components, and helps control system voltage.
- *Reliability* - DG that is 'controllable' may increase the reliability of distribution networks as it is an alternative to redundancy.
- *Balancing* - There might be a need for additional balancing power because of the intermittent character of some DG sources (such as wind or PV systems). Generally, the ability to balance the distribution system depends on the way that a DG generation facility is controllable and can present a burden or a benefit to the distribution system.
- *Transaction costs* - DG that is active in the different power markets will generate extra transaction costs.

Especially with respect to the energy related values one has to differentiate between intermittent and controllable DG contributions. The more controllable and hence reliable they are the higher is their economic value.

A.2 The role of connection charges

When integrating DG into distribution networks an important factor influencing cost-effectiveness are the connection charges and the way costs incurred (to the DSO) by this connection are allocated through these charges. Basically, two main types of connection charges with different economic rationales can be distinguished: shallow and deep connection charges (Uyterlinde et al, 2002).

Shallow connection charges

Shallow connection charges only bring into account the cost of line extension to the nearest connection point and the equipment needed to connect the line to the rest of the grid. No charges are made for adjustments, reinforcements and upgrades necessary to facilitate the integration of a generator into the grid beyond the point of connection. The costs of such grid adjustments are recovered by the DSO through the grid use tariffs and are thus socialised among all users of the grid, including the consumers who see these costs included in the electricity price.

Shallow connection charges can be standardised relatively easily. For example, in the Netherlands the cost of the line from the cut (the point of connection to the grid) to the plant is standardised per meter. Also in Germany and Denmark, only direct connection costs are borne by the RES developer, while all costs incurred by necessary grid reinforcements are to be borne by the DSO.

Shallow connection charges have benefits for DG operators in that they reduce the uncertainty relating to the cost of connecting to the system. On the other hand DG operators will not be credited for possible benefits they bring to the system with the required reinforcements. Moreover, if DSOs are subject to regulation that requires them to cut their cost annually they may be reluctant to connect a DG operator when this entails grid adjustments. This disincentive to connect may cause DSOs and TSOs to obstruct or slow down connection procedures.

Deep connection charges
Deep connection charges, used for instance in the United Kingdom, bring into account all the costs of integration of a generator into the network, including the costs of all adjustments beyond the point of connection to the network. Not only will the cost of deep connection charges usually be higher, it will also be much more uncertain as the cost will be highly specific per location, generation capacity and mode of operation. Thus the costs have to be independently assessed for each new generator. The methodology of assessing which technical adjustments are necessary and how the cost of these is going to be assessed is often non-transparent. With deep connection charges the costs are not socialised.

With shallow connection charges a project developer would generally aim to connect to the nearest point on the grid, as this is the cheapest solution from the project developer's point of view. However, determining the point of connection with deep connection charges is more complicated, because the location specific cost of grid adjustments will be taken into account both by the generator and the network operator. Both the project developer and the network company will seek to minimise their costs.

The cost of grid adjustments for different points of connection is related to the costing methodology and furthermore depends on existing grid expansion and capacity plans. These plans generally do not account for the connection of decentralised electricity sources. The grid operator has an interest to align the point of connection and the technical adjustments as much as possible with the existing grid structure and plans for grid expansion and upgrades. The DG operator on the other hand merely wishes to minimise their cost of connection.

A.3 New approach to connection charging

A new approach in the allocation of costs and benefits will be required, targeted first of all at the role of the DSO as the owner/operator of the distribution network. Regulatory incentives need to be designed to encourage DSOs to consider costs and benefits of all network users (including DG) related to network services. This should enable DSOs to operate the network efficiently and at least costs.

DSOs in the current electricity supply industry are passive organisations whose sole objective is the provision of distribution network services, mainly transport of electricity. The operation of the system and provision of ancillary services is generally done by the Transmission System Operators. However, if the expected increase in DG wants to be successfully accommodated in the electricity system, electricity networks should reconfigure into active networks, where DSOs evolve from this passive organisation into more active actors. In other words, DSOs should become active and innovative entrepreneurs that would facilitate and profit from the connection of DG into the system. By doing so and because DSOs would receive the benefits DG creates, they would on the one hand be provided with incentives to connect DG and, on the other hand, provide the correct signals to generators and consumers in order to efficiently manage the network.

Different approaches are possible in incentivising DSOs to connect DG and take into account DG in managing their networks. Mitchell (2002) for example argues that, in order to achieve a more sustainable regulatory system in the United Kingdom, the distribution regulatory framework should be based on an overall charging and incentivisation package of three equal and linked parts:

- Shallow connection charges, Use of System Charges (per kWh of electricity transported over the network) with entry and exit charges, and performance based incentives.

- A shallow connection charge in conjunction with an entry charge, plus performance standards, should provide the most economic incentive for appropriate connection from the perspective of the DSO.
- With the entry and exit charges, the DSOs could send locational signals to generators, to site or to suppliers to reduce demand. This should reduce their overall costs of designing and operating the network, which should give them further reason for supporting DG.

This recommendation is based on the situation in the United Kingdom where at the moment deep connection charges exist. The proposal would therefore mean an improvement from the current situation for the DG operator, but also for the DSO in a way that it is able to provide locational signals to the DG operators in line with a sustainable operation of its network. In countries with shallow connection charges, this situation may not be very profitable in the short term for DG operators, but the DSO will certainly benefit from such a system. This example shows that every country has its own peculiarities and not one solution fits for all circumstances.

APPENDIX B DISTRIBUTED GENERATION NETWORK TECHNOLOGIES

Table B.1 *Planning and design tools*

Tool	Description
Dynamic simulation of grid with RES and DG	Simulation of frequency instability followed by load shedding, rotating reserve optimisation, voltage stability
Decentralised energy supply concepts/management	Increased energy economic benefit of RES/DG by integration of reasonably usable energy sources in decentralised energy supply systems with local optimisation. This includes external energy exchange in connection with storage systems, controllable loads, cogeneration and controllable virtual large power plants
Low voltage RES and DG network consumption/ production and load balance control	This solution solves problem of consumption/production and load-balance control for RES and DG power plants. In this area or application the main idea is to measure and control local source load and to contact high voltage network only if overload is found. This solution is based on 'REMPLI - Real-time Energy Management via Power-lines and Internet' project This project is oriented to implementation of single-chip controllers for energy measurement and consumption control using power lines for information interchange with high-level controllers/ operator stations and new extension of current options.
Decentralised energy management system - DEMS	Managing use of energy with RES/DG in an energetic, ecological and environmental optimised way
Trading network reinforcements against generator operating when connecting new generation to distribution networks	When a new generator connects it is sometimes necessary to reinforce the network. The analysis to determine the reinforcement required is normally based on 'worst-case' conditions - full output from the generator and zero local load. This can result in excessive connection costs, making the generation un-economic. Reinforcement may be reduced if the net effect of generation and load is considered. Instead of paying for full reinforcement, the generator may accept operating constraints, designed to exploit the local load profile. The cost of constraints may be less than the cost of full reinforcement.

Table B.2 *Power quality and control devices*

Tool	Description
Co-operative Distributed Power Quality Improvement	The capacity of the distribution grid increases by the local production of reactive power by distributed generators that are not in use, due to e.g. low insulation. Filtering of harmonics. Local voltage control by reactive current.
Grid Control Unit (GCU)	The newly developed Grid Control Unit (GCU) can influence the operational behaviour of renewable and other small power stations (wind turbines, photovoltaic plants, CPP or small hydroelectric power plants) similarly to conventional power plants. This way they can play an active role in grid support particularly by manipulation of the grid voltage due to regulated reactive power feed-in. The GCU system is to be composed of a GCU central unit and decentralised located measurement data acquisition units (data logger and sensors for the acquisition of electrical and other e.g. meteorological variables). The data exchange between the GCU central unit and the measuring data acquisition units is carried out by a suitable communication bus.
PV generator operated by a final customer	The customer owning a PV generator can sell all the electricity generated at a fixed price (0.39667 €/kWh) to the DSO, who is forced to purchase it. The customer purchases the electricity he/she needs at a fixed tariff price (0.080401 €/kWh). The customer receives a higher price for all the electricity generated, not only the generated extra electricity. The DSO passes the costs of purchasing renewable energy at higher prices to all the electricity consumers
Virtual Power Plant with CHP	The central control of the distributed electricity generation has to be brought into agreement with the local heat demand. Therefore it is essential to consider technical and economic standpoints as well.
Bi-directional inverters	The problem is the reactive power on grid at one certain time. In that moment, you need a level of reactive and with a storage system you can supply this reactive power on grid.
Harmonics compensator	The problem is the level of harmonics on grid, and it is necessary in any system to compensate it.
Static Var Compensator	Dynamic compensation of reactive power is an effective means of safeguarding power quality as well as voltage stability.
Wind energy for correcting network reactive power	Grid electricity is slightly inductive. To compensate it, grid operators are forced to make investments in capacitive kits. Regulations already penalise power generators that supply electricity exceeding certain values of reactive power. However, these economic penalisations are not able to fully compensate power quality. Adaptation of wind energy technology can voluntarily generate a certain amount of reactive power by means of electronically controlled manipulation of the electricity created at the generator. Therefore, upon request of the grid operator, wind farms will instantly supply power to compensate reactive power of the grid.

Tool	Description
Power Quality unit dedicated to network with DG	This option comprises a group of devices which basic configuration is 6 pulse PWM controlled inverter. The units can be applied for: 1. Power Quality improvement i.e. reduction of PQ phenomena such as voltage fluctuation, variation, harmonics and unbalance to the level established in the binding standards. 2. Maintaining voltage stability in transient and steady states. 3. Islanding operation of the network with DG sources.
Automatic safety disconnect switch in LV network connection	In respect with the principle, that DG must not oblige the DSO to operate on the network as if the voltage is applied, it is necessary to have an accessible lockable disconnection switch. Without expensive adaptation of the premise, accessibility in LV is illusory because in most of the cases the isolating switch located inside private houses will be out of accessibility. House occupants are not always in their houses so what about emergency operation? In LV, a permanently accessible isolating switch is unfeasible without an expensive adaptation. It is the reason why an automatic safety switching is the only realistic solution.
Soft starter for wind turbines	Some wind turbines generate a very big starting or inrush current. This current can be greater than the current at maximum production. If the connection costs are based on the inrush current, then these costs can be very high; therefore it is beneficial to limit this current by a ‘soft starter’. The ‘soft starter’ is based on power electronic technology.
Current limiter	A circuit breaker in for example the distribution network has to be able to break a certain short circuit current. If this current can be limited, the costs for the network equipment can be reduced. This can be important in case of connection of distributed generators to the network.

Table B.3 *Communication devices (including ICT applications)*

Tool	Description
Electronic power markets using fine-grained demand-supply side management using new ICT	ICT and new software models will enable small-scale sustainable energy systems.
Remote control of operational wind farms and access to wind turbine parameters (e.g. Nordex ‘Control 2’ SCADA system)	This technology allows off-site access to operational parameters of the wind farm, such as: wind speeds, ambient temperature, machine vibration, voltage, power output, trips, alarms, etc). The information can be accessed daily by the manufacturer, owner/ operator using a modem link. The manufacturer can diagnose and reset turbine trips/ lockouts remotely, greatly reducing the cost of fault correction.
Application of e-Science Grid Computing to link RES and DG for dispatching, control, dynamic stability, power network security and energy trading functions	When a large number of generators is connected to the electrical grid the need for the various computational functions currently performed for each conventional generator will still remain. Problems such as generator dynamic stability, load frequency control, economic dispatch (or energy trading), on-off generator scheduling, analysis of transmission and distribution network security, state estimation, etc. will need to be performed by an autonomous distributed computing approach. When a new generator is synchronised to the electrical grid at the same time the necessary computational models and data are 'synchronised' to the computing grid.
Interface between grid operator and wind farm, using the possibility of disconnecting wind turbines to maintain a minimal grid quality	When operating a grid with a high proportion of wind DG, the maximum wind penetration is often limited by the impact of the wind farm(s) in grid fault conditions, or grid specific conditions (peak, low load, etc). These conditions have a low probability of occurrence. It is possible to accept a disconnection of some wind turbines in these occasional cases. But revenue losses for the wind farm operator should be shared. The wind turbines disconnection should be controlled through ICT. This solution would allow to increase very significantly the wind penetration on small grids.

Table B.4 *Energy storage devices*

Tool	Description
Energy storage connected to the transmission network	A network with many intermittent generators can have a balancing problem. The ability to store energy is beneficial to the balancing problem.
Power quality system having as energy storage means a high speed flywheel	In AC applications the system works for (0-100%) dip voltage compensation and has a DC/AC converter as grid interface. In DC applications it can control and stabilise line voltage.
GESAL - generation and storage of PV energy	This project has developed the necessary technology to generate and store electricity from photovoltaic solar energy. This system, connected to a number of PV panels allows conditioning the solar energy into directly usable electricity. It can be used in an independent way, or can also be sold through the electrical network. Study on the development of a family of sinusoidal invertors with a transformer to connect in string the photovoltaic panels.
Using electricity storage providing minimum power guarantee and improve grid quality when operated in parallel with wind farms	When wind is above a minimum level, the probability of having a rapid and high decrease of energy generation is low. This can be compensated by a short term energy storage system that compensate for energy variations and keep the generation level above a predictable value. A storage facility can also help to improve the quality of supply from the wind farm (harmonics, flicker, voltage variations compensation)
Hydropower as storage technology for dealing with intermittency	Small hydro power plants can supply remote mountainous areas and thus avoid power distribution costs. Run-off river plants with daily storage can shift electricity produced in high generation hours of wind to daily peak load hours. Hydro power plants with seasonal storage can shift energy on a monthly to half yearly basis. Pumped storage power plants can de-couple intermittent power generation and variable load demand on a time scale from minutes to up to one year. By stochastic operation optimisation tools the storage potential can be fully activated for an optimal and market oriented operation of electricity systems with high share of DG.